Monday, September 10, 2018

09:30 - 10:00 **Opening Remarks** **Shirotori Hall**

Session Type: Others

10:00 - 11:30 **Mo-A1-S Plenary Session** **Shirotori Hall**

Session Type: Plenary
Chair(s)/Convenor(s)/Facilitator(s): Daniel Mittleman
Discussant(s):

10:00 **THz Aqueous Photonics And Beyond** **Mo-A1-S-1**

Qi Jin[1]; Yiwen E[1]; Liangliang Zhang[2]; Cunlin Zhang[2]; Anton Tcypkin[3]; Sergei Kozlov[3]; Xi-Cheng Zhang[1]
[1]University of Rochester, United States; [2]Capital Normal University, China; [3]ITMO University, Russian Federation
Three of four states of matter: solid, gas, and plasma have been used for THz wave generation for decades. However, the demonstration of THz wave generation from liquid sources was conspicuously absent, especially from liquid water, due to its infamously strong absorption characteristics in the THz regime. Liquids have a high plasma density and a relatively low ionization threshold, meaning that light over a certain area will interact with many more molecules than an equivalent cross-section of gases and will generate more electrons. This makes liquids potential candidates for the generation of THz waves.

10:45 **The Long Journey From Far-infrared To THz** **Mo-A1-S-2**

Qing Hu
MIT, United States
In this Button Prize speech, the author will review the long journey, spanning over his entire research career, from far-infrared to THz.

12:30 - 14:00 **Mo-P1-R1 Spectroscopy and Material Properties I** **Shirotori Hall**

Session Type: Oral

12:30 **[Keynote] Terahertz Spectroscopy Of 2D Materials** **Mo-P1-R1-1**

Lyubov Titova[1]; Guangjiang Li[1]; Kateryna Kushnir[2]; Mengjing Wang[3]; Yongchang Dong[4]; Kristie Koski[5]; Ramakrishna Podila[4]
[1]Worcester Polytechnic Institute, United States; [2]Worcester Polytechnic Insitute, United States; [3]Brown University, United States; [4]Clemson University, United States; [5]University of California Davis, United States
We use time-resolved THz spectroscopy to study the effects of photoexcitation on conductivity and ultrafast carrier in 2D layered materials with different electronic properties: metallic transition metal carbides (MXenes) and semiconducting germanium sulfide (GeS)

13:00 **Changed Graphene THz Conductivity Mapping Under E-beam Excitation** **Mo-P1-R1-2**

Xiaodong Feng; Zhuocheng Zhang; Sen Gong; Min Hu; Jun Zhou; Shenggang Liu
University of Electronic Science and Technology of China, China
Based on terahertz (THz) time-domain spectroscopy, the effects of a 100 eV electron beam (e-beam) excitation ongraphene THz conductivity are presented. The results indicate that a 100 eV e-beam excitation induces a decrease in THz conductivity of graphene, interpreted as electron doping in graphene from the interaction of the e-beam with graphene resulting in the decrease in hole concentration as the graphene is initially p-type doping. Besides, through two-dimensional scanning of graphene by THz spectra without and with e-beam irradiation, the in situ mapping image of changed graphene THz conductivity is obtained, showing carrier transport process in graphene. The findings are of significance for understanding the carrier transport in graphene under e-beam irradiation and for the development of THz electronic devices based on graphene.

13:15 **Probing Photo-induced Vibrational Kinetics In Perovskite Thin Films** **Mo-P1-R1-3**

Qiushuo Sun[1]; Xudong Liu[1]; Jie Cao[1]; Rayko Stantchev[1]; Yang Zhou[1]; Xuequan

Chen[1]; Edward Parrott[1]; Ni Zhao[1]; Emma MacPherson[2]
[1]The Chinese University of Hong Kong, Hong Kong; [2]University of Warwick, United Kingdom
Subwavelength perovskite thin films can only cause less than a 10% intensity reduction of the transmitted terahertz (THz) signal; this small dynamic range makes it difficult to track minor changes in the phonon modes. We propose a THz thin film total internal reflection (TF-TIR) spectroscopy technique to characterize photo-induced spectral changes of $MAPbI_3$, $MAPbI_{2.5}Br_{0.5}$, $MAPbI_2Br_1$ and $MAPbBr_3$. Our approach enhanced the THz responsivity of the perovskites thin films by a factor of 4 compared to THz transmission spectroscopy. The light induced the strength of the phonon modes at around 2 THz to increase after 5 min of illumination, corresponding to the enhanced stretching of the lead halide bond. After 10 min, the strength of the phonon modes at around 1 THz started to decrease, corresponding to the weakened bending of the lead halide bond. Blue shifts were observed on the resonant frequencies apart from $MAPbBr_3$. By comparing the results of four perovskites, we conclude the perovskites that have higher iodide ratio are more unstable in the presence of light and moisture. With the support of X-ray diffraction measurements, we suggest that THz TF-TIR spectroscopy provides distinct information of vibrational kinetics of lead-halide bond in perovskites.

13:30 **[Keynote] Strong Terahertz Plasmonic Resonances In Thin-film Cd3As2: A Three-dimensional Dirac Semimetal** **Mo-P1-R1-4**

Ashish Chanana; Berardi-Sensale Rodriguez; Prashnath R Gopalan
University of Utah, United States
Abstract-- Linear dispersion of energy band-diagram in Dirac semimetals has been associated with strong plasmon coupling in terahertz regime. Graphene, in this regard, has been projected to play crucial role in terahertz optoelectronics due to high carrier mobility and conductivity. However, in the realm of quantum materials, a three-dimension analogue of graphene, Cd3As2, so called 3D semimetal, has been shown to have carrier mobility and fermi-velocity well exceeding that in graphene. We experimentally demonstrate synthesis of high-quality large-area Cd3As2 thin-films and realization of THz plasmonic structures. The structures exhibit quality factor ~5, at frequency of ~0.7 THz, the highest reported to-date at room temperature in any semiconductor or semimetal. Our results evidence that the 3D nature of Cd3As2 provides for a more robust platform for terahertz applications than what is otherwise possible in graphene.

12:30 - 14:00 **Mo-P1-1b High-Field THz Wave Generation and Nonlinear THz Physics I** **Room 131+132**

Session Type: Oral

12:30 **[Keynote] Terahertz Quasiparticle Acceleration: From Electron--Hole Collisions To Lightwave Valleytronics** **Mo-P1-1b-1**

Fabian Langer[1]; Christoph P. Schmid[1]; Stefan Schlauderer[1]; Philipp Nagler[1]; Christian Schüller[1]; Tobias Korn[1]; Martin Gmitra[1]; Jaroslav Fabian[1]; Peter G. Hawkins[2]; Johannes T. Steiner[2]; Ulrich Huttner[2]; Stephan W. Koch[2]; Mackillo Kira[3]; Rupert Huber[1]
[1]University of Regensburg, Germany; [2]University of Marburg, Germany; [3]University of Michigan, United States
Intense lightwaves can accelerate quasiparticles inside solids. This strong-field light-matter interaction results in the emission of high-harmonic or high-order sideband radiation. While the former process relies on a complex coupling between simultaneously driven interband polarization and intraband currents, high-order sidebands originate from a ballistic acceleration of the quasiparticles within the bands. This mechanism allows for the implementation of a quasiparticle collider in order to study those entities in close analogy to conventional collision experiments. Accelerating electrons and holes in a monolayer of transition metal dichalcogenides extends this scheme to internal quantum degrees of freedom. Our experiments show a lightwave-induced switching of the valley pseudospin, paving the way for ultimately fast valleytronics.

13:00 **Influence Of Pump Laser Phase And Amplitude Distortions On Terahertz Generation Efficiency** **Mo-P1-1b-2**

Lu Wang; Arya Fallahi; Koustuban Ravi; Franz Kaertner
DESY, Germany
We analyze the impact of phase front and intensity profile distortions of the pump laser on the generation of narrow-band terahertz radiation by difference frequency

generation in periodically poled Lithium Niobate (PPLN). A code employing finite difference method for beam propagation and nonlinear interaction in cylindrical symmetric system is developed. The simulation accounts for difference frequency generation, self-focusing, self-phase modulation, diffraction, dispersion and terahertz absorption. We find that terahertz generation in PPLN crystals shows negligible sensitivity to spatial intensity modulation. In contrast, phase front modulations may drastically reduce the terahertz generation efficiency. Thus, care must be taken to avoid large phase distortions in high power laser beams for laser-driven terahertz sources.

13:15 **Mass Spectrometry For The Organic Solids Using An Intense THz Free Electron Laser Pulse** **Mo-P1-1b-3**

Masaya Nagai[1]; Eiichi Matsubara[2]; Masaaki Ashida[1]; Masanori Fuyuki[3]; Keigo Kawase[1]; Akinori Irizawa[1]; Goro Isoyama[1]; Jun Aoki[1]; Michisato Toyoda[1]
[1]Osaka University, Japan; [2]Osaka Dental University, Japan; [3]Kio University, Japan

We performed the time-of-flight mass spectrometry for the sugar under the irradiation of the single picosecond THz free electron laser pulse and characterized the desorbed molecules from a solid by the THz pulse for the first time.

13:30 **Narrowband THz Generation By Colliding Plasma Waves With Different Transverse Sizes** **Mo-P1-1b-4**

Vladimir Annenkov[1]; Igor Timofeev[2]; Evgeniia Volchok[2]
[1]BINP SB RAS, Russian Federation; [2]Budker Institute of Nuclear Physics, Russian Federation

It has been recently found that nonlinear interaction of counterpropagating plasma wakes with different potential profiles can generate high-power narrowband THz radiation. Such radiation is concentrated near the second harmonic of the plasma frequency with the line width of several percent and can easily escape from the plasma. In this work, we discuss effects of ion dynamics on THz emission duration in the case of short laser drivers and study whether the radiation efficiency in such a scheme can be significantly increased by using long-pulse electron beams driving plasma waves via the two-stream instability. This mechanism can be a basis for efficient and easily tunable sources of narrow-band terahertz radiation capable of reaching the gigawatt power level and millijoule energy content.

13:45 **Generation Of High-Power Cherenkov Superradiance Pulses Using Oversized 2D Slow-Wave Structures** **Mo-P1-1b-5**

Vladislav Zaslavsky; Naum Ginzburg; Andrey Malkin; Alexander Sergeev; Irina Zotova
IAP RAS, Russian Federation

For stabilization of the output azimuthal pattern of Cherenkov superradiance (SR) pulses we propose to use two-dimensional slow-wave structures (2D SWS). Due to the formation of azimuthal wave fluxes such structures should ensure synchronization of the radiation of a tubular electronic bunch of large diameter. In the framework of a quasi-optical approach and based on 3D PIC simulations we demonstrate the possibility of generation of sub-GW nanosecond SR pulses in the short millimeter waveband (W- and G-band).

12:30 - 14:00 **Mo-P1-1a Applications in Industry, Security and Inspection I** **Room 141+142**

Session Type: Oral

12:30 **[Keynote] In-situ Monitoring Of Powder Density Using Terahertz Pulsed Imaging** **Mo-P1-1a-1**

Daniel Markl[1]; Runqiao Dong[2]; Jingyi Li[2]; Axel Zeitler[2]
[1]University of Strathclyde, United Kingdom; [2]University of Cambridge, United Kingdom

We developed an approach to investigate density variations in a moving powder bed by means of terahertz pulsed imaging. Terahertz measurements were acquired continuously during the rotation of a container filled with different grades of lactose and microcrystalline cellulose powder. Relative density distributions were resolved for different compaction stages of the powder, which indicated high variations of the powder density.

13:00 **[Keynote] Quantification Of Liquids With Terahertz Waves** **Mo-P1-1a-2**

Andreas Keil; Fabian Friederich
Fraunhofer ITWM, Germany

Liquid detection and humidity measurements are a prime example of terahertz

based measurement techniques. Here we want to report quantitative measurements on the amount of liquid in absorbing materials. This research is applicable for using terahertz imaging in nondestructive testing for dry materials, materials with a certain humidity and real-time imaging of the diffusion of liquids in materials.

13:30 **Thickness Measurements With Multistatic Sparse Arrays** **Mo-P1-1a-3**

Andreas Keil; Nina Schreiner; Fabian Friederich
Fraunhofer ITWM, Germany
Thickness measurements using terahertz waves have received great attention in the area of industrial non-destructive testing. Currently these technologies are limited to individual thickness measurements using scanning probes. Within this contribution we demonstrate that a state of the art terahertz imaging system based on a multistatic sparse array can be used to acquire real-time data und to establish thicknesses of bulk materials on an industrial scale. We are discussing extensions how to go below the inherent resolution determined by the bandwidth of the signal.

13:45 **All-electronic High-resolution Terahertz Thickness Measurements** **Mo-P1-1a-4**

Nina Schreiner[1]; Wolfgang Sauer-Greff[2]; Ralph Urbansky[1]; Fabian Friederich[1]
[1]Fraunhofer ITWM, Germany; [2]Kaiserslautern University of Technology, Germany
Broadband laser based terahertz systems become currently established for inline multilayer paint inspection in the automotive industry. This technology has also proven to be suitable for inspections of certain multilayer plastic structures with up to a few millimeters of thickness. We present a complementary technique for the measurement of dielectric multilayer structures with thicknesses of submillimeter to several centimeters, using frequency-modulated continuous-wave electronic transceivers. In order to resolve layers below the inherent resolution limit by the modulation bandwidth, we take advantage of model-based signal processing techniques.

12:30 - 14:00 **Mo-P1-4 Devices, Components, and Systems I** **Room 432**
Session Type: Oral

12:30 **Incoherent, Spatially-mapped THz Spectral Analysis** **Mo-P1-4-1**

Daniel Headland; Philipp Hillger; Robin Zatta; Ullrich Pfeiffer
University of Wuppertal, Germany
We employ a lens-coupled CMOS terahertz camera to measure the dispersion of an inexpensive reflective diffraction grating. Thus, although the terahertz camera was originally intended for terahertz imaging applications, we show that it can be re-purposed to perform spectral analysis. Two different experiments to determine the spectral content of a source under test are performed. These experiments target separate frequency bands, and hence they must make use of different sources and gratings. As such, we demonstrate a modular and low-cost technique for spectral analysis in the terahertz range.

12:45 **Broadband Low-Permittivity Elliptical Lens Fed By A Leaky-Wave Antenna For Communications Applications** **Mo-P1-4-2**

Darwin Blanco; Marta Arias Campo; Nuria Llombart
Tu Delft University, Netherlands
In this paper, a leaky-wave fed lens antenna working at G-band for future XG communications is presented. A lens with a diameter of 16λ_0 is proposed in HDPE material with a feed matching better than -10dB over a 45% of relative bandwidth. Analytical tools have been applied to achieve an aperture efficiency higher than 80% in the entire frequency band. One prototype have been fabricated and measured and the results agree well with the generated from both analytical approach and full-wave simulations.

13:00 **[Keynote] Evolution Of Rod Antennas For Integrated Terahertz Photonics** **Mo-P1-4-3**

Withawat Withayachumnankul[1]; Ryoumei Yamada[2]; Masayuki Fujita[2]; Tadao Nagatsuma[2]
[1]The University of Adelaide, Australia; [2]Osaka University, Japan
Integrated terahertz photonics has emerged as a viable option for routing and processing terahertz signals with high efficiency and broad bandwidth. This can be implemented by using photonic crystal waveguides entirely made of a float-zone intrinsic silicon slab that has exceptionally low loss for terahertz waves. A challenge

presented here is to couple guided waves in this integrated platform with free-space waves. It is imperative that the coupling antennas must have low loss, high bandwidth, and high gain, and be integrated as a part of the platform. Here we present an evolution of antenna designs from a single dielectric rod to a rod array that can satisfy all these requirements. All these antennas are integrated onto the same silicon photonic crystal slab used for waveguiding.

13:30 **[Keynote] Terahertz Applications Inspired By Photonics** **Mo-P1-4-4**

Tadao Nagatsuma
Osaka University, Japan
This paper discusses how photonics technologies can be efficiently utilized in terahertz (THz) applications, by showing some of our recent results. First, an information tag, which is attached to the object for identification, is designed and fabricated using a THz photonic crystal slab. By storing information in both frequency and spatial domains, the information density of the tag is increased to 48 bit/cm^2, which is the highest capacity achieved to date among THz tags. Second, a photonic nanojet phenomenon, which generates localized electromagnetic fields in the shadow side of a dielectric sphere, is applied to enhance a spatial resolution of THz imaging by a factor of 2.2, i.e., 275-GHz-imaging resolution can be obtained by using a 125-GHz signal source.

14:30 - 16:00 **Mo-P2-R1 Spectroscopy and Material Properties II** **Shirotori Hall**

Session Type: Oral

14:30 **Ultraviolet Light-induced Terahertz Modulation Of An Indium Oxide Film** **Mo-P2-R1-1**

Hongyu Ji[1]; Bo Zhang[1]; Wei Wang[1]; Longfeng Lv[2]; Jingling Shen[1]
[1]Capital Normal University, China; [2]Institution of Semiconductors, Chinese Academy of Sciences, China
Active ultraviolet light-induced terahertz modulation of an indium oxide film is investigated. A large absorption modulation of ~66% is achieved upon illumination with a low intensity UV laser (11 mW/cm2). The interaction between indium oxide and a flexible metamaterial structure is investigated owing to the large UV-induced enhancement of photo carriers observed in an indium oxide film. We are able to realize absorption peak shifts of 37 GHz by changing the UV excitation light intensity. We also propose a multi-frequency switch by building a circular metallic split ring resonator whose gaps are filled with silicon, germanium, and indium oxide. In future, a photo-excited tunable multi-frequency metamaterial switch can be realized by irradiating the structure with multi-wavelength laser beam.

14:45 **Ultrafast Charge Carrier Dynamics In Diketopyrrolopyrrole-Linked Tetrabenzoporphyrin Films Studied By Time-Resolved Terahertz Spectroscopy** **Mo-P2-R1-2**

Kaoru Ohta[1]; Yuichi Hiramatsu[2]; Kohtaro Takahashi[3]; Mitsuharu Suzuki[3]; Hiroko Yamada[3]; Keisuke Tominaga[1]
[1]Molecular Photoscience Research Center, Kobe University, Japan; [2]Graduate School of Science, Kobe University, Japan; [3]Division of Materials Science, Graduate School of Science and Technology, NAIST, Japan
Organic semiconductors are important ingredients for plasitc solar cells. Tetrabenzoporphrin (BP) is a well-known p-type organic semiconductor that has excellent photophysical properties such as a strong absorption in the visible region and high hole mobility. Recent study showed that the power conversion efficiency of the C4-DPP-BP-based BHJ solar cell is high (5.2%) compared with BP-based ones (0.02%). Therefore it is very interesting to see whether the charge carrier dynamics in C4-DPP-BP thin film is different from BP or not. In this work, we use time-resolved terahertz (THz) spectroscopy to study the charge carrier dynamics of diketopyrrolopyrrole-linked tetrabenzoporphyrin (C4-DPP-BP) thin films and C4-DPP-BP:PC61BM bulk heterojunction (BHJ) thin films. For BHJ thin films, the results show that the amplitude of the picosecond decaying components depends on the excitation fluence. We consider that the annihilation of charge pairs is responsible for the fast decaying components in BHJ thin film at higher excitation fluence.

15:00 **[Keynote] Terahertz Time Domain Spectroscopy For Spin Reorientation Phase Transition In SmFeO3 At High Temperature** **Mo-P2-R1-3**

Makoto Nakajima; Kazumasa Hirota; Hongsong Qiu; Kosaku Kato; Masashi Yoshimura
Osaka University, Japan

The optical response of the magnetic resonances in terahertz region for $SmFeO_3$ was investigated by terahertz time domain spectroscopy at various temperature. The temporal oscillation due to the ferromagnetic and anti-ferromagnetic resonances are observed. Different polarization dependence is observed at high temperature region, which indicates that the spin reorientation phase transition occurs around 480 K. Terahertz time domain spectroscopy is powerful tool for the solid state physics especially magnetic response in terahertz frequency region. Up to now, we demonstrated the observation of the ferromagnetic and anti-ferromagnetic resonance modes for rare-earth orthoferrite ($AFeO_3$, A: rare-earth element) in terahertz region. We confirmed that the spin reorientation phase transition can be observed by this method. Very recently, the ultrafast control of the macroscopic magnetization around the spin reorientation transition for $ErFeO_3$ by the combination of the terahertz and optical pump excitation. The ferromagnetic and anti-ferromagnetic resonance modes for $SmFeO_3$ were observed at only low temperature region up to now.In this study, we investigated the magnetic response for $SmFeO_3$ from low to high temperature regions. The ferromagnetic and anti-ferromagnetic resonance modes are observed at various temperature. The single crystals of $SmFeO_3$ were grown by the floating zone method. The direction of the crystal axes was evaluated by the Laue measurement. We prepared two wafers with the different (010) and (100) surfaces, because the polarization selection rule for observing the two resonances modes are different, which provides the important information for the spin reorientation phase transition. Terahertz time domain spectroscopy using femtosecond pulse laser was performed at various temperature. The photoconductive antennas were used as the terahertz emitter and detector. The sample was set into a cryostat. We used dry air purge for excluding the effect of the absorption by vapor in air. To obtain the signals efficiently from the ferromagnetic resonance with higher signal to noise ratio, we performed the subtraction of the waveforms between the signals applying magnetic field in opposite directions. The temperature dependences of the transmitted terahertz waveforms are measured from 100 to 500 K. The observed oscillation components were Fourier-transformed for the analysis. We succeeded to obtain signals due to ferromagnetic and anti-ferromagnetic resonance at not only low temperature but also high temperature regions for the first time. The oscillation frequencies were plotted in Fig.1. Lower frequency shift is confirmed as the temperature increases. The signals due to the antiferromagnetic resonance for the (010) surface disappear around 480 K, while those for the (100) surface appear. This change indicates that the spin reorientation transition occurs around 480 K.

15:30 **Terahertz-infrared Electrodynamics Of Lead-doped Single Crystalline Ba(1-x)Pb(x)Fe12O19 M-type Hexagonal Ferrite** **Mo-P2-R1-4**

Liudmila Alyabyeva[1]; Alexander Chechetkin[1]; Victor Torgashev[2]; Elena Zhukova[1]; Denis Vinnik[3]; Anatoliy Prokhorov[1]; Svetlana Gudkova[3]; Boris Gorshunov[1]
[1]Moscow Institute of Physics and Technology (State University), Russian Federation; [2]Southern Federal University, Russian Federation; [3]South Ural State University, Russian Federation

We report on spectroscopic investigation of the influence of crystal structure on dielectric response in lead substituted M-type barium hexaferrite ($Ba_{1-x}Pb_xFe_{12}O_{19}$) single crystals. Broad-band spectra of complex dielectric permittivity have been measured in the frequency range from 10 cm^{-1} to 8000 cm^{-1} and at temperatures from 10 K to 300 K. Low-energy (terahertz) dielectric response and infrared phonon spectra are studied as dependent on lead content, x(Pb)=0.1; 0.6; 0.8.

15:45 **Polar Soft Mode In Titanium-doped Single Crystalline BaFe12-xTixO19 M-type Hexaferrite** **Mo-P2-R1-5**

Liudmila Alyabyeva[1]; Samvel Yegiyan[1]; Victor Torgashev[2]; Elena Zhukova[1]; Denis Vinnik[3]; Anatoliy Prokhorov[1]; Svetlana Gudkova[3]; Boris Gorshunov[1]
[1]Moscow Institute of Physics and Technology (State University), Russian Federation; [2]Southern Federal University, Russian Federation; [3]South Ural State University, Russian Federation

Electrodynamic response of single-crystalline M-type barium hexaferrite doped with Ti^{4+} is studied for two principal polarizations in the temperature range 10-300 K by means of terahertz-infrared spectroscopy. The dynamics of polar phonons is investigated along with low-energy absorption mechanisms connected with

relaxation process in polar domain walls and with anharmonic contributions of multiple phonons interaction.

14:30 - 16:00 **Mo-P2-1b High-Field THz Wave Generation and Nonlinear THz Physics II** **Room 131+132**

Session Type: Oral

14:30 **Demonstration Of A Tilted-Pulse-Front Pumped Planparallel Slab Terahertz Source** **Mo-P2-1b-1**

József A. Fülöp[1]; Priyo S. Nugraya[1]; László Pálfalvi[2]; Gergő Krizsán[2]; Csaba Lombosi[2]; György Toth[2]; Gabor Almasi[2]; Janos Hebling[2]
[1]MTA-PTE High-Field Terahertz Research Group, Hungary; [2]University of Pécs, Hungary
THz pulse generation in a nonlinear echelon slab structure is demonstrated. The setup uses a planeparallel nonlinear optical crystal slab, which ensures a good-quality, symmetric THz beam and enables scalability to high pulse energies.

14:45 **Terahertz Wave Generation From Liquid Gas** **Mo-P2-1b-2**

Alexander Shkurinov
Lomonosov Moscow State University, Russian Federation
We present the results of research, carried out for the first time, on the generation of terahertz (THz) radiation under the action of high power femtosecond laser pulses on Liquid Gas - Liquid Nitrogen (LN). The results of our experiments are supported by theoretical interpretation. We assumed that the mobility of ions and electrons in the liquid can play an essential role, forming a quasi-static electric field by means of ambipolar diffusion mechanism. The energy and polarization properties of generated THz radiation are determined by coherent superposition of contributions described in the frame of both as multiwave mixing and liquid-ionization theories.

15:00 **Electrical Switching Between Terahertz Second And Third Harmonic Generation In Photo-doped GaAs** **Mo-P2-1b-3**

Kanghee Lee[1]; Jagang Park[1]; Bong Joo Kang[1]; Won Tae Kim[1]; Hyeon-Don Kim[1]; Soo-Jeong Baek[1]; Kwang Jun Ahn[2]; Bumki Min[1]; Fabian Rotermund[1]
[1]KAIST, Korea, Republic of; [2]Ajou University, Korea, Republic of
We investigate the competing terahertz (THz) nonlinear harmonic generation in photo-doped GaAs and the conversion efficiency changes with variation of bias voltages. Due to the intrinsic third-order nonlinearity, THz third harmonic generation (THG) can be observed in the photo-doped GaAs without bias voltages. The THG decreases as the bias increases, while the second harmonic generation (SHG) can be observed by the induced second-order nonlinear polarization. In a case of SHG, the efficiency increases as the bias increases. This electrical switching behavior between THG and SHG could be understood from the surface current saturation in GaAs.

15:15 **Damage And Micropattern Formation In Ge-Sb-Te Phase Change Materials Induced By Intense Terahertz Pulse Train** **Mo-P2-1b-4**

Kotaro Makino[1]; Kosaku Kato[2]; Keisuke Takano[2]; Yuta Saito[1]; Junji Tominaga[1]; Takashi Nakano[1]; Goro Isoyama[3]; Makoto Nakajima[2]
[1]National Institute of Advanced Industrial Science & Technology (AIST), Japan; [2]Institute of Laser Engineering, Osaka University, Japan; [3]Institute of Scienti c and Industrial Research, Osaka University, Japan
Intense terahertz radiation is expected to be utilized for material control and understanding of the THz-matter interactions is important research topic. Among various kinds of THz radiation sources, free electron laser (FEL) is a ideal experimental tool that is expected to pave the way for new material processing and test bench for extreme operating conditions in high-speed small-size electrical and magnetic devices by exploiting strong THz fields. In this study, we investigated the effect of intense THz pulses derived from an FEL on Ge-Sb-Te phase change material samples.We irradiated amorphous and crystalline Ge-Sb-Te thin films with a train of THz pulses and found that a discolored mark was formed in the THz-irradiated area when the fluence of THz pulse train is higher than a certain threshold value. The THz-irradiated discolored area was found to consist of two different regions; one is characterized by a significant volume expansion and the other is a undulation pattern in which approximately parallel black lines are aligned along the polarization of THz pulses. Since these features are formed in both amorphous and crystalline samples, the color change is different from

amorphization phase change. We attributed the volume expansion to the precursor to ablation or damage. On the other hand, the undulation pattern is thought to be a sort of laser induced periodic structure (LIPSS) that is one of important phenomena in the field of laser material processing. Absence of amorphization implies that photo- or electrical-excitation plays an important role for fast phase change operation.

15:30 **[Keynote] Compact THz Accelerators: From Fiction To Reality** **Mo-P2-1b-5**

Franz Kärtner[1]; Dongfang Zhang[2]; Arya Fallahi[2]; Michael Hemmer[2]; Moein Fakhari[2]; Yi Hua[2]; Huseyin Cankaya[2]; Anne-Laure Calendron[2]; Luis Zapata[2]; Nicholas Matlis[2]
[1]CFEL-DESY / University of Hamburg, Germany; [2]CFEL-DESY, Germany
The use of THz radiation for electron acceleration and manipulation of electron bunches has progressed over the last decade to a level where practical implementations of THz-powered photoguns, LINACs and a wide range of beam manipulators have become possible. Here, we present a segmented terahertz electron accelerator and manipulator (STEAM) capable of performing multiple high-field operations on the 6D-phase-space of ultrashort electron bunches. With this single device, powered by few-micro-Joule, single-cycle, 0.3 THz pulses, we demonstrate record THz-acceleration of >30 keV, streaking with <10 fs resolution, focusing with >2 kT/m strength, compression to ~100 fs as well as real-time switching between these modes of operation. The STEAM device demonstrates the feasibility of THz-based electron accelerators, manipulators and diagnostic tools enabling science beyond current resolution frontiers with transformative impact.

14:30 - 16:00 **Mo-P2-1c Laser Driven THz Sources I** **Room 133+134**

Session Type: Oral

14:30 **Spin-current Related Terahertz Emission From The Co/Pt Heterostructure** **Mo-P2-1c-1**

Hongsong Qiu; Kosaku Kato; Kazumasa Hirota; Nobuhiko Sarukura; Masashi Yoshimura; Makoto Nakajima
Institute of laser engineering, Japan
The terahertz emission based on the spin current in the ferromagnetic heterostructure Co/Pt is demonstrated. The mechanism of the terahertz emission was studied by detecting the terahertz emission under opposite magnetization directions and sample orientations. The polarity reversal of the terahertz waveforms when the magnetization direction or the sample orientation was changed proved that the spin current was responsible to the THz emission from Co/Pt heterostructures. The NIR femtosecond laser pulse launched the spin transient in the Co/Pt heterostructure. The spin current was converted into the in-plane charge current due to the inverse spin Hall effect, which gave rise to the terahertz emission into the free space.

14:45 **Coherent Control Of Femtosecond Spin Current Investigated By Polarization Dependent Terahertz Emission Spectroscopy In Ferromagnetic Heterostructures** **Mo-P2-1c-2**

Yang Gao[1]; Deyin Kong[1]; Bo Wang[2]; xiaojun wu[1]; Tianxiao Nie[1]; Li Wang[2]; Cunjun Ruan[1]; Weisheng Zhao[1]; Jungang Miao[1]
[1]Beihang University, China; [2]IOP, CAS, China
Approaches towards highly-efficient generation of controllable ellipitical terahertz pulses in ferromagnetic nano-heterostructures are demonstrated. The mechanism for the coherent control of femtosecond spin current in ferromagnetic heterostructures are discussed.

15:00 **[Keynote] Single-Laser Polarization-Controlled Optical Sampling System For THz-TDS** **Mo-P2-1c-3**

Michael kolano; Oliver Boidol; Stefan Weber; Daniel Molter; Georg von Freymann
Fraunhofer ITWM, Germany
We demonstrate a polarization-multiplexed, singlelaser system for terahertz (THz) time-domain spectroscopy without an external delay line. The fiber laser emits two pulse trains with independently adjustable repetition rates, utilizing only one laser-active section and one pump diode. With a standard fiber-coupled THz setup and an optical amplifier stage, we are able to measure transients with a spectral bandwidth of 2.5 THz and a dynamic range of 50 dB in a measurement time of 1 s with a timing accuracy of the THz pulse of approximately 50 fs. Based on the novel laser

architecture, we call this new approach single-laser polarization-controlled optical sampling, or SLAPCOPS.

15:30 **Enhancement Of THz Generation Using Multilayer Spintronic Emitters** **Mo-P2-1c-4**

Laura Scheuer[1]; Garik Torosyan[2]; Sascha Keller[1]; Evangelos Papaioannou[1]; Rene Beigang[1]
[1]University of Kaiserslautern, Germany; [2]Photonic Center Kaiserslautern, Germany
The properties of a three-layer Ta/Fe/Pt spintronic THz emitter based on the inverse spin Hall effect (ISHE) are investigated. Although Ta shows only a very weak ISHE a considerable enhancement of the generated THz amplitude was observed in comparison with a two-layer Fe/Pt system. The dependence on the total layer thickness is discussed in detail and explained in terms of the modified total impedance of the three-layer system.

15:45 **Properties Of An Optimized Fe/Pt-based Spintronic Terahertz Emitter: Excitation Power And Wavelength Dependences** **Mo-P2-1c-5**

Valynn Katrine Mag-usara[1]; Garik Torosyan[2]; Jessica Afalla[1]; Joselito Muldera[1]; Dmitry Bulgarevich[1]; Hideaki Kitahara[1]; Mary Clare Sison Escaño[1]; Sascha Keller[3]; Laura Scheuer[3]; Johannes L'huillier[2]; René Beigang[3]; Evangelos Th. Papaioannou[3]; Masahiko Tani[1]
[1]Research Center for Development of Far-Infrared Region, University of Fukui, Japan; [2]Photonic Center Kaiserslautern and Research Center OPTIMAS, University of Kaiserslautern, Germany; [3]Research Center OPTIMAS and Department of Physics, University of Kaiserslautern, Germany
A spintronic bilayer structure of 2-nm Fe and 3-nm Pt epitaxial grown on MgO substrate was evaluated as a viable THz radiation source for different excitation wavelengths and various average pump power levels. We demonstrate that this optimized Fe/Pt structure is an efficient THz emitter for 800-nm and 1550-nm pump wavelengths even with low excitation power.

14:30 - 16:00 **Mo-P2-1a Applications in Industry, Security and Inspection II** **Room 141+142**

Session Type: Oral

14:30 **Real Time Thickness Measurement Based On Terahertz Time-domain Spectroscopy For Chip-top Epoxy Molding Compound In Semiconductor Package** **Mo-P2-1a-1**

Gyung-Hwan Oh[1]; Dong-Woon Park[2]; Dug-Joong Kim[2]; Hak-Sung Kim[2]
[1]Hanyang university, Korea, Republic of; [2]Hanyang University, Korea, Republic of
The refractive index and thickness of EMC were measured non-destructively using the terahertz time-domain spectroscopy (THz--TDS) system. A theoretical model was developed using an analysis of time response on transmission and reflection THz signals. Using this developed theoretical model, the refractive index of EMC was measured within 1% of the error range. Simultaneously, the thickness of EMC was calculated through the measured refractive index and induced time delay. As a result, the refractive index and thickness of EMC was measured within the error range of 0.9% and 3.0%, respectively.

14:45 **Visualization Of The Internal Field In The GaAs-based Solar Cell Under Its Operating Condition With Terahertz Radiation** **Mo-P2-1a-2**

Keita Miyagawa[1]; Masaya Nagai[1]; Changsu Kim[2]; Hidefumi Akiyama[2]; Yoshihiko Kanemitsu[3]; Masaaki Ashida[1]
[1]Osaka University, Japan; [2]The University of Tokyo, Japan; [3]Kyoto University, Japan
We demonstrated the visualization of the internal field in the GaAs-based solar cell under its operating condition with estimating the first half-period of the terahertz (THz) wave generated by the simultaneous excitation of the weak ultrashort optical pulse. We observed the reduction of the internal field with increasing the intensity of the continuous light excitation, which is relevant to the performance of the solar cells.

15:00 **Evaluation Of Li-ion Battery Using A Terahertz Chemical Microscope** **Mo-P2-1a-3**

Yuki Akiwa; Kentaro Fujiwara; Yumi Yoshikawa; Takashi Teranishi; Kenji Sakai; Toshihiko Kiwa; Keiji Tsukada
Okayama University, Japan
We measured the terahertz wave intensity of the active material surface using TCM as a method to evaluate lithium ion batteries. We made a battery with a sensing

plate attached to measure with TCM. As a result, changes in the terahertz wave intensity due to charging and discharging of the battery could be measured. This result indicates that the extraction and insertion of lithium in the active material can be measured by TCM in the future.

15:15 **Millimeter-Wave Discharge Below Critical Intensity Using A 28 GHz Gyrotron** **Mo-P2-1a-4**

Kuniyoshi Tabata[1]; Yusuke Nakamura[1]; Kimiya Komurasaki[1]; Tsuyoshi Kariya[2]; Ryutaro Minami[2]
[1]The University of Tokyo, Japan; [2]University of Tsukuba, Japan

Microwave Rocket is one of beamed energy propulsion systems, whose energy is wirelessly supplied by using a millimeter-wave beam. Although millimeter-wave discharge plasma in under-critical conditions is necessary for its thrust generation, it has not been clarified why discharge is sustained below the critical intensity. One of the possible mechanisms is the one in which the plasma is composed of many excited molecules which can be ionized by lower-energy electrons than those in a ground state. Therefore, experiments using a 28 GHz gyrotron was conducted to confirm the physical modeling. Assuming that electron excitation temperature is higher than vibrational temperature, vibrational temperature was examined. As a result, the measured vibrational temperature of nitrogen molecules is higher at low peak intensity of millimeter-wave beam. The result implies that electron excitation temperature is higher in those regions and molecules of high excitation temperature are important for ionization below the critical intensity.

15:30 **Interferometry-aided Terahertz Time-domain Spectroscopy For Robust Measurements In Reflection** **Mo-P2-1a-5**

Daniel Molter[1]; Stefan Weber[1]; Tobias Pfeiffer[1]; Jens Klier[1]; Sebastian Bachtler[1]; Frank Ellrich[2]; Joachim Jonuscheit[1]; Georg von Freymann[1]
[1]Fraunhofer ITWM, Germany; [2]TH Bingen, Germany

Terahertz time-domain spectroscopy systems rely on a correct time base of the acquired signals. In reflection geometry, two sources of optical delays have to be considered: the optical delay line, which enables the sampling principle, and the distance from the emitter and detector to the sample. Both optical paths can be perfectly monitored by using interferometric methods, which leads to a drastic enhancement of the stability and precision of the acquired measurement data. In this contribution we specially focus on the effect of vibrations of the sample or measurement head, which can lead to drastically reduced accuracy of the measurement results when considering layer thickness measurements.

15:45 **Extremely Fast Thickness Measurements With An ECOPS-Based TD-THz System** **Mo-P2-1a-6**

Milad Yahyapour[1]; Katja Dutzi[1]; Bernhard Schmauss[2]; Patrick Leisching[1]; Nico Vieweg[1]; Anselm Deninger[1]
[1]TOPTICA Photonics AG, Germany; [2]University Erlangen-Nürnberg, Germany

We employed a time-domain terahertz system based on electronically controlled optical sampling to measure the thickness of a piece of a silicon wafer. The system acquired 1600 terahertz pulse traces per second, which -- to the best of our knowledge -- represents the fastest thickness measurement achieved with any terahertz system to-date. We compare the results to values measured with a conventional terahertz system and a micrometer gauge.

14:30 - 15:30 **Mo-P2-R2 Applications in Biology and Medicine I** **Reception Hall**

Session Type: Oral

14:30 **[Keynote] The 2018 Young Scientist Award Lecture: Terahertz Diagnostics In Multidisciplinary Fields** **Mo-P2-R2-1**

Enrique Castro-Camus
Centro de Investigaciones en Optica A.C., Mexico

In this talk I will present a series of applied research projects that my group has worked in the last few years that involve the use of terahertz radiation in many fields including cultural heritage evaluation, industrial quality control, materials science, biology and medicine. I will also try to summarize the work of some other groups in terahertz applications and discuss the challenges and opportunities I see in the implementation of applications of terahertz radiation in many fields.

15:00 **Three-color Spectroscopic Terahertz Images As An Indicator For Diabetic Foot Syndrome Deterioration** **Mo-P2-R2-3**

Goretti Hernandez-Cardoso[1]; Mariana Alfaro-Gomez[2]; S. Carolina Rojas-Landeros[3];

Irving Salas-Gutierrez[4]; Enrique Castro-Camus[3]
[1]Centro de Investigaciones en Optica, A.C., Mexico; [2]Universidad Autonoma de Aguascalientes, Mexico; [3]Centro de Investigaciones en Optica, Mexico; [4]Hospital Angeles Leon, Mexico
In this paper we present three-color images of the foot soles of diabetic and non-diabetic subjects. The degree of hydration of the skin on the sole of the foot of diabetic and non-diabetic subjects was coded in three-color (red, yellow and greed) images which allow to easily identify areas in risk of ulceration. These three-color images represent a quantitative indicator of the deterioration caused by the diabetic foot syndrome.

15:15 **Low Frequency PCA Studies For Breast Tissue Segmentation** **Mo-P2-R2-4**

Quentin Cassar[1]; Amel Al-Ibadi[1]; Laven Mavarani[2]; Philipp Hillger[2]; Janusz Grzyb[2]; Gaëtan MacGrogan[3]; Ullrich Pfeiffer[2]; Thomas Zimmer[1]; Jean-Paul Guillet[1]; Mounaix Patrick[1]
[1]Laboratoire de l'Intégration du Matériau au Système (IMS), France; [2]Institute for High-Frequency, and Communication Technology, Germany; [3]Institut Bergonié, Centre Régional de Lutte Contre le Cancer, France
Breast conserving surgery is mainly limited by the accuracy of tumor margin delineations. One over five is the estimated risk to undergo a second procedure following the failure of the first breast cancer removal attempt. In order to lessen this ratio, several teams take part in a general effort to develop a THz-based surgery room tissue type recognizer. However, at this time, no robust definition of a numerical tissue segmentation has been provided by the community. In an attempt to draw the basis for such a numerical tissue boarder description, we report here the investigation led on freshly excised breast tissues with Principal Component Analysis (PCA) to recognize tissue types and their associated margins within the 300 -- 600 GHz band.

14:30 - 16:00 **Mo-P2-4 Devices, Components, and Systems II** **Room 432**
Session Type: Oral

14:30 **Electrically Tunable Terahertz Liquid Crystal Spatial Phase Shifter** **Mo-P2-4-1**

Kaidi Li; Rui Zhang
the Chinese University of Hong Kong, Hong Kong
We present an electrically tunable terahertz (THz) spatial phase shifter (SPS) based on liquid crystal (LC). Anintegrated structure was proposed, consisting of two LC layers (with horizontal and vertical grating electrode respectively) and a 45 degree linear polarization plate in the middle. The performance of this device provides actively controllable spatial phase modulation capabilities, which has many potential applications. Moreover,one application as adaptive THz lens was also implemented. The initial measurement results show good focusing capacity and adjustable focal length.

14:45 **A Near-perfect THz Modulator Enabled By Impedance Matching Method With VO2 Thin Films** **Mo-P2-4-2**

Liang-Hui Du[1]; Hong-Fu Zhu[2]; Jiang Li[1]; Qi-Wu Shi[2]; Li-Guo Zhu[1]
[1]Institute of Fluid Physics, China Academy of Engineering Physics, China; [2]College of Materials Science and Engineering, Sichuan University, China
We present a terahertz (THz) amplitude modulator with near perfect modulation depth based on the impedance matching method during the thermally induced insulator-metal transition (IMT) of VO2 thin films. It has been observed that the impedance matching-induced THz amplitude modulation was sensitive to the resistance switching characteristics of the VO2 thin films. With four orders of change in resistance of the properly designed VO2 films during the IMT, we experimentally achieved a near perfect THz modulator with an intensity modulation depth of 99.7% between the insulator phase of VO2 and the impedance matching state, and intensity modulation depth of 99.94% between the impedance matching state and the metallic phase of VO2. The experimental results were well explained by numerical simulations based on the transfer matrix model.In the presentation, more details about the experimental results and the numerical simulations will be discussed, as well as some recent results and analysis.

15:00 **Transmission Loss In Coplanar Waveguide And Planar Goubau Line Between 0.75 THz And 1.1 THz** **Mo-P2-4-3**

Juan Cabello-Sánchez; Helena Rodilla; Vladimir Drakinskiy; Jan Stake

Chalmers University of Technology, Sweden
Two popular planar waveguides for terahertz frequencies, Coplanar Waveguide (CPW) and Planar Goubau Line (PGL), are compared between 0.75 THz and 1.1 THz using VNA on-wafer S-parameter measurements. To deembed the PGL's transition, the calibration plane is set along the PGL using a multiline TRL calibration standard. Measurement results across the band show attenuation constant between 0.68 mm^{-1} and 0.99 mm^{-1} for the CPW, and between 0.87 mm^{-1} and 1.27 mm^{-1} for the PGL. This makes the attenuation constant approximately 0.25 mm^{-1} lower in the CPW than in the PGL.

15:15 **Comparative Study Of Terahertz Waveguides In Reflection Mode Configuration** **Mo-P2-4-4**

Mingming Pan[1]; Jean-Paul Guillet[2]; Georges Humbert[3]; Frédéric Fauquet[4]; Dean Lewis[4]; Patrick Mounaix[4]
[1]Bordeaux University, IMS Laboratory, UMR 5218CNRS, 351 cours de la libération 33405, France, France; [2]Bordeaux University, IMS laboratory, France; [3]XLIM Research Institute, UMR 7252 CNRS University of Limoges, Limoges, France, France; [4]Bordeaux University, IMS Laboratory, UMR CNRS 5218, 351 cours de la libération 33405, France, France
In this study, we propose to test and compare the different waveguides in reflection topology. Guided terahertz pulse reflectometry (GTPR) system consists of a double-photoconductive antenna and waveguide, which allows the reflection-mode measurements without optic to focus and manipulate the THz beam. For now, we have tested a glass waveguide and applied this system for the THz imaging. A 561.23μm resolution at the frequency 480 GHz is achieved by doing a raster scan with an USAF 1951 target. This system has more potential in diverse domain and we can get a better performance by taking advantage of development of THz waveguides.We plan to make further measurements on other waveguides to offer a comparison between more waveguides by the conference

15:30 **[Keynote] Characterizing A Terahertz-driven Dielectric-lined Waveguide For Electron Beam Manipulation** **Mo-P2-4-5**

Morgan Hibberd[1]; Vasileios Georgiadis[1]; Alisa Healy[2]; Graeme Burt[2]; Steven Jamison[3]; Darren Graham[1]
[1]School of Physics and Astronomy & Photon Science Institute, The University of Manchester, United Kingdom; [2]Department of Engineering, Lancaster University, United Kingdom; [3]Department of Physics, Lancaster University, United Kingdom
We report on the transmission properties of a single-cycle terahertz pulse through a dielectric-lined waveguide designed for terahertz-driven manipulation of 100 keV electrons.

Intense ultrafast terahertz (THz) pulses are extremely promising for the future design of high-energy, compact particle accelerators. THz radiation can provide accelerating field gradients on the order of multi-GVm^{-1}, exceeding the breakdown threshold limiting conventional radio frequency-based schemes. The key challenge in utilizing THz radiation for particle acceleration and manipulation is in obtaining sub-luminal phase velocities required to match the velocity of the particle beam. This can be achieved using a dielectric-lined waveguide (DLW) to reduce the THz phase velocity below the speed of light and was recently demonstrated by accelerating non-relativistic 60 keV electrons by 7 keV, using high-field strength THz radiation focused into a cylindrical DLW. However, the waveguide dispersion limited the interaction length to only 3 mm, demonstrating that characterizing the DLW dispersion properties is essential for developing an effective THz-driven particle accelerator.

We report experimental measurements of the effect of waveguide dispersion on an input single-cycle THz pulse. Our DLW was designed to deflect 100 keV electrons using a THz pulse with center frequency of 0.5 THz. As shown in Fig. 1, the design used a hollow rectangular copper structure lined at the top and bottom with 240 μm-thick fused quartz, leaving a 200 μm free space aperture in the center for electron propagation. A tapered coupler at the DLW entrance was used to improve the coupling efficiency of the THz radiation.

THz radiation was generated from a spintronic source and focused into the DLW coupler with an off-axis parabolic mirror. A 2 mm-thick (110)-cut ZnTe crystal was placed at the exit of the DLW and used in an electro-optic sampling, back-reflection

geometry to directly measure the amplitude and phase of the transmitted THz radiation, with example results shown in Fig. 2. An identical DLW has been fabricated with a length of 5 mm and therefore by comparing the phase of the THz pulse transmitted through both the 5mm and 10mm DLWs, we are able to eliminate the effect of the coupler and directly determine the dispersion of the DLW over a THz frequency range of 0.1 to 2 THz. In addition to simulations supporting the experimental results, we will also show how the THz polarization mode generated by the spintronic source can be tailored to create and maximize an accelerating THz field inside the DLW.

16:30 - 18:00 **Mo-P3-R1 Spectroscopy and Material Properties III** — **Shirotori Hall**

Session Type: Oral

16:30 **[Keynote] High-Tc Superconducting Metasurfaces For Ultra-strong Coupling Experiments At THz Frequencies** — **Mo-P3-R1-1**

Janine Keller; Giacomo Scalari; Felice Appugliese; Eleni Mavrona; Martin Süess; Mattias Beck; Jerome Faist
ETH Zürich, Switzerland

We realized a metasurface at THz frequencies using a high temperature superconductor which has a high quality factor, is fully switchable when the superconductivity is destroyed and is at the same time very robust in magnetic field. This makes the metasurface an ideal cavity for ultra-strong coupling experiments with Landau level transitions where the cyclotron energy can be tuned by magnetic field. We demonstrate a coupling strength of as high as ~20% by bringing a two dimensional electron gas in close vicinity to the superconducting metasurface.

17:00 **Terahertz Photoconductivity In Optimally And Underdoped YBa2Cu3O7-δ** — **Mo-P3-R1-2**

Alexandra Galeeva[1]; Alexey Parafin[2]; Dmitry Masterov[2]; Sergey Pavlov[2]; Andrey Pankratov[2]; Sergey Danilov[3]; Ludmila Ryabova[1]; Dmitry Khokhlov[1]
[1]M.V. Lomonosov Moscow State University, Russian Federation; [2]Institute for Physics of Microstructures RAS, Russian Federation; [3]University of Regensburg, Germany

We have studied photoconductivity under the action of strong laser terahertz pulses in optimally doped and underdoped films of the high-T_c superconductor $YBa_2Cu_3O_{7-\delta}$ in the vicinity of the critical temperature. In the optimally doped film, the negative photoconductivity with delayed signal increment and decay has been observed. In the underdoped film, a fast positive photoresponse has been detected on top of the negative photoconductivity background at temperatures above the transition temperature. Possible mechanisms responsible for the effects observed are discussed.

17:15 **Picoseconds Ion Motions In Materials For Solid Oxide Fuel Cell** — **Mo-P3-R1-3**

Tomohide Morimoto[1]; Masaya Nagai[2]; Masaaki Ashida[3]; Yoichiro Yokotani[4]; Yuji Okuyama[5]; Yukimune Kani[6]
[1]Osaka University, Japan; [2]Graduate School of Engineering Science/Osaka University, Panasonic Science Research Alliance Laborat, Japan; [3]Graduate School of Engineering Science/Osaka University, Japan; [4]3rd Division, Institute for Academic Initiatives/Osaka University, Japan; [5]Department of Environmental Robotics, Faculty of Engineering/University of Miyazaki, Japan; [6]Technology Innovation Division/Panasonic Corporation, Japan

We measured the THz conductivity in typical electrolytes of solid oxide fuel cell with THz time-domain spectroscopy up to 1273 K. The measured conductivity reflected the microscopic ion motions just before hopping to the adjacent site. We evaluated the binding energy from the temperature dependence of the THz conductivity, which is difficult to be accessed with other conventional measurements. Our results will open a new application of THz spectroscopy for clarifying the ionic conduction mechanism and exploring novel fuel cell materials.

17:30 **Characterization Of Materials In The 50-750 GHz Range Using A Scatterometer** — **Mo-P3-R1-4**

Tonny Rubaek[1]; Per Heighwood Nielsen[1]; Cecilia Cappellin[1]; Roger Appleby[2]; Richard Wylde[3]; Phil Atkin[4]; Elena Saenz[5]

[1]TICRA, Denmark; [2]Roger Appleby MMW Consulting, United Kingdom; [3]Thomas Keating Ltd., United Kingdom; [4]Pixel Analytics, United Kingdom; [5]ESA/ESTEC, Netherlands
A scatterometer has been constructed as part of an ESA project. In this work, we present some of the initial measurement results from the scatterometer and discuss some of the design challenges encountered during the design of the scatterometer.

17:45 **Phase Delay Of Terahertz Fabry-Perot Resonator Characterized By A Photonic Two-Tone Spectroscopy System With Self-Heterodyne Receiver** **Mo-P3-R1-5**

Sebastian Dülme[1]; Nils Schrinski[1]; Matthias Steeg[1]; Peng Lu[1]; Besher Khani[1]; Carsten Brenner[2]; Martin R. Hofmann[2]; Andreas Stöhr[1]
[1]University of Duisburg-Essen, Germany; [2]Ruhr Universität Bochum, Germany
Terahertz phase delay of high-resistive Silicon based Fabry-Perot resonators (FPR) is experimentally investigated using a photonic two-tone THz spectroscopy system with a self-heterodyne receiver. The photonic spectroscopy system consists of two free-running lasers of which one is externally modulated and an InP-based photodiode for two-tone THz signal generation. A Schottky barrier diode (SBD) is employed as self-heterodyne THz receiver. This way, spectroscopic THz phase and amplitude characterization is enabled without bulky delay lines and the phase noise of the two free running lasers is canceled out. By employing the developed photonic spectroscopy system, phase delay and transmission of a THz FPR is experimentally character¬-ized between 270 GHz and 305 GHz. It is furthermore shown, that the measured THz phase delay difference and FSR of 23 degrees and 13 GHz, respectively, as well as the measured THz transmission coefficient agree well with an analytic model for the phase delay of a Fabry-Perot resonator.

16:30 - 18:00 Mo-P3-1b High-Field THz Wave Generation and Nonlinear THz Physics III — Room 131+132

Session Type: Oral

16:30 **In Situ Observation Of LIPSS Formation On Si Wafers Under THz-FEL Irradiation** **Mo-P3-1b-1**

Takeshi Nagashima[1]; Akinori Irizawa[2]; Masaki Hashida[3]; Atsushi Higashiya[1]; Shigemasa Suga[2]; Shuji Sakabe[3]
[1]Setsunan University, Japan; [2]Osaka University, Japan; [3]Kyoto University, Japan
In order to investigate the mechanism of the formation of laser induced periodic surface structures (LIPSS), in situ observation of LIPSS formation on Si wafers under the irradiation of intense THz pulses with a center wavelength of ~72 μm emitted from a free electron laser (THz-FEL) was performed. When the number N of the irradiated THz pulse is less than 50~70, fine LIPSS with a period of 3~4 μm almost parallel to the polarization of the THz pulses were observed. For N > 250, coarse structures with a period of 30~40 μm emerged.

16:45 **Gain Recovery Dynamics In Broadband Terahertz Quantum Lasers** **Mo-P3-1b-2**

Christian Georg Derntl[1]; Giacomo Scalari[2]; Mattias Beck[2]; Jérôme Faist[2]; Karl Unterrainer[1]; Juraj Darmo[1]
[1]TU Wien, Austria; [2]ETH Zürich, Switzerland
We present the results of our experimental study of the gain recovery time of a broadband (from 2.1 THz and 2.9 THz) terahertz quantum cascade heterostructure (QCH) based on a stacked four-quantum-well resonant phonon depopulation design using terahertz time domain spectroscopy. The measurements were performed above the lasing threshold and result in gain recovery times between 35 ps and 45 ps.

17:00 **Third Harmonic Generation From InSb Excited By Free Electron Laser** **Mo-P3-1b-3**

Thanh Nhat Khoa Phan[1]; Kosaku Kato[1]; Goro Isoyama[2]; Masashi Yoshimura[1]; Shinsuke Fujioka[1]; Makoto Nakajima[1]
[1]Institute of Laser Engineering, Osaka University, Japan; [2]Research Laboratory for Quantum Beam Science, Osaka University, Japan
Using intense beam with frequency 4 THz from Free Electron Laser to pump the InSb crystal, we obtained strong third harmonic generation (THG) with efficiency up to 4 x 10-4 at room temperature. The THG can originate from the nonlinear third order electric current due to non-parabolicity of the band structure in InSb. InSb yields significantly higher THG signal compared with InAs whose shape of energy band structure is more parabolic.

17:15 **Dual-mode Tunable Terahertz Generation In Lithium Niobate Driven By Spatially Shaped Femtosecond Laser** **Mo-P3-1b-4**

Sen-Cheng Zhong
China Academy of Engineering Physics, China

A new approach for dual-mode (namely broadband mode and narrowband mode) THz pulses generation in a single lithium niobate (LN) crystal excited by spatially shaped tilted-pulse-front femtosecond (fs) laser pulse was proposed and experimentally demonstrated. The two THz emission modes are generated simultaneously while spatially separated. Both central frequency and bandwidth of narrowband THz emission is controllable by in-situ tuning the spatial modulation period and beam size of the fs-laser, and the broadband (0.1-1.5 THz) THz emission keeps almost unchanged while tuning the narrowband emission. Further optimization achieves the narrowband THz emission with energy spectral density up to 0.27 μJ/THz and with bandwidth narrowly down to 23 GHz.Such dual-mode THz source is useful for nonlinear THz optics, such as selected resonant THz excitation with broadband THz probe spectroscopy of crystalline matters.

17:30 **[Keynote] Terahertz Rectification In A Triangular Ring Of Quantum Barriers** **Mo-P3-1b-5**

Dai-Sik Kim
Seoul National university, Korea, Republic of

Terahertz waves are focused onto extreme aspect ratio slot antennas. In the middle of the nano slot antenna, the electric field intensity can be a million times stronger than the incident one. Thereby, at a large enough incident field, tunneling of electrons are inevitable [1-3]. These efforts originated from nearly perfect transmission through terahertz slot antennas with tens of microns of feature sizes, which evolved into its nanometer sized and Angstrom sized cousins [4-5]. We will discuss our recent results on tunneling through closed, macroscopic rings of quantum barriers. Surface current driven tunneling provides a new paradigm compared with the conventional voltage driven tunneling, being ultrasensitive to the global 2D geometry and its symmetry. Macroscopic geometries can be turned into another useful tool to govern total tunneling currents.[1] Y. M. Bahk et al., "Electromagnetic Saturation of Angstrom-Sized Quantum Barriers at Terahertz Frequencies", Physical Review Letters 115, 125501(2015) *cover article.[2] Joon-Yeon Kim et al., "Terahertz Quantum Plasmonics of Nanoslot Antennas in Nonlinear Regime", Nano Letters 15 (10), 6683-6688 (2015).[3] Xiaoshu Chen, H. R. Park et al., "Atomic layer lithography of wafer-scale nanogap arrays for extreme confinement of electromagnetic waves", Nat. Comm. 4, 2361 (2013). [4] J. W. Lee et al., "Terahertz Electromagnetic Wave Transmission through Random Arrays of Single Rectangular Holes and Slits in Thin Metallic Sheets", Physical Review Letters 99, 137401 (2007). [5] M. A. Seo et al., "Terahertz field enhancement by a metallic nano slit operating beyond the skin-depth limit", Nat. Photonics 3, 152 (2009).

16:30 - 18:00 Mo-P3-1c Laser Driven THz Sources II

Room 133+134

Session Type: Oral

16:30 **Magnetic-field Patterning Of A Spintronic Source For Arbitrary Terahertz Polarization Control** **Mo-P3-1c-1**

Morgan Hibberd[1]; Daniel Lake[1]; August Johansson[2]; Thomas Thomson[2]; Steven Jamison[3]; Darren Graham[1]
[1]School of Physics and Astronomy & Photon Science Institute, The University of Manchester, United Kingdom; [2]School of Computer Science, The University of Manchester, United Kingdom; [3]Accelerator Science and Technology Centre, Science and Technology Facilities Council, Daresbury Labo, United Kingdom

We demonstrate that a magnetic field pattern can successfully manipulate the magnetic state of a spintronic terahertz emitter, opening up the possibility to directly tailor arbitrary terahertz polarization modes for novel applications.

Spintronic terahertz (THz) emitters utilize the laser-induced electron spin properties in magnetic multi-layers to produce high-field strength (300 $kVcm^{-1}$), gap-free, broadband (1-30 THz) THz radiation. The emitters have the unique property that the generated THz radiation is independent of the pump laser polarization but polarized perpendicular to the moment of the magnetic structure, requiring an applied magnetic field on the order of 10 mT to saturate the magnetic state. We exploit this dependence to directly tailor the transverse polarization profile of the

emitted THz radiation, with applications employing both standard and unconventional THz beam polarization envisaged in THz spectroscopy, coherent control and THz-particle beam interactions.

A magnetic field pattern was applied to our spintronic emitter ($Ni_{80}Fe_{20}$ (2 nm)/Pt (2 nm) bilayer on a MgO substrate) by placing it between two permanent magnets, causing the magnetic domains of the $Ni_{80}Fe_{20}$ layer to align to the local magnetic field direction. As shown in Fig. 1, magnets oriented with aligned or opposing polarity, resulted in THz radiation emitted from the source (after laser excitation) with either linear or quadrupole-like THz polarization, respectively.

For both magnet configurations, characterization of the focused THz beam was accomplished by electro-optic sampling, with example results shown in Fig. 2. For aligned magnetic polarity (Fig. 2(a) and (b)), the linearly polarized THz radiation focused to a Gaussian spot (FWHM = 0.65 mm at 1 THz) with peak on-axis THz electric field of 3.6 $kVcm^{-1}$. For opposing magnetic polarity (Fig. 2(c) and (d)), the quadrupole-like THz polarization mode resulted in a polarity flip at the focus, with zero on-axis THz electric field and approximately equal splitting into each positive and negative lobe with peak fields of 1.9 $kVcm^{-1}$ and -1.6 $kVcm^{-1}$.

We will also show that for the quadrupole-like THz polarization mode, generated using an opposing magnetic polarity configuration applied to the spintronic source, the longitudinal electric field components of the focused THz beam can be enhanced by an order of magnitude compared with an aligned magnetic polarity configuration. After optimization, a peak longitudinal THz electric field of 17.7 $kVcm^{-1}$ was achieved, demonstrating the potential of magnetic-field patterned spintronic sources in applications requiring intense longitudinal THz fields, such as particle acceleration.

16:45 **Continuous Wave Generation Up To 1.3 THz Using Antenna-coupled Silicon Integrated Ge Photodiodes.** **Mo-P3-1c-2**

Peter Offermans[1]; Lei Zhang[2]; Peter De Heyn[3]; Sofie Janssen[3]; Sadhishkumar Balakrishnan[3]; Xavier Rottenberg[3]; Joris Van Campenhout[3]
[1]imec, Netherlands; [2]imec, United States; [3]imec, Belgium

We report continuous wave emission up to 1.3 THz using antenna-coupled silicon-integrated germanium photodiodes fabricated using an industrial SOI process. The optical-to-THz conversion efficiency of about 1% at 100 GHz is attributed to the high responsivity of 1.2 A/W and small capacitance (~5 fF) of the photodiodes. Such devices are suitable for the fabrication of highly efficient phased THz emitter arrays based on photomixing.

17:00 **Improving Efficiency Of Terahertz Photoconductive Antenna Using Dielectric Nano-Layer Encapsulation** **Mo-P3-1c-3**

ABHISHEK GUPTA[1]; GOUTAM RANA[2]; ARKABRATA BHATTACHARYA[3]; ABHISHEK SINGH[4]; RAVIKUMAR JAIN[3]; RUDHEER D. BAPAT[3]; S.P DUTTAGUPTA[2]; S.S. PRABHU[3]; Shriganesh Prabhu[3]
[1]Tata Institute of Fundamental Research, India; [2]INDIAN INSTITUTE OF TECHNOLOGY, MUMBAI, India; [3]TATA INSTITUTE OF FUNDAMENTAL RESEARCH, MUMBAI, India; [4]HELMHOLTZ ZENTRUM DRESDAN ROSSENDORF, GERMANY, Germany

Due to the low optical-to-THz conversion efficiencies, applications of photoconductive antennas are limited in current scenario. In this paper, we report up to an order of enhancement in THz emission efficiency from conventional PCAs by coating a nano-layer of dielectric (TiO2) on the active area between the electrodes of a Semi-Insulating GaAs (SI-GaAs) based device. Effect of different thicknesses of the TiO2 layer on THz power enhancement with different applied optical power and bias voltages were studied. Simulations in COMSOL Multiphysics were performed to elucidate the underlying physics behind the enhancement of efficiency of the PCA.

17:15 **Terahertz-Wave Generation Devices Using Electro-Optic Polymer Waveguides And Terahertz-Wave Low-Loss Cladding Materials** **Mo-P3-1c-4**

Takahiro Kaji; Yukihiro Tominari; Toshiki Yamada; Shingo Saito; Isao Morohashi; Akira Otomo
National Institute of Information and Communications Technology (NICT), Japan

We fabricated terahertz (THz)-wave generation devices using electro-optic (EO) polymer waveguides and THz-wave low-loss cladding materials and demonstrated THz-wave generation from the fabricated EO polymer waveguide devices.

17:30 **[Keynote] High-efficiency Sub-single-cycle THz Wave Generation By Three-color Air Plasma** **Mo-P3-1c-5**

Binbin Zhou; Yazhou Wang; Lujun Hong; Daena Madhi; Peter Jepsen
Department of Photonics Engineering, Technical University of Denmark, Denmark

THz pulses generation from 3-color (ω-2ω-3ω) air plasma is experimentally investigated. THz yield enhancement factor up to 45 is measured compared to the 2-color (ω-2ω) case. With 40 fs optical pump pulses, the generated THz pulse spectrum is spanning from below 3 to more than 300 μm (or from < 1 to > 100 THz) and supporting sub-5 fs sub-single-cycle far/mid-IR pulses.

16:30 - 18:00 **Mo-P3-1a Applications in Industry, Security and Inspection III** **Room 141+142**

Session Type: Oral

16:30 **New Terahertz Security Body Scanner** **Mo-P3-1a-1**

Gombo Tsydynzhapov; Pavel Gusikhin; Vyacheslav Muravev; Ivan Andreev; Igor Kukushkin
TeraSense Group, Inc., United States

Terahertz radiation has great potential for security applications due to its penetrating ability combined with harmlessness for living organisms. Here we report about development of the terahertz security system for the remote detection of hidden objects. The system works in the reflection mode and includes 32Ã—32 pixel imaging camera, objective lens, and several (six or more) 100 GHz IMPATT diode sources.

16:45 **[Keynote] Volume Inspection Of Composite Structures In Aircraft Radomes With FMCW Terahertz Radar At 100 And 150 GHz** **Mo-P3-1a-2**

Maris Bauer[1]; Andreas Keil[1]; Carsten Matheis[1]; Joachim Jonuscheit[1]; Michael Moor[2]; David Denman[3]; Jamie Bramble[3]; Nick Savage[3]; Fabian Friederich[1]
[1]Fraunhofer ITWM, Germany; [2]Meggitt Polymmers and Composites, United Kingdom; [3]Meggitt Polymers and Composites, United Kingdom

We present a terahertz imaging system for aircraft radome inspection based on a two-frequency FMCW radar working at center frequencies of 100 and 150 GHz and with 40 and 60 GHz bandwidth, respectively. The imaging sensor combines two all-electronic multiplier chains at the respective frequencies and is integrated in the production environment of radomes built of glass fiber-reinforced composite structures. While images acquired at the two distinct working frequencies can yield different information of possible structural defects, at the same time, a data fusion algorithm is applied combining the signals of both terahertz sensors for enhanced depth resolution by a total FMCW bandwidth of 100 GHz.

17:15 **Study Of 3D Imaging Using A CW Diode Terahertz Source For Practical Applications** **Mo-P3-1a-3**

Homare Momiyama[1]; Yoshiaki Sasaki[2]; Isao Yoshimine[2]; Shigenori Nagano[1]; Tetsuya Yuasa[3]; Chiko Otani[2]
[1]Topcon Corporation, Japan; [2]RIKEN, Japan; [3]Yamagata University, Japan

We have constructed compact terahertz 3D imaging systems for practical imaging applications such as inspection of the defects of building walls and infrastructures. A swept source optical coherence tomography (SS-OCT) system and a phase-shifting interferometry system used for evaluating their depth resolution. The depth resolution of 6 mm and 10 Âμm were obtained for each system, respectively. We have also performed 3D imaging of a plastic sample by the SS-OCT system and discuss about the reconstructed images.

17:30 **Monitoring Soybean Leaf Water Status Using Terahertz Spectroscopy** **Mo-P3-1a-4**

BIN LI
NERCITA, China

Water status of soybean leaves can truly reflect the degree of soil water deficit. The strong attenuation of terahertz radiation in water makes it a contact-less probe, which does not require contact with the sample. As a result, terahertz spectroscopy technology was studied to rapidly and conveniently estimate water content in soybean canopy leaf, so as to monitor the health status of plant and help scientific water-saving irrigation management.THz-TDS is an emerging and effective

coherent detection technology. It is a complementary to infrared and raman spectroscopy. The strong attenuation of terahertz radiation by water makes radiation in this spectral band a highly sensitive probe of hydration in plants. In this work, a steady calculation model of soybean leaf water content using THz was established. Therefore, the results demonstrate the capacity of THz techniques to measure the water content in porous materials, such as leaves.

17:45 **Optical Response Change Of Black Rubbers Under Cyclic DeformationInvestigated By Terahertz Polarization Spectroscopy** **Mo-P3-1a-5**

Takato Tsujimoto; Atsuto Moriwaki; Misako Fujii; Makoto Okano; Shinichi Watanabe
Keio University, Japan

We recently demonstrated that the nondestructive and contactless inspection of visibly-opaque black rubbers with a conductive carbon fillers, which is required for the rubber industrial community, by terahertz polarization spectroscopy. In this work, the terahertz-optical and mechanical properties of the black rubbers were simultaneously measured under cyclic deformation. The black rubbers show the hysteresis in the draw ratio dependence of the terahertz birefringence as well as the well-known hysteresis behavior in the stress. The result implies that the terahertz optical response of black rubbers have correlation with their mechanical properties.

16:30 - 18:00 **Mo-P3-R2 Applications in Biology and Medicine II** **Reception Hall**

Session Type: Oral

16:30 **[Keynote] Intensity-dependent Suppression Of Calcium Signaling In Human Skin Tissue Models Induced By Intense THz Pulses** **Mo-P3-R2-1**

Cameron Hough[1]; David Purschke[1]; Chenxi Huang[1]; Lyubov Titova[2]; Olga Kovalchuk[3]; Brad Warkentin[1]; Frank Hegmann[1]
[1]University of Alberta, Canada; [2]Worcester Polytechnic Institute, United States; [3]University of Lethbridge, Canada

The biological effects of intense THz pulses on human skin tissue models are investigated by applying gene ontology and pathway perturbation analyses to measured global differential gene expression profiles. Biological processes and cellular structures that regulate epidermal differentiation are highly over-represented by THz-affected genes, and several signaling pathways that regulate the development of human cancer are predicted to be dysregulated. In particular, the calcium signaling pathway is predicted to be suppressed by THz exposures, and this effect increases with THz intensity. Mechanisms for the predicted suppression are identified and discussed in the context of potential clinical considerations of intense THz pulses.

17:00 **Label-free Monitoring Of Cell Death Induced By Oxidative Stress In Living Human Cells Using Terahertz ATR Spectroscopy** **Mo-P3-R2-2**

Yi Zou; Qiao Liu; Jianheng Zhao; Liguo Zhu
China Academy of Engineering Physics, China

We demonstrated that attenuated total reflectance terahertz time-domain spectroscopy (ATR THz-TDS) is able to monitor oxidative stress response of living human cells, which is proven in this work that it is an efficient non-invasive, label-free, real-time and in-situ monitoring of cell death. Furthermore, the dielectric constant and dielectric loss of cultured living human breast epithelial cells, and along with their evolution under oxidative stress response induced by high concentration of H2O2, were quantitatively determined in the work. Our observation and results were finally confirmed using standard fluorescence-labeled flow cytometry measurements and visible fluorescence imaging.

17:15 **(Withdrawn)** **Mo-P3-R2-3**

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17:30 **The Effect Of Pressure On Terahertz In Vivo Spectroscopic Imaging** **Mo-P3-R2-4**

Jiarui Wang[1]; Rayko I. Stantchev[1]; Qiushuo Sun[1]; Emma Pickwell- MacPherson[2]
[1]The Chinese University of Hong Kong, Hong Kong; [2]Warwick University, United Kingdom

Spectroscopic THz imaging of human skin can reveal hydration levels and yield insight into skin afflictions. However, in-vivo measurements necessitate careful studies of all variables that can affect the skin's response. Here, we investigate how pressure affects the response of human skin during THz in-vivo investigations. Our

findings show that increasing the pressure increases the refractive index. Therefore inconsistent control of the pressure during THz in-vivo imaging will cause measurement inaccuracies and hinder valid diagnosis. Here we present how to monitor and control the pressure, our results can potentially be used for calibration of THz in vivo measurements.

17:45 **Detection Of Volatile Organic Compounds In Exhaled Human Breath By Millimeter-Wave/Terahertz Spectroscopy** **Mo-P3-R2-5**

Nick Rothbart[1]; Klaus Schmalz[2]; Johannes Borngräber[2]; Dietmar Kissinger[2]; Heinz-Wilhelm Hübers[3]

[1]Humboldt-Universität zu Berlin, Germany; [2]IHP, Germany; [3]German Aerospace Center (DLR), Germany

We present results on the detection of Volatile Organic Compounds (VOCs) in exhaled human breath by mmW/THz spectroscopy. Two spectrometers were used: The first one is based on a transmitter and a receiver in SiGe BiCMOS technology. In a breath sample, 240 ppm of ethanol were detected through its absorption spectrum around 242 GHz. This corresponds to a sensitivity of 250 ppb/□Hz for ethanol. With a laboratory spectrometer based on commercial components, we detected several other VOCs in human breath samples. All samples were collected in 2 liter Tedlar bags, commonly used in medical breath gas studies.

16:30 - 18:00 **Mo-P3-4 Devices, Components, and Systems III** **Room 432**
Session Type: Oral

16:30 **Results From Mm-Wave Accelerating Structure High-Gradient Tests** **Mo-P3-4-1**

Emilio Nanni[1]; Valery Dolgashev[1]; Jeffrey Neilson[1]; Sami Tantawi[1]; Sudheer Jawal[2]; Samuel Schaub[2]; Richard Temkin[2]; Bruno Spataro[3]

[1]SLAC National Accelerator Laboratory, United States; [2]MIT, United States; [3]INFN, Italy

We have built and are preparing to test 110 GHz mm-wave accelerating structures with high power pulses. The purpose of this work is to study the basic physics of ultrahigh vacuum rf breakdown in high-gradient rf accelerators. The accelerating structures consist of pi-mode standing-wave cavities fed with the circular TM01 mode waveguide. The structures will be powered with short pulses from a MW gyrotron oscillator. One MW of RF power from the gyrotron may allow us to reach a peak accelerating gradient of 400 MeV/m.

16:45 **Pseudospark-sourced Sheet Electron Beam For Application In High Power Millimeter Wave Radiation Generation** **Mo-P3-4-2**

Huabi Yin[1]; Guoxiang Shu[2]; Liang Zhang[1]; Wenlong He[1]; Junping Zhao[3]; Alan Phelps[1]; Adrian Cross[1]

[1]University of Strathclyde, United Kingdom; [2]Shenzhen University, China; [3]Xi'an Jiaotong University, China

This paper presents the plasma-sourced sheet electron beam generation based on a pseudospark discharge. This beam source has advantages of high current density, ion-channel assisted beam focus, long life and simplicity with no external guiding magnetic field needed for beam transportation. A collimator of cross section size of 2.0mm × 0.25mm is used in the sheet beam generation and propagation experiments. Sheet beam currents in the range of 6A to 21 A (~104 A/cm2 current density) and peak voltage of ~32 kV were measured after the sheet beam has propagated a distance of 10-mm without any external focusing magnetic field. Furthermore the pseudospark-sourced sheet electron beams were successfully used to drive both a W-band (75-110 GHz) and a G-band (200 GHz) planar extended interaction oscillator (EIO), with beam tunnel of approximately 2.8mm × 0.5mm and 1.0 mm × 0.17 mm in cross sectional size respectively.

17:00 **Nano-structured Top Contact With Low Optical Polarization Dependencefor THz Generation Using Photodiodes** **Mo-P3-4-3**

Sara Bretin; Maximilien Billet; Emilien Peytavit; François Vaurette; Christophe Coinon; Xavier Wallart; Jean-François Lampin; Malek Zegaoui; Guillaume Ducournau; Mohammed Zaknoune

IEMN, France

Uni-travelling carrier photodiodes (UTC-PD) with different top optical and electrical accesses is proposed towards optical polarization sensitivity reduction. With the proposed structure, only 1 percent dependence in optical polarization is obtained while ensuring good RF access. Measurements up to 110 GHz are presented at -1V bias and 29 mW optical power.

17:15 **Graphene Ballistic Rectifiers For THz Detection And Imaging** **Mo-P3-4-4**

Gregory Auton[1]; Dmytro But[2]; Jiawei Zhang[1]; Ernie Hill[1]; Dominique Coquillat[2]; Christophe Consejo[2]; Philippe Nouvel[2]; Wojciech Knap[2]; Luca VARANI[2]; Frédéric Teppe[2]; Jeremie TORRES[2]; Aimin Song[1]
[1]University of Manchester, United Kingdom; [2]University of Montpellier, France
A graphene ballistic rectifier is used in conjunction with an antenna to demonstrate a rectenna as a terahertz (THz) detector shows a peak extrinsic responsivity of 764 V/W and a corresponding noise equivalent power of 34 pW.Hz^1/2 at room temperature with no indications of a cutoff frequency up to 0.45 THz. The device is used to take an image of an optically opaque object demonstrating potential in both medical and security imaging applications.

17:30 **[Keynote] Planar Asymmetric Semiconductor Nanodiodes For THz Detection** **Mo-P3-4-5**

Javier Mateos[1]; Ignacio Iñiguez-de-la-Torre[1]; Susana Pérez[1]; Héctor Sánchez-Martín[1]; José Antonio Novoa[1]; Guillaume Ducournau[2]; Christophe Gaquiére[2]; Tomás González[1]
[1]University of Salamanca, Spain; [2]Institut d'Electronique, Microélectronique et Nanotecnologies, IEMN, France
The large range of potential applications of the THz range of the electromagnetic spectrum, specifically for imaging and spectroscopic analysis, is presently encouraging the research for new detector technologies with higher sensitivity and bandwidth. The Self-Switching Diode (SSD) architecture, based on planar assymmetric topology of nanodiodes, has been explored as a possible candidate as THz device since 2003, when A. M. Song claimed it as a promising device for mm-wave and THz detection and mixing. This particular geometry propagates the applied bias into a lateral field effect, which depending on the polarity is able to open or close the channel as a result of electrostatic and surface effects. The use of high mobility materials like InGaAs, InAs or graphene for fabricating SSDs has allowed to envisage its use in relevant THz applications such as zero-bias detectors for passive imaging. In addition, GaN despite of its lower mobility is also suitable for sub-THz detection, and even if it is not the optimal material for fabricating high frequency detectors, it has inherent advantages for being used as high power detector, where the responsivity is not the key figure of merit, but the power handling capability. Moreover, Monte Carlo simulations have shown the possibility of producing Gunn oscillations in GaN SSDs, so that both sub-THz wave sources and detectors could be combined to produce an integrated transceiver based on this architecture.Previous studies, focused on the improvement of the intrinsic performance of the SSDs, show that reducing the width of the channel enhances their responsivity. However it increases the impedance mismatch with the access transmission line due to the larger impedance of the diode and leads to an additional drawback, the variability on their performance. It is difficult to precisely control such stringent fabrication process and reproducibly fabricate SSDs with channel widths below 100 nm. Moreover, the detection performance depends on the non-linearity of the I-V curve of the SSDs, which critically depends on the presence of surface charges at the sidewalls of the channels, so that many unknown trap mechanisms, especially in the GaN technology, arise. In this contribution we will focus on the optimization towards the implementation of practical detectors following two different strategies: i) improving the impedance matching by fabricating several diodes in parallel and ii) using of a top gate to control the conductance of the channels and tuning the performance of the devices as THz detectors.

18:00 - 19:30 **Mo-POS Poster Session** **Event Hall**
Session Type: Poster

18:00 **Collagen And Muscle Fibrous Tissue As A Contrast Mechanism In The THz Region** **Mo-POS-01**

Shuting Fan[1]; Zhengfang Qian[1]; Vincent Wallace[2]
[1]Shenzhen University, China; [2]The University of Western Australia, Australia
We imaged a thin paraffin embedded sample with a terahertz time domain spectroscopy (THz-TDS) system. The sample was prepared from the laboratory guinea pigs after 7 weeks recovery from a brain surgery. The surgical wound and the surrounding normal skin tissue showed a clear contrast in the terahertz band despite of the sub-wavelength thickness of the sample. The comparison between

the terahertz images and the stained histological images suggests that the contrast comes from the collagen-rich wound and the muscle fibrous tissue. This work demonstrates a potential contrast mechanism in terahertz tissue imaging.

18:00 **Investigation Into Polymorphism Of Lamivudine Using Terahertz Time-domain Spectroscopy** **Mo-POS-02**

Yong Du[1]; Dan Qin[2]; Huili Zhang[2]; Zhi Hong[2]
[1]Centre for THz Research, China Jiliang University, China; [2]China Jiliang University, China

Terahertz absorption spectra were obtained for hydrated and anhydrous polymorphic forms of lamivudine. The results show that the interaction between crystalline water and lamivudine molecule has an important effect on the vibration modes of lamivudine polymorphs. The differences in the terahertz spectra were correlated with the corresponding structures and shown to be mainly due to the inter-molecular interactions effect.

18:00 **Terahertz Irradiation Stimulates Actin Polymerization** **Mo-POS-03**

Shota Yamazaki[1]; Masahiko Harata[2]; Toshitaka Idehara[3]; Keiji Konagaya[4]; Ginji Yokoyama[2]; Hiromichi Hoshina[1]; Yuichi Ogawa[4]
[1]RIKEN Center for Advanced Photonics, Japan; [2]Tohoku University, Japan; [3]University of Fukui, Japan; [4]Kyoto University, Japan

Assembled actin filaments have essential roles in cell motility, growth, differentiation, and gene reprogramming. Therefore, technique of manipulating actin dynamics is important for understanding and regulating multiple biological functions. Here, we demonstrate terahertz (THz) wave irradiation as a novel method for inducing actin polymerization. THz waves, generated by a Gyrotron, were applied to actin polymerization process. The formation of actin filaments was observed as a function of time, using the fluorescence of pyrene actin fluorophores. After the completion of polymerization, fluorescence microscope images were observed to determine the size distribution of the actin filaments. The fluorescence signal of the actin filaments increased by 3.5-times after irradiation of 5.7 mJ/cm2 for 20 minutes. In the microscopic images of irradiated and un-irradiated samples, no morphological changes of actin filaments were observed, but the length distribution showed a clear difference between the two. This suggests that the elongation phase of the actin nucleation was accelerated with THz irradiation.

18:00 **Epigenetic Modifications Induced By Submillimeter Wave Exposure** **Mo-POS-04**

Jody Cantu[1]; Xomalin Peralta[2]; Catherine Millar-Haskell[3]; Cesario Cerna[1]; Ibtissam Echchgadda[3]
[1]General Dynamics Information Technology, United States; [2]National Academy of Sciences, United States; [3]AIr Force Research Laboratory, United States

Recent reports have shown that exposure to non-ionizing electromagnetic waves, including submillimeter waves (sub-MMWs), can influence gene expression in skin tissues and various cell types. However, the mechanism(s) by which exposure to sub-MMWs alters gene expression has not been elucidated. In the present study, we hypothesize that sub-MMW exposure induces epigenetic modifications that result in altered gene expression. Specifically, we explore the effects of sub-MMW exposure on DNA methylation in human primary skin cell lines. Cells were exposed to sub-MMWs for different time durations, and changes in global DNA methylation were examined following each exposure. The results presented herein are essential for understanding the role DNA methylation plays in gene regulation in sub-MMW exposed cells.

18:00 **Impact Of Sub-Millimeter Waves On The Assembly Kinetics Of Microtubules** **Mo-POS-05**

Xomalin Peralta[1]; Jody Cantu[2]; Cesario Cerna[2]; Ibtissam Echchgadda[1]
[1]Air Force Research Laboratory, United States; [2]General Dynamics Information Technology, United States

Microtubules are highly dynamic intracellular structures critical to many biological functions in eukaryotic cells. They grow and shrink via the addition or subtraction of tubulin heterodimers and, given their polar nature, are expected to interact with electromagnetic fields. We evaluated the effect that externally applied submillimeter (sub-MM) waves have on the assembly kinetics of MTs. We observed a difference in MT formation due to exposure to sub-MM waves of MTs in solution and in cultured cells. Preliminary results indicate an effect on cell morphology and cell metabolism.

Understanding the dynamic behavior of MTs opens an avenue to control various fundamental cellular processes.

18:00 **Investigation Of Glycation Products By THz Time-domain Spectroscopy** **Mo-POS-06**

Olga Cherkasova[1]; Maxim Nazarov[2]; Yuri Kistenev[3]; Alexander Shkurinov[4]; Alexey Borisov[3]; Anastasia Knyazkova[3]
[1]Institute of Laser Physics of SB RAS, Russian Federation; [2]Kurchatov Institute National Research Center, Russian Federation; [3]Tomsk State University, Russian Federation; [4]Lomonosov Moscow State University;Institute on Laser and Information Technologies of RAS, Russian Federation

Glycation is the non-enzymatic reaction between reducing sugars, such as glucose, and proteins, lipids or nucleic acids. This process involvement in various pathologies of the human body, including diabetes and aging, and is an intensive field of research. Terahertz time-domain spectroscopy (THz-TDS) has been used for assay of glycation products. The transmission and the attenuated total internal reflection geometries have been used for measuring of a number glycation products in aqueous solutions at 0.2-2.5 THz.

18:00 **Evaluation Of Penetration Of Cosmetic Liquids Using Terahertz Time Of Flight Method** **Mo-POS-07**

Taihei Kuroda; Taiga Morimoto; Toshihiko Kiwa; Keiji Tsukada; Kenji Sakai
Okayama University, Japan

The terahertz time-of-flight method was applied to evaluate the the penetration speed and the depth of the skin lotion into the skin. The result suggests that the terahertz time-of-flight method is one of useful option in this field.

18:00 **Study On Difference Among The THz Spectra Obtained From Commercial Caffeine And Sodium Benzoate (CSB) On The Market** **Mo-POS-08**

Tomoaki Sakamoto[1]; Tetsuo Sasaki[2]; Yasuto Fujimaki[3]; Toshiyuki Chikuma[1]; Yukihiro Goda[4]
[1]National Institute of Health Sciences, Japan; [2]Shizuoka University, Japan; [3]Tokyo Metropolitan Industrial Technology Research Institute, Japan; [4]National Institite of Health Sciences, Japan

We investigated about influence of physicochemical property of an active pharmaceutical ingredient on qualitative analysis using terahertz spectroscopy in order to apply for detection of counterfeit and substandard drugs. In this study, one of the central nervous system (CNS) stimulant, caffeine and sodium benzoate (CSB) which sometimes is used illegally with amphetamines to obtain sexual arousal, was used. Among the CSBs distributed as the Japanese Pharmacopoeia APIs manufactured by the three pharmaceutical companies, the terahertz spectrum of one company was different (Fig.1). The powder X-ray diffraction (PXRD) pattern of the CSB product distributed by the manufacturer C was almost same, but just few difference of PXRD peaks compared with other two CSB APIs was observed (Fig.2). This observation seems to be due to slightly different crystal structure of CSB distributed by that manufacturer. This compound is a salt complex of caffeine and benzoic acid, and it seems that it may be different conformation depending on the manufacturing process. The characteristic spectral pattern based on the manufacturing process can be expected to be utilized as fingerprint information at each manufacturing company. For example, it will be considered to be applicable to detect fake API and/or product such as identification of manufacturers in market distributing drugs or mixing of counterfeit drugs different from the genuine APIs such as underground products and reagents. Furthermore, comparison of terahertz spectrum between confiscated samples and the reference CSB spectrum may be contributed for not only illegal manufacturer but also investigation of acquisition route. Thus, it is also expected to provide useful information against criminal investigation. We performed cross-sectional vibrational spectroscopic analysis using mid-IR, near-IR, and Raman spectroscopy in order to investigate relevance of differences of terahertz spectra among three CSBs using infrared and Raman active phonon and molecular vibration. We also examined internal quantum efficiency to obtain further information. Moreover, we investigated organic impurities included in CSBs using gas-chromatography mass spectroscopy.

18:00 **Terahertz Pulse Data Dimensional Reduction And Classification For Hepatic Tissue Samples** **Mo-POS-09**

Zhenwei Zhang; Haishun Liu; Cunlin Zhang
Capital Normal University, China

The dimensionality reduction techniques of PCA and Isomap used to deal with

normal hepatic and tumor tissue data of THz pulse and coupling with SVM and PNN for classification were executed and compared in this manuscript. Low-dimensional data scatter distribution as well as classification results building on classifiers demonstrated the advantage of Isomap in dealing with this type of intricate THz pulse data. Thus the dissimilar THz properties for two types of normal hepatic and tumor tissues could be well embodied in Isomap by removing the undesired components of the original data. The apropos combination of dimensionality reduction and classification model based on THz pulse is a promising way to discern the hepatic tumors.

18:00 **Terahertz Polarimetric Sensing For Linear Encoder** **Mo-POS-10**

Kota Sadamoto[1]; Wataru Tsujita[1]; Yoshitsugu Sawa[1]; Bingnan Wang[2]; Rui Ma[2]; Pu Wang[2]; Koon Hoo Teo[2]; Philip Orlik[2]; Kosaku Kato[3]; Makoto Nakajima[3]
[1]Advanced Technology R&D Center, Mitsubishi Electric Corp., Japan; [2]Mitsubishi Electric Research Laboratories, United States; [3]Institute of Laser Engineering, Osaka University, Japan
We propose a linear encoder which utilizes Terahertz (THz) wave and polarization information. The encoder consists of periodic polarizer linear array as a scale and a polarization angle reader as a read head. The read head determines its position based on polarization angle on the scale. This technology has possibility to have resistance to fine particles and gap fluctuation between the read head and scale. We demonstrated experimentally that the linear encoder based on the terahertz polarimetric sensing is useful for the industrial applications.

18:00 **Manned Spacecraft Safely Nondestructive Inspection By Terahertz Radiation** **Mo-POS-11**

Xuling Lin[1]; Zhi Zhang[1]; Xiaoli Ji[2]; Zhongbo Zhu[3]
[1]Beijing Institute of Space Mechanics and Electricity, China; [2]Nanjing University, China; [3]National Key Laboratory of Science and Technology on Space Microwave, China
In this paper, we present a portable, video rate, low-cost and high imaging quality terahertz imager which is suitable for manned spacecraft on-orbit nondestructive examination and security inspection, the imager can hand-held by astronaut or space station's robot arm, and some components test results are given.

18:00 **Terahertz Time Domain Spectroscopy For Plastic Films Using A Tapered Parallel Plate Waveguide** **Mo-POS-12**

Ayano Kitamura[1]; Ayato Iba[1]; Makoto Ikeda[1]; Makoto Nakajima[2]
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Measurement for thin films without modifications of the shape and properties is very important for industrial applications. A tapered parallel plate waveguide is proposed to measure such thin films. We demonstrated that the measurement using tapered parallel plate waveguide is very effective for the evaluation of the thin films and the results of the sample length dependence well agree with the Lambert-Beer's law.

18:00 **Terahertz Imaging Of Multi-Level Pseudo-Random Reflectance** **Mo-POS-13**

Pu Wang[1]; Haoyu Fu[2]; Toshiaki Koike-Akino[1]; Rui Ma[1]; Bingnan Wang[1]; Philip Orlik[1]; Wataru Tsujita[3]; Kota Sadamoto[3]; Yoshitsugu Sawa[3]; Kosaku Kato[4]; Makoto Nakajima[4]
[1]Mitsubishi Electric Research Laboratories, United States; [2]Ohio State University, United States; [3]Mitsubishi Electric Corporation Advanced Technology R&D center, Japan; [4]Osaka University, Japan
This paper aims to recover multi-level pseudo-random reflectance patterns used in encoder systems for high-resolutionpositioning. Specifically, we develop a variational Bayesian approach to exploit the fixed alphabet of reflectance levels and enable a pixel-wise iterative inference for fast recovery. Numerical results confirm the effectiveness of the proposed method.

18:00 **Quality Evaluation Of Engineered Wood By THz-TDS** **Mo-POS-14**

Moe Kashima; Satoru Tsuchikawa; Tetsuya Inagaki
Nagoya University, Japan
This study attempts simultaneous prediction of grain angle, density and moisture content by THz time domain spectroscopy (THz-TDS) which has sufficient spatial

resolution and transparency for wood. Terahertz waves transmitted through wood contain information on moisture content, density, grain angle and crystallinity of the sample. In this study, we measured spectra of 14 kinds of wood (5 soft wood, 9 hard woods) at various moisture contents and air-dried douglas fir while rotating the sample against the polarization of the terahertz wave. It was shown that the fiber orientation, density and moisture content of wood can be predicted simultaneously from the calculated complex permittivity.

18:00 **Inspection Of Microfibril Angle Of Sugi Wood By THz-TDS** **Mo-POS-15**

Han WANG; Satoru Tsuchikawa; Tetsuya Inagaki
Nagoya University, Japan
Wood as a biological material has large differences in individual properties, and terahertz time-domain spectroscopy (THz-TDS) provide a new possibility for the wood products industry since THz exhibits high transparency to wood with big birefringence and diattenuation. By using the complex refractive index and absorption coefficient, THz is excepted to estimate important properties such as fiber orientation, microfibril angle (MFA) etc. simultaneously. In this study, sugi was used as sample because of its simple structure. Density and moisture content were predicted by using the real part of complex refractive index combined with absorption coefficient and showed a high correlation between measured and predicted values, prediction of MFA is still an ongoing mission.

18:00 **Infrared Modulators Based On Liquid Crystals** **Mo-POS-16**

Urszula Chodorow; Rafał Mazur; Przemysław Morawiak; Wiktor Piecek; Przemysław Kula; Piotr Harmata; Piotr Martyniuk
Military University of Technology, Poland
In this work liquid crystal (LC) modulators are considered. First one is based on electrically controlled birefringence (ECB) effect. A transducer with the thickness of 59 μm was prepared and liquid crystal material designed for infrared applications was used. The LC material shows mesomorphic phase in the room temperature and it has decreased absorption bands in the mid-infrared range (3 -- 5 μm). The other considered modulator is a Fabry-Perot interferometer which can be used as a narrow band filter.

18:00 **Four-channel Terahertz Time-domain Spectroscopy System For Industrial Pipe Inspection** **Mo-POS-17**

Jens Klier[1]; Dmytro Kharik[1]; Wladimir Zwetow[1]; Dominik Gundacker[1]; Stefan Weber[1]; Daniel Molter[1]; Frank Ellrich[2]; Joachim Jonuscheit[1]; Georg von Freymann[1]
[1]Fraunhofer ITWM, Germany; [2]TH Bingen, Germany
The measurement of layer thicknesses is one of the most promising fields of applications of terahertz measurement systems. Besides the investigation of coatings in the automotive or aeronautic industry, the inline inspection of wall thickness in pipe production processes is another highly interesting application scenario for terahertz technology. We present a four-channel terahertz time-domain spectroscopy systems developed for the inline measurement of pipe wall thickness measurements.

18:00 **Neutron Generator Based On A Plasma Source With Gyrotron Heating** **Mo-POS-18**

Alexander Sidorov; Sergey Golubev; Ivan Izotov; Roman Lapin; Sergey Razin; Roman Shaposhnikov; Vadim Skalyga; Alexey Bokhanov; Mikhail Kazakov; Sergey Shlepnev; Mikhail Glyavin; Alexander Tsvetkov; Mikhail Morozkin; Mikhail Proyavin; Ivan Plotnikov
Institute of Applied Physics, Russian Federation
A new type of ECR ion sources -- a gasdynamic ECR ion source was developed recently at the Institute of Applied Physics (IAP RAS, Nizhniy Novgorod, Russia). Such devices use powerful millimeter wave radiation of modern gyrotrons to produce plasma with parameters suitable for extremely high current ion beam production. The major part of previous experiments had been carried out in a pulsed mode. A new experimental facility named GISMO (Gasdynamic Ion Source for Multipurpose Operation) is under construction at the IAP RAS to develop a continuous working gasdynamic ion source. Future source will utilize 28 and 37.5 GHz / 10 - 20 kW gyrotron radiation for plasma heating. In 2013 the authors suggested an approach for high yield compact D-D neutron generator based on a high current gasdynamic ECR ion source. The GISMO facility should become a prototype of the intense neutron source suitable for boron neutron capture therapy.

18:00 **Pharmaceutical Analysis Using Broadband Terahertz Quantum Cascade Laser Sources Based On Difference Frequency Generation** **Mo-POS-19**

Kazuki Horita[1]; Atsushi Nakanishi[1]; Kazuue Fujita[1]; Koichiro Akiyama[1]; Tomoaki Sakamoto[2]; Yukihiro Goda[2]; Hironori Takahashi[1]
[1]HAMAMATSU PHOTONICS K.K., Japan; [2]National Institute of Health Sciences, Japan

We present a pharmaceutical analysis method for a quantitative evaluation of theophylline polymorphism, based on terahertz difference-frequency quantum cascade laser sources (THz DFG-QCL). In the experiments, samples consisting of an additive and hydrous or anhydrous theophylline were used as model drugs. The absorbance of the samples was obtained by illuminating with a THz DFG-QCL producing broadband THz emission. While no correlation was found between the anhydrate concentration and absorbance, a significant correlation was observed for the hydrate (R2 = 0.92). The results successfully demonstrate the evaluation of pseudo-polymorphism of theophylline despite requiring no complicated optical system.IntroductionRecently, in-line process monitoring has been required for the quality control of the end-product in pharmaceutical manufacturing. Unlike a conventional chemical analysis, spectroscopic techniques such as near-infrared, terahertz and Raman spectroscopy do not require pretreatment and sampling; thus, these techniques are anticipated in process monitoring methods. Among them, terahertz spectroscopy is especially promising for investigating coating thickness [1], crystal polymorphism [2]. Only few studies have reported terahertz spectroscopy which was utilized as in-line or on-line process analytical tool, because the terahertz time-domain spectroscopy, used in the frequency range, has several problems including measurement speed, stability and size. Therefore, in order to realize compact spectroscopic system, small THz light sources are essentially important. As a promising candidate, THz quantum cascade laser (QCL) sources based on intracavity difference-frequency generation (DFG) have been demonstrated, which are only electrically pumped monolithic semiconductor THz sources operable at room temperature. We have developed THz DFG-QCL featuring broadband THz emission, continuously more than one octave in frequency between 1.6 and 3.8 THz at room temperature [3]. Although the device performance of THz DFG-QCLs has significantly been improved, these devices have not been used in real applications. In this study, we performed a pharmaceutical analysis with THz DFG-QCL, and as a result, we obtained a significant relationship between the hydrate or anhydrate concentration and absorbance. Since the change of crystal form may directly affect solubility, dissolution and hence the drug bioavailability, the real-time measurement of polymorphism analysis is substantially important for the quality control of pharmaceutical products.

18:00 **Quantitative Analysis And Inspection For Pharmaceutical Polymorphism With Injection-seeded Terahertz Parametric Generation Technique** **Mo-POS-20**

Mizuki Mohara; Kenji Aiko; Kei Shimura; Touya Ono
Hitachi high-technologies corp., Japan

Terahertz (THz) spectroscopy with injection-seeded terahertz parametric generation technique has potential as a nondestructive transmission inspection (is-TPG) technique for pharmaceutical tablets because of high peak power THz wave and wide dynamic range. Using a spectrometer with is-TPG technique, enalapril maleate polymorphs were identified by their specific absorption peaks. We conducted quantitative analysis of enalapril maleate Form I and obtained the limit of detection of 0.4 wt%.

18:00 **Ultra-broadband THz Spectroscopy For Sensing And Identification For Security Applications** **Mo-POS-21**

Korbinian Kaltenecker[1]; Binbin Zhou[1]; Kai-Henning Tybussek[2]; Sebastian Engelbrecht[3]; Roy Lehmann[4]; Stewart Walker[4]; Peter Jepsen[1]; Bernd Michael Fischer[2]
[1]Technical University of Denmark, Denmark; [2]French-German Research Institute of Saint-Louis, France; [3]French-German Research Institute of Saint Louis, France; [4]Flinders University, Australia

Ultra-broadband THz data recorded by air-plasma based systems, as well as synchrotron data will be presented for sensing and identification applications. The evolution from a precursor to home-made explosives can be nicely resolved using THz-TDS. Modelling these spectra by ab-initio DFT and molecular crystal simulation tools allows to identify the different inter- and intra-molecular character of the vibrational modes in this frequency range.

18:00 **Numerical Study Of Millimeter-Wave Discharge And Application To Launching System For Small Satellites** **Mo-POS-22**

Masayuki Takahashi; Naofumi Ohnishi
Tohoku University, Japan

Microwave rocket was proposed as a next-generation transportation scheme to reduce launching costs of small satellites. A high-averaged power microwave is transmitted to the vehicle to save an on-board fuel for rocket launching. An external magnetic filed is applied to the breakdown region to enhance the thrust performance at lower pressures. A plasma fluid model was developed to reproduce the breakdown process under the magnetic field, while saving a computational cost. The plasma structure reproduced by the fluid model was compared with that reproduced by the particle model. The electron density obtained in the fluid model had a good agreement with that obtained in the particle model. The propagation speed of the plasma front becomes slower when the magnetic field is applied because the electron diffusion is suppressed. The critical density is increased owing to the magnetic field, which increases the maximum electron density.

18:00 **A Design Of Industrial Robot For THz-TDS Nondestructive Testing Application** **Mo-POS-23**

Xiaoli Qiao[1]; Jian Gu[1]; Lijuan Li[1]; Yundong Zhu[1]; Jianjun Xiong[2]; Dacheng Liu[2]
[1]Changchun University of Science and Technology, China; [2]Chengdu Aircraft Design Institute, China

The detection accuracy is affected by the incidence angle in reflective THz-TDS nondestructive testing application. The amplitude maximum and the energy of the signal received are in rapid decline, when the incidence angle is over a certain threshold, resulting in the distortion of the detection result and the error judgment of defects. We designed an integrated application with THz-TDS imaging system and the industrial robot because two dimensional guides cannot be used to detect curvature samples. Experiments demonstrated that the design is effective for overcoming the distortion of the curvature sample test results.

18:00 **A Non-Cooperative Fast Millimeter-Wave Imaging Method By Using MIMO Linear Array** **Mo-POS-24**

Yang Yu; Lingbo Qiao; Ziran Zhao
Tsinghua University, China

A non-cooperative fast Millimeter-Wave imaging method based on multiple-input--multiple-output(MIMO) linear array is presented. The MIMO linear array here cooperating with a dielectric lens realizes a fast fan-beam scanning in vertical direction, and the images of horizontal direction can be obtained by non-cooperative moving of human without motion blur. Simulations are performed by using FEKO and the results demonstrate the performance of the imaging method.

18:00 **Numerical Study Of Discharge Physics Induced By Subcritical Millimeter Wave** **Mo-POS-25**

Kanta Hamasaki; Masayuki Takahashi; Naofumi Ohnishi
Tohoku University, Japan

Discharge experiments induced by an intense millimeter wave became possible since the 1980s because millimeter-wave source for current drive was developed in fields of nuclear fusion. The discharge experiment is classified as a subcritical condition when the intensity of a local electric field at a breakdown volume (E_0) does not exceed the threshold for triggering the gas breakdown (E_c).At the subcritical condition, a flight experiment of a beamed-energy rocket, which utilizes intense millimeter waves as a propulsion energy, was conducted by Oda et al. using a 1-MW, 170-GHz pulsed gyrotron. The experiment revealed that a granular plasmoid continuously propagated toward the millimeter-wave source, which did not change depending on the observation angle. Although a numerical simulation, which is based on a computational fluid dynamics and a plasma transport, was conducted to reproduce formation of the plasma structure at the subcritical condition , a propagation speed of ionization sfront was underestimated and the breakdown was not maintained at $E_{0,rms} < 0.8$ MV/m which was same condition as that in Oda's experiments. It is necessary to introduce additional physical processes for triggering the breakdown under the subcritical condition. In this study, the discharge structure induced by the subcritical millimeter-wave beams is numerically reproduced at the different beam intensities under air atmosphere. A one-dimensional (1D) fluid model for the plasma is used when it is coupled with an electromagnetic wave propagation and a neutral gas dynamics to capture interactions between the gas heating of neutral particles and the plasma transport.

In addition, a change of chemical species population in atmospheric gas is coupled with the 1D plasma fluid model. The root-mean-square (rms) values of the incident microwave $E_{0,rms}$ are changed in a range from 0.4 to 1.2 MV/m, which are classified as the subcritical condition. The electromagnetic wave is injected from x=0. The simulation is performed in dry air (N_2:O_2=0.8:0.2). The initial pressure and temperature of neutral particles are set as 1.0 atm and 300 K, respectively. $E_{0,rms}$ is increased at the initial spot (x=1.25λ) to model the beam focusing and the initial breakdown. A population of $O_2(a^1)$ becomes higher than that of O_2 at the ionization front. Therefore, the plasma propagation with a shock wave is captured even at $E_{0,rms}$=0.6 MV/m due to a decrease in an average ionization energy of a heated air. The propagation speed of the ionization front is evaluated as 220 m/s, which is half of an experimental result. We consider that it is necessary to introduce effects of radiation at the ionization front.

18:00 **Microwave Pyrolysis Of Peat: Simulations And Experimental Results** **Mo-POS-26**

Tatiana Krapivnitckaia[1]; Alexander Bogdashov[2]; Andrei Denisenko[1]; Mikhail Glyavin[1]; Nikolai Peskov[1]; Ludmila Semenycheva[3]; Dmitry Vorozhtcov[3]
[1]Institute of Applied Physics of Russian Academy of Sciences, Russian Federation; [2]Institute of Applied Physics RAS, Russian Federation; [3]Nizhegorodsky State University, Russian Federation

Development of the systems for research of effect of powerful microwave radiation on various chemical materials and bio- agricultural objects is carried out in collaboration between IAP RAS and Nizhegorodsky University. For investigation of the process of microwave pyrolysis the laboratory set-up based on a coaxial resonator and irradiated by 2.45 GHz industrial magnetron was constructed. The paper presents results of the thermodynamic and electromagnetic simulations of this system and results of experimental studies of the microwave pyrolysis of peat. Samples of gas, liquid, and solid phases were obtained and analyzed.

18:00 **Terahertz Resonator Diagnostics Of Filamentary Dielectric Objects** **Mo-POS-27**

Alexander Badin; Vitalii Bessonov; Kirill Dorozhkin; Igor Dorofeev; Grigorii Dunaevskii; Ba Hiu Le
National Research Tomsk state University, Russian Federation

For quasioptical open resonant terahertz diagnostics, in some cases it is possible to develop methods already used at lower frequencies. In SHF range a device was created to control ultrathin conductors using an open resonator. This technique is useful for quality control of filaments, such as medical threads, microwire, fishing lines and other industrially manufactured products. The control of permittivity and diameter is especially important for precision 3D-printing. For filamentary objects, but already dielectric, such a quasioptical approach can also be quite effective. In this paper we consider a model of an open resonator with extended dielectric filamentary object at millimeter and submillimeter wave ranges. When electric field of the basic mode of oscillation is thin in comparison with the wavelength of dielectric cylinder in center of open resonator, resonance frequency shift of this mode can be determined from equation. The experimental setup was created on basis of the terahertz spectrometer STD-21. As a source of monochromatic radiation backward-wave oscillator (BWO) was used, detector - Golay cell. The open resonator with two spherical reflectors was used with the following parameters: distance between mirrors L = 66 mm, the concavity radius of the mirrors was 84 mm, diameter of mirror was 40 mm. Matching between resonator and quasi-optical path was carried out through teflon film with thickness of 200 μm. Results of calculations using equation and also measurements of shifts at resonant frequencies of main modes of open resonator with samples of polymer filaments with diameters from 150 μm to 400 μm are shown. Thus, theoretical model of open resonator with thin cylindrical objects is consistent with the results of measurements for thin samples in submillimeter wave range. The possibility of using a resonator converter in THz devices for contactless diagnostics of filamentary objects is shown.

18:00 **Non-Destructive Evaluation Of Soft Body Armour Condition Using Fourier Transform Infrared Spectroscopy** **Mo-POS-28**

Ebubekir Avci; Mark Tunnicliffe; Salem Alsallal
Massey University, New Zealand

The aim of this study is to identify an effective Non-Destructive Evaluation (NDE) approach that can differentiate between a usable and unusable piece of aged soft

body armour that is for protection of body. Firstly, target materials were aged artificially through heating and humidity. Secondly, new and aged samples were analyzed in terms of strength through Fourier Transform Infrared Spectroscopy (FTIR). The outcome of FTIR was compared with the tensile test result to validate the proposed NDE approach.

18:00 **Insulator-Metal Transition In PrYCaCoO3 Thin Films Studied By TerahertzSpectroscopy** **Mo-POS-29**

Christelle Kadlec[1]; Hynek Němec[1]; Karel Knı´žek[1]; Jiři´ Hejmánek[1]; Veronica Goian[1]; Josef Buršı´k[2]

[1]Institute of Physics, Czech Academy of Sciences, Czech Republic; [2]Institute of Inorganic Chemistry, Czech Academy of Sciences, Czech Republic

Charge transport in $PrYCaCoO_3$ thin films wasstudied experimentally by THz and infrared spectroscopy andby dc conductivity measurements. The metal-insulator transitionis clearly visible in THz conductivity, whereas the observed weaktemperature dependence of dc conductivity is limited by inter-grain charge transport.

18:00 **The Prediction Of Laminate Stacking Sequence Of E-glass/epoxy Laminated Composites Using Electromagnetic Behavior Of Terahertz Wave** **Mo-POS-30**

DongWoon Park; Gyung-Hwan Oh; Hak-Sung Kim

Hanyang university, Korea, Republic of

INTRODUCTION The use of fiber reinforced composites provides the benefits including lower structural weight, lower fabrication cost and improved mechanical strength compared to traditional structural materials. The number of its application on various area has increased in recent years while fiber reinforced polymeric laminate composite is tailored by adjusting its composition. However, certain types of internal defects such as delamination and crack might occur between layers during the manufacturing and maintenance. Eventually, the use of fiber-reinforced composites has created the need for non-destructive evaluation (NDE) method for inspecting the defects. Ultrasonic methods and x-ray methods has been suggested for non-destructive evaluation without damage. Since requiring a liquid medium or damaging the electronic devices and harmful to the human body, these method has its own weakness. On the other hand, Terahertz (THz) inspection technique has merits that can be easy inspection in real time without these drawbacks. Among many laminate composites, E-glass/epoxy laminate composites have received attention for low loss dielectric material and superior mechanical properties. However, the electromagnetic properties of E-glass/epoxy laminate composite are not well studied in THz frequency range. In this work, the pulse type Terahertz time domain spectroscopy(THz -- TDS) system was used and its penetration and reflection behavior in the glass fiber reinforced composite were investigated in the analytical analysis as well as the finite element method using commercial multi-physics simulation software COMSOL. In THz frequency range, the electromagnetic properties of E-glass/epoxy laminate composites were measured with respect to the angle($\boldsymbol{\theta}$) between the fiber orientation and the electric field vector of THz wave. From the experimental result, the complex relative permittivities was correlated with the test variable. To describe the complex properties behavior of specific laminating sequences, theoretical models and laminating equation for estimating its complex properties were proposed and experimentally verified. Based on the study above, the new algorithm could be developed and proposed to identify the laminating sequence of the glass-epoxy composite laminates based on the measured terahertz wave's complex relative permittivities non-destructively.RESULTThe complex permittivies of E-glass/epoxy laminated composites of 〚[±30]〛_3s was measured respect to the angle($\boldsymbol{\theta}$) from 0° to 90° at 0.43 THz. Using the transformation equation for the second-order tensor and the measured values of dielectric constant measured at angle 0° and 90°, the dielectric constant was calculated with respect to the angle between 0° and 90°. The results were compared with the experimental value(Fig. 1). It was found that the calculated dielectric constant was agreed well with the theoretically calculated ones.

18:00 **Charge Carrier Dynamics In Bulk Heterojunction Organic Semiconductor By Optical-Pump Terahertz-Probe Spectroscopy** **Mo-POS-31**

Yuichi Hiramatsu[1]; Kaoru Ohta[2]; Kohtaro Takahashi[3]; Mitsuharu Suzuki[3]; Hiroko Yamada[3]; Keisuke Tominaga[2]

[1]Graduate School of Science, Kobe University, Japan; [2]Molecular Photoscience

Research Center, Kobe University, Japan; [3]Division of Materials Science, Graduate School of Science and Technology, NAIST, Japan
Organic semiconductor is an important material in photovoltaic solar cells, which are cost effective and environmentally friendly compared to the silicon-based ones. However, the power conversion efficiency (PCE) is still not high enough for practical use. To improve PCE, it is important to understand detailed mechanisms of charge generation, recombination, and quantify the charge-carrier mobility. Tetrabenzoporphyrin (BP) is one of well-known organic semiconductors which exhibit strong absorption in the visible region, but PCE of BP:PCBM bulk heterojunction (BHJ) solar cell is very low (0.1 %). By conjugating diketopyrrolopyrrole (DPP) groups to BP, Takahashi et al. demonstrated that the length of alkyl chains on DPP units strongly affects PCE for DPP-BP:PCBM BHJ solar cell. PCE improves up to 5.2 % when n-butyl group (C4) is attached to DPP. In this study, we use optical-pump terahertz (THz)-probe spectroscopy to investigate charge carrier dynamics in DPP-BP:PCBM BHJ thin film. Transient THz signals decay with the time constants of 0.7 ps and 18 ps. Compared with BP:PCBM thin film, we find that mobile charge carriers survive on a longer time scale. Furthermore, the amplitude of fast decay components depends on the excitation fluence, which is due to charge pair annihilation at the higher carrier density.

18:00 **Anisotropy Of Electrical Properties Of 3D-printing MWCNT Composites At The THz Frequency Range** **Mo-POS-32**

Alexander Badin; Grigorii Kuleshov; Kirill Dorozhkin; Grigorii Dunaevskii; Valentin Suslyaev; Victor Zhuravlev
National Research Tomsk state University, Russian Federation
In recent years the additive manufacturing are actively developing. Use of additives based on modifications of carbon as a filler of filaments for 3D-printing has many possibilities. 3D-printed objects based on filaments with additions of carbon nanotubes or graphene have significant conductivity and perfect mechanical properties. The formation of ordered structures based on MWNTs in a dielectric matrix allows one to create anisotropic materials for elements of THz frequency band technique. It is of interest to develop and fabricate composite material with an ordered conducting structure by method of layer-by-layer fusion for creating elements of terahertz technology. The samples of the 3D-printing MWCNT composites was prepared for researches. MWCNTs with average diameter of 9.4 nm were produced by method of the catalytic gas-phase deposition of ethylene in the presence of catalyst FeCo. The conductive filament was made by hot extruding mixture of nanotubes and styrene acrylonitrile butadiene. The conductivity of the resulting filament was 3.8*10-4 Sm/m. Composite consisting of dielectric acrylonitrile butadiene styrene substrate with thickness 200 Âμm and conductive periodic structure of strips made of a composite with MWCNT was modeled and printed on industrial 3D printer by fused deposition method with nozzle 200 Âμm in diameter. Averaged real part of permittivity of filament at frequency range 34-350 GHz was 7.43, the imaginary part was 0.9. The resonance frequency of individual strips was calculated by formula. The calculation for 500-μm-wide strips with real part of permittivity of 7.43 shows presence of resonance at frequency of 212 GHz for m = 2. The angular dependences of transmission coefficient were measured by using of the system of precise positioning of samples in quasi optical beam Measured spectrum shows a change of 44% of the transmission coefficient, depending on the orientation of the sample. The resonance at frequency near 200 GHz is observed. The resonant frequency is less than calculated which can be explained by expansion of plastic at 3D printing. Thus, it was shown the possibility of creating THz control elements by using 3D-printed anisotropic composites which were based on MWNT and styrene acrylonitrile.

18:00 **An Different Optical Path Scheme To Improve Parameters Extraction In Terahertz Frequency** **Mo-POS-33**

Dehua Li; BeiBei Ji; Wei Zhou; zhaoxin Li
Shandong University of Science &Technology, China
In this paper, a more accurate material parameters extracting method, the different optical path method (DOP), was theoretically derived and experimentally demonstrated. A HDPE sample was measured to compare the DOP method with regular terahertz spectroscopy. The results show that DOP can reveal some of absorption line which can't be revealed by the normal terahertz spectroscopy, and can carry out a more precious measurement of material parameters.

18:00 **Varnishes Of Painting Material Studied By Terahertz Spectroscopy** **Mo-POS-34**

Quentin Cassar[1]; Corinna Koch-Dandolo[1]; Marie Roux[2]; Frédéric Fauquet[1]; Jean-Paul Guillet[1]; Patrick Mounaix[1]
[1]Laboratoire de l'Intégration du Matériau au Système (IMS), France; [2]L'Atelier des Renaissances, France
We report on further development of terahertz systems for measuring the thickness of multiple films for non-contact control in heritage science. The analysis of time-domain data is described and the results of the measurements made on an ancient real painting on copper, exhibiting two layers, are shown. We specially focus on the dielectric characterization of the varnish layer.

18:00 **Low-dimensional Narrow-gap Semiconductors Studied By Photoluminescence Spectroscopy** **Mo-POS-35**

jun shao; Xiren Chen; Liangqing Zhu
Shanghai institute of technical physics, Chinese academy of sciences, China
With a brief introduction of infrared modulated photoluminescence (PL) method, experimental data acquired with PL measurements are presented for narrow-gap InGaNAs quantum wells and HgTe/CdTe superlattices under different temperatures and/or magnetic fields. The effects of interfacial roughness and/or electric field are analyzed. The results indicate the modulated PL method an efficient vehicle for interfacial effects and also in long-wavelength infrared.

18:00 **Photoluminescence And Terahertz Time-domain Spectroscopy Of MBE-grown Single-layered InAs/GaAs Quantum Dots** **Mo-POS-36**

Alexander De Los Reyes[1]; John Daniel Vasquez[2]; Lorenzo Lopez, Jr[2]; Hannah Bardolaza[2]; Che-Yung Chang[3]; Der-Jun Jang[3]; Armando Somintac[1]; Arnel Salvador[1]; Elmer Estacio[1]
[1]National Institute of Physics, University of the Philippines Diliman, Philippines; [2]Materials Science and Engineering Program, University of the Philippines Diliman, Philippines; [3]Department of Physics, National Sun-Yat-Sen University, Taiwan
We report on the temperature-dependence of the photoluminescence (PL) and terahertz (THz) emission characteristics of single-layered InAs/GaAs quantum dots (QD's) grown via molecular beam epitaxy (MBE). Results from photoluminescence (PL) spectroscopy revealed the presence of energy peaks corresponding to two possible QD size distributions. The THz emission was found to increase as temperature increases, which we attribute to be due to the increase in the number of carriers undergoing transport.

18:00 **Temperature Dependence Of THz Conductivities Of Polyaniline Emeraldine Salt/Bentonite Pellets** **Mo-POS-37**

Alvin Karlo Tapia[1]; Lou Serafin Lozada[1]; Keisuke Tominaga[2]
[1]Institute of Mathematical Sciences and Physics, University of the Philippines Los Banos, Philippines; [2]Molecular Photoscience Research Center, Kobe University, Japan
The THz conductivities of Polyaniline Emeraldine Salt/Bentonite pellets were studied from 80 K to 290 K. Results show that the conductivities increase with increasing temperature. The negative imaginary conductivities reflect backscattering. The complex conductivities were fit by the combined Drude-Smith-Lorentz model. The conduction mechanism in the pellets appear to follow coupling between charges and localized vibrations.

18:00 **β-BBO: Optical Properties And Phase-Matching For THz Wave Generation** **Mo-POS-38**

Alexander Mamrashev[1]; Nazar Nikolaev[1]; Valery Antsygin[1]; Tatyana Bekker[2]; Alexander Kokh[2]; Konstantin Kokh[2]; Grigory Lanskii[3]; Valery Svetlichnyi[4]; Yury Andreev[3]
[1]Institute of Automation and Electrometry SB RAS, Russian Federation; [2]Institute of Geology and Mineralogy SB RAS, Russian Federation; [3]Institute of Monitoring of Climatic and Ecological Systems SB RAS, Russian Federation; [4]Siberian Physical Technical Institute of Tomsk State University, Russian Federation
Optical properties of β-BBO crystals i. e. absorption coefficient and refractive index dispersions, were studied using a custom-made THz-TDS in the range of 0.2-2.0 THz at the temperatures of 293 K and 81 K. The measured o- and e-wave refractive indices were formulated in the form of Sellmeier equations. Phase-matching conditions for the IR-THz and THz-THz frequency conversion were calculated

18:00 **Spatially Resolved Mid-infrared Photoluminescence Of InAs/GaSb Superlattices For Focal Plane Array** **Mo-POS-39**

Xiren Chen; Jun Shao
Shanghai institute of technical physics, China
To examine the electronic homogeneity of semiconductors for mid-infrared focal plane array (FPA), spatially resolved mid-infrared photoluminescence (PL) was developed and performed on as-grown and rapid-annealed InAs/GaSb superlattices (SLs). Comparison of the PL mapping between as-grown and annealed SLs shows that the in-plane distribution of radiative recombination is uniformed due to rapid-annealing. This work suggests the availability of spatially resolved mid-infrared PL in revealing the nonradiative channels distribution for InAs/GaSb SLs.

18:00 **Terahertz Time-Domain Spectroscopy Of Protein Myoglobin: Detectionof Boson Peak And Fracton** **Mo-POS-40**

Leona Motoji[1]; Tatsuya Mori[1]; Yasuhiro Fujii[2]; Akitoshi Koreeda[2]; Kentaro Shiraki[1]; Yohei Yamamoto[1]; Seiji Kojima[1]
[1]Division of Materials Science, University of Tsukuba, Japan; [2]Department of Physical Sciences, Ritsumeikan University, Japan
We performed terahertz time-domain spectroscopy and low-frequency Raman scattering on protein myoglobin, to detect universal boson peak (BP) behavior in glassy materials and fracton expected to universally appear in polymer glasses. The obtained spectral shape of log ε'' vs log frequency [ε'': the imaginary part of complex dielectric constants] indicates that the fracton region appears above the BP frequency. Fractal and fracton dimensions are evaluated from the obtained spectra.

18:00 **Anisotropy In The Low Energy Dynamics Of semi-metallic CaIrO3 Thin Film** **Mo-POS-41**

Santhosh kumar Kadakuntla
IISER Bhopal, India
we have investigated the low energy dynamics in the CaIrO3 thin film along two pseudo-cubic in-plane crystal orientations. THz conductivity along two in-plane axes reveals significant difference including semi-metallic characteristics such as low zero frequency conductivity followed by THz absorption peak and high dielectric constants. These signatures are further investigated using photoemission spectroscopy. Along with these results, anisotropy in magnetoresistance along both directions shows that the strength of spin-orbit coupling modifies the low energy dynamics of the system.

18:00 **Demonstration Of Magnetoplasmon Polariton At InSb/dielectric Interface** **Mo-POS-42**

Jan Chochol[1]; Martin Micica[1]; Kamil Postava[1]; Mathias Vanwolleghem[2]; Jean-François Lampin[2]; Michael Cada[3]; Jaromir Pistora[4]
[1]VSB - Technical University Ostrava, Czech Republic; [2]Institut d'Electronique, de Microelectronique et de Nanotechnologie, France; [3]Department of Electrical and Computer Engineering, Dalhousie University, Canada; [4]VSB - Technical University of Ostrava, Czech Republic
A surface plasmon resonance (SPR) in terahertz range is demonstrated in InSb. Using an Otto configuration, the surface plasmon is excited on the interface between semiconductor and a thin polymer film by silicon prism. Due to the low effective mass of InSb it is possible to tune SPR by an external magnetic field in transversal configuration. It is possible to achieve resonance shift up to 100 GHz with magnetic field 0.25 T. The experimental results show good agreement with the theoretical model.

18:00 **Development Of NbN Polarization Sensitive KID For Fusion Applications** **Mo-POS-43**

Francesco Mazzocchi[1]; Eduard Driessen[2]; Shibo Shu[2]; Giovanni Grossetti[1]; Dirk Strauss[1]; Theo Scherer[1]
[1]Karlsruhe Institute Of Technology, Germany; [2]IRAM Grenoble, France
In this paper, we present the preliminary study for the design of Kinetic Inductance Detectors (KID) sensitive to polarization to be employed in an innovative polarimetric system for fusion plasma diagnostics application.

18:00 **Broadband High-Directivity THz Photoconductive Antennas Based On A Defective Photonic Crystal Substrate** **Mo-POS-44**

Ehsan Rahmati; Mehdi Ahmadi-Boroujeni
Sharif University of Technology, Iran
In this paper, we report on the design and analysis of THz photoconductive antennas (PCAs) based on a defective photonic crystal (DPC) substrate. We show that employing the DPC substrate in PCA arrays reduces the amount of power

coupled to the substrate surface waves and, at the same time, decreases the coupling between the elements of the array antenna. Therefore, radiation in undesirable directions is reduced and directivity of the THz PCA is increased. In addition, this technique can overcome the adverse effects of the thick substrate in THz PCAs and can reduce the necessity of exploiting hyper-hemispherical Si lenses. By using the proposed DPC substrate, the average directivity of PCA array is increased by more than 8 dB over a wide bandwidth.

18:00 **Monolithic Integrated Ka-band Frequency Doublers Based On GaN Schottky Barrier Diodes** **Mo-POS-45**

Li Li; Jianping Zeng; Ning An; Jun Jiang; Xianjin Deng
Microsystem and Terahertz Research Center, Institute of Electronic Engineering, China Academy of Eng, China

In this paper, we report a Ka-band monolithic integrated doubler circuit using GaN-based Schottky barrier diode(SBD) for the first time. The measured results show that output power achieved 10.5mW at 28.5GHz with constantly 50mW driven power, the efficiency is over 17% from 25.5GHz to 31.5GHz. Also, the doublers with different devices which have different anode dimension and doping level are measured and analyzed.

Firstly, the GaN device is designed, fabricated and analyzed, the parameters such as series resistance (Rs) and junction capacitance (Cj) are determined, and the three dimension model are established. Then, based on the GaN diodes character, the frequency doubler circuit is designed using CAD software HFSS and ADS combined. Finally, the whole circuit is fabricated on 0.1mm sapphire substrates, the GaN epitaxial layers are grown by an in-house Metal-organic Chemical Vapor Deposition (MOCVD) system.

GaN SBD devices with two anode dimensions are fabricated with two kinds of wafer which have different doping level and epitaxial layer thickness. Specifically, the anodes are rectangular with dimensions of 4μm χ 10μm and 2μm χ 10μm, and the parameters of two kinds of wafers are shown in TABLE I.

The doubler circuits have the highest efficiency of 21% at 28.5GHz, and the efficiency is over 17% between 25.5GHz - 31.5GHz, as shown in Fig. 2. All the measurements are carried out at the input power of 50mW, and the maximum output power is 10.5mW.The parameters of SBD type 1 on wafer 1 are: Rs=34Ω ; fc=339GHz ; Bv=-14.2V; Cj0=13.77fF.

18:00 **Basic Performance Of Rectangular Waveguide Type Liquid Crystal Phase Shifter Driven By Magnetic Field** **Mo-POS-46**

Toshiaki Nose; Tomoya Ito; Ryota Ito; Michinori Honma
Akita Pref. Univ., Japan

Rectangular waveguide type phase shifter which is working in the MMW region is prepared by confining nematic liquid crystal (LC) material in U-band rectangular waveguide. Since the LC molecular orientation control in such a huge cell is difficult to expect the help of surface alignment effects from the cell walls, switching off time becomes extremely long even any kinds of driving methods. In this work, magnetic field drive method is adopted for the metal surrounded cell, and vector control magnetic field is applied by using quadrupole electric magnet for versatile control of the LC molecular orientation.

18:00 **High Terahertz Transmittance And Blocking IR Background Noise Package Window Design For Terahertz Focal Plane Array Detectors** **Mo-POS-47**

Jun Wang
School of Optoelectronic Science and Engineering, University of Electronic Science and Technology of, China

Terahertz (THz) detector array with micro-bolometer structure indicates obvious benefits, such as room temperature operation, easy integrating with ROIC, real time imaging, and so on.In order to improve the THz transmittance of detector window, anti-reflection thin film was coated on HRFZ-Si window and FTIR test results indicated over 90% transmissivity in the designed THz waveband. Moreover, very low long wave infrared radiation in environmentcould transport through metal square array covered substrate, which would reduce the background noise for the THz detector.

18:00 **Waveguide Coupling Of Resonant-Tunneling Diode Terahertz Oscillator** **Mo-POS-48**

Hironori Matsumoto[1]; Safumi Suzuki[2]; Masahiro Asada[2]; Yasuaki Monnai[1]

[1]Keio University, Japan; [2]Tokyo Institute of Technology, Japan
We propose a coupler which extracts the terahertz output of a resonant-tunneling diode (RTD) oscillator into a rectangular waveguide. In the proposed structure, the RTD is embedded in a hyperhemispherical silicon lens to reshape the radiation diverging from a tiny chip into a collimated beam, which is sub-sequently converted into a fundamental mode of a WR-2.2 standard waveguide by a linearly tapered horn. This approach allows handy use of RTD oscillators as a platform for a variety of terahertz applications without bulky quasi-optical components.

18:00 **Design Of 0.27-0.37THz Wideband Double-ridge Waveguide Window For Traveling-Wave Tube** **Mo-POS-49**

Gangxiong Wu; Hairong Yin; Fan Wang; Ruichao Yang; Qian Li; Xia Lei; Chong Ding; Xuebing Jiang; Shuangzhu Fang; Lingna Yue; Jin Xu; Wenxiang Wang; Yanyu Wei
University of Electronic Science and Technology of China, China
A broadband coaxial line to double-ridge waveguide window for traveling-wave tube amplifier is proposed in this paper. The bandwidth reaches 0.1THz from 270 GHz to 370 GHz with S11 < -20.2 dB, VSWR <1.21.

18:00 **Liquid Crystal Based Terahertz Phase Shifter With Bi-Layer Structure** **Mo-POS-50**

Anup Kumar Sahoo[1]; Chan-Shan Yang[2]; Chun-Ling Yen[1]; Hung Chun Lin[3]; Yu-Jen Wang[3]; Yi-Hsin Lin[3]; Osamu Wada[4]; Ci-Ling Pan[1]
[1]National Tsing Hua University, Taiwan; [2]National Taiwan Normal University, Taiwan; [3]National Chiao Tung University, Taiwan; [4]Kobe University, Japan
We propose and demonstrate a liquid crystal (LC)based terahertz phase shifter with a thick (550 μm in total) bi-layerLC cell structure incorporating a thin transparent polymericintermediate layer. The present phase shifter exhibitedremarkable performance improvement. The phase shift increasedfrom 94 degree to 111 degree; threshold and drive voltages decreased from2.2Vrms to 1Vrms and from 10 Vrms to 8.4 Vrms, respectively, incomparison with those for single-layer cell structure.

18:00 **InP-Based Grounded Coplanar Waveguide To WR3 Transition For Monolithic Integration With THz Photodiodes** **Mo-POS-51**

Besher Khani; Sumer Makhlouf; Sebastian Dülme; Andreas Stöhr
University of Duisburg-Essen, Germany
A novel monolithic integration concept of an indium phosphide (InP) THz-photodiode (PD) featuring a rectangular waveguide output is presented. The concept is based on a planar grounded coplanar waveguide to rectangular waveguide (GCPW-to-WR3) transition designed on an InP substrate. The presented integration eliminates the need for complex and high-cost hybrid integration and packaging techniques, like flip-chip, wire-bonding, and split-block. The numerical analysis of the designed transition shows a 3dB bandwidth of 44 GHz in the WR3 band. Its electrical performance and bandwidth are compared with the ultra-thin low-dielectric liquid crystalline polymer-based GCPW-to-WR3 transition.

18:00 **Graphene Based Organic Optical Terahertz Modulator** **Mo-POS-52**

Bo Zhang[1]; Guocui Wang[1]; Hongyu Ji[1]; Bin Li[2]; Jingling Shen[1]
[1]Department of Physics, Capital Normal University, China; [2]Beijing Research Center for information technology in Agriculture, China
We investigate a high-efficiency broadband terahertz wave modulator with structures made from the conjugated polymer MEH-PPV, graphene, and Si, irradiated with an external excitation laser. We demonstrate a strategy that can alleviate the tradeoff between the requirements of modulation depth and modulation speed in polymer/silicon terahertz wave modulators. Using terahertz time-domain and continuous-wave systems, we measured both the terahertz transmission modulation properties and the time responses of the modulator structures. The conjugated polymer/graphene/silicon structure achieved a high modulation factor of 93% for transmission as well as improved the modulation speed of the devices based on polymer/silicon. The high modulation efficiency of the polymer/graphene/silicon structure was induced by the enhancement in carrier density and the extremely high carrier mobility of graphene, respectively.

18:00 **Active Optically-controlled Broadband Terahertz Modulator Based On Fe3O4 Nanoparticles** **Mo-POS-53**

Bo Zhang; Luyao Xiong; Jingling Shen
Department of Physics, Capital Normal University, China

We report an active broadband terahertz modulator based on an Fe3O4 nanoparticle/Si structure, where the interface effects were measured in a THz time-domain spectroscopy system. The Fe3O4 nanoparticle thin film on the Si substrate was easily attained by spin-coating ferrofluids. A modulation depth as high as 92% was achieved at an external laser irradiance of 3.6 W/cm2. This result can be explained by the accumulation of carriers at the interface of the hybrid structure, which induces intense absorption of the terahertz transmission. The superior performance of this device for THz wave modulation compared to other nano-material-based terahertz modulators and the ease of fabrication both illustrate that this is a promising method to modulate THz transmission.

18:00 **Modelling And Study Of A THz Hollow Photonic Crystal Integrated Waveguide** **Mo-POS-54**

Binbin Hong; Nutapong Somjit; John Cunningham; Ian Robertson
University of Leeds, United Kingdom
We present a novel design of low-loss single-mode flat hollow photonic crystal integrated waveguide (HPCIW). The simulated propagation loss is below 1 dB/cm over the operating frequency range between 0.92 THz and 1.06 THz, with a representative loss of 0.8 dB/cm at 1 THz. Compared with substrate integrated waveguide (SIW) and photonic crystal waveguide, the proposed HPCIW requires no via and can be integrated vertically, which make the HPCIW a promising candidate for multilayer THz system in package (TSiP) applications.

18:00 **A 0.55 THz On-Chip Substrate Integrated Waveguide Antenna** **Mo-POS-55**

Kirti Dhwaj[1]; Yan ZHAO[2]; richard Al hadi[2]; M.C. Frank Chang[2]; Xiaoqiang Li[2]; Tatsuo Itoh[2]
[1]University of California, Los Angeles, United States; [2]UCLA, United States
An on-chip Substrate Integrated Waveguide (SIW) antenna operating in Half (HF) mode and One and a Half (OHF) mode is presented. The antenna is implemented in compliance with design rule of Commercial 65 nm CMOS technology. The proposed antenna shows increased bandwidth (compared to resonant antennas) of 20 GHz (0.54 THz -- 0.56 THZ). Moreover, antenna shows a measured directivity of 9.4 dBi, leading to a gain of 2.8 dBi, when calculated with simulated efficiency.

18:00 **Liquid Crystal Based Terahertz Devices** **Mo-POS-56**

Lei Wang[1]; Makoto Nakajima[2]; Yanqing Lu[3]
[1]Nanjing University of Posts and Telecommunications, China; [2]Osaka University, Japan; [3]Nanjing University, China
We first develop a large birefringence liquid crystal (LC) material in terahertz (THz) range. Then broadband tunable transmissive driven with porous graphene and reflective THz waveplates based on this LC are proposed. Furthermore, graphene-assisted high efficiency tunable THz metamaterial absorber is demonstrated. Finally, visible measurement of THz power based on capsulized cholesteric LC film is introduced.

18:00 **Parallel Architecture Of A Sine Waveguide Traveling Wave Tube Amplifier** **Mo-POS-57**

Giacomo Ulisse; Viktor Krozer
Johann Wolfgang Goethe-Universität, Germany
Travelling wave tubes are promising high power sources at millimeter-wave and THz frequencies. At these frequencies the major obstacle is the realization of the slow-wave structure. This work describes the design of a sine waveguide traveling wave tube (TWT) amplifier operating around 168 GHz. A novel parallel architecture was designed considering the use of a single electron beam. The novel architecture permits to achieve high output power maintaining good linearity and to maintain small dimensions of the device. The designed TWT showed a maximum gain of about 30 dB and an output power of 3.73 W at 158 GHz.

18:00 **Versatile Photonic Integrated Optical Frequency Combs Generators For Millimeter-Wave Generation** **Mo-POS-58**

Guillermo Carpintero; Mu Chieh Lo; Alberto Zarzuelo; Robinson C Guzman; Horacio Lamela
Universidad Carlos III de Madrid, Spain
Optical frequency comb generators (OFCG) are optical sources providing equidistant optical wavelengths which enable turning an unknown optical wavelength into a measurable electronic frequency. Photonic integration technology can be advantageously used to produce low-cost, miniaturised footprint OFCGs, in which

the integration of the system on a single substrate also provides enhanced reliability. Recently, silicon nitride micro-resonator Kerr soliton combs has been reported achieving > 50 Tbit/s data-stream and AlGaAs-on-insulator up to 661 Tbit/s. These techniques require high-power single-wavelength pump, making them rather bulky. On-chip mode-locked laser diodes are promising candidates. Single-section quantum-dash mode-locked laser diodes (MLLD) have proved the potential for coherent terabit communications. With the emergence of InP-based generic foundry platform approaches, advanced MLLDs have been developed combining active and passive elements, enabling scalable PIC solutions. We demonstrated MLLDs structures using integrated mirrors with repetition rates ranging from as low as 1 GHz and up to 60 GHz. In this paper, we show that a slight modification of this structure, adding an on-chip coupled feedback cavity or additional absorbers, we can switch the wavelength spacing. We present different types of optical frequency comb structures based on mode-locked lasers, fabricated on generic platform, as high coherence sources. The optical signal does not require cleaved facets, which enables the use of integrated optical multiplexers/demultiplexers to modulate each wavelength separately on the same chip. In addition, the presented comb structures feature wide spectral bandwidth and mode spacing selectability.

18:00 **Study Of Two-section Rectangular Beam TWTs Based On Folded Waveguide** **Mo-POS-59**

Fengying Lu; Yong Wang; Guohui Zhao; Long Yao
University of Chinese Academy of Sciences, China
This paper presents a two-section rectangular beam FW-TWT. By observing the electric field distribution along with the z axis, it is concluded that over longer interaction length leads to lower output power oppositely due to the reflection in the FW circuit. Two section two-section FW-TWT introducing an attender was simulated and compared with the conventional FW-TWT. It shows that attender can reduce the reflection efficiently and thus improve the output power. Finally, the property of the attender are studied by varying the dielectric constant. Proper material should be selected for attender to get the improved output power.

18:00 **Development Of Terahertz Radiation Source With Slit-Array Structure** **Mo-POS-60**

Dazhi Li[1]; T. N. K. Phan[2]; K. Kato[2]; M. Nakajima[2]; M. R. Asakawa[3]; M. Hashida[4]; M. Tani[5]; W. Liu[6]; Y. Wei[7]
[1]Institute for Laser Technology, Japan; [2]Institute of Laser Engineering, Osaka University, Japan; [3]Faculty of Engineering Science, Kansai University, Japan; [4]Advanced Research Center for Beam Science, ICR, Kyoto University, Japan; [5]Research Center for Development of Far-Infrared Region, University of Fukui, Japan; [6]Key Laboratory of High Power Microwave Sources and Technologies, Institute of Electronics, Chinese A, China; [7]School of Physical Electronics, University of Electronic Science and Technology of China, China
We have proposed a slit-array configuration demonstrating higher efficiency in terahertz radiation. Based on the radiation mechanism, we planned to develop terahertz emitter and coherent radiation sources. Research on the geometrical structure, the output methods, and the radiation characteristics are being performed, and the experimental setup is under construction. In this paper, we report on the radiation physics and the consideration on effectively outputting the terahertz radiation, and introduce the recent progress in experiments.

18:00 **An Advanced Terahertz EIO Operating With TM31 Mode** **Mo-POS-61**

Shuang Li; Dongyang Wang; Yan Teng; Guangqiang Wang
northwest institute of nuclear technology, China
In order to increase the feasibility and reliability of the terahertz extended interaction oscillator (EIO), the method of adopting TM31 in the reentry cavity is proposed. The characteristics of high-order EIO is theoretically analyzed, including its electromagnetic properties and the field distributions in it. Compared with the traditional EIOs those operating at the fundamental mode, the advantages of higher power capability and less difficulty in fabrication for the high-order EIOs are proved. Then the structure of high-order EIO is optimized and the performance is studied by the particle-in-cell (PIC) simulations. Under the conditions of 15kV and 150mA for the electron beam, the output power reaches about 85W, corresponding to the efficiency of 3.7%. The frequency is 338.4GHz and the operating mode is verified as TM31 mode, which is stable.

18:00 **Sheet Beam Electron Gun With High Current For 220 GHz TWT** **Mo-POS-**

Shengkun Jiang[1]; Zhaoyun Duan[2]; Guang Yang[2]; Leidong Jin[2]; Xirui Zhan[2]; Hanwen Tian[2]; Zhanliang Wang[2]; Huarong Gong[2]; Yubin Gong[2]
[1]University of Electronic Science and Technology of China, China; [2]School of Electronic Science and Engineering, University of Electronic Science and Technology of Chi, China

A new structure of 220 GHz sheet beam electron gun with high current is proposed and we have attained a desired current density of cathode emission surface ~27.6 A/cm2, which is easily realized for the present cathode emission materials. The sheet beam passes through the beam channel successfully and is not captured. Currently, the proposed electron gun is being built and the current testing and beam transport experiments will be done in the mid of April 2018.

18:00 **Enhancement Of Electric Field In E-plane Sectoral Horn Antennas Reconsidered By Plasmonic Theory** **Mo-POS-63**

Kazuyoshi Kurihara[1]; Kiwamu Kusama[1]; Fumiyoshi Kuwashima[2]; Osamu Morikawa[3]; Kohji Yamamoto[1]; Hideaki Kitahara[1]; Masahiko Tani[1]
[1]University of Fukui, Japan; [2]Fukui University of Technology, Japan; [3]Japan Coast Guard Academy, Japan

Plasmonic theory is applied to the E-plane sectoral horn antennas discussed in microwave technology where metals is treated as perfect conductors approximately. The theory enables us to reconsider the sectoral horn antennas with a finite metallic permittivity for more realistic estimation of an enhancement factor of electric field that enters at the mouth of the sectoral horn antennas through the throat to the parallel- plate waveguide as a limit case of the rectangular waveguide.

18:00 **Terahertz Wave Parametric Amplifier With An Amplification Factor Of Two Billion** **Mo-POS-64**

yunzhuo guo; kousuke murate; kazuki maeda; kodo kawase
nagoya university, Japan

In this research, we demonstrated a high-gain terahertz(THz) parametric amplifier for an extremely weak THz-wave of low frequency (963 GHz). The amplification factor reached more than 94 dB by dividing the amplifier into two parts: the pre-amplifier and the main-amplifier.

18:00 **Optical Generation Of High-power Terahertz Pulses For Tunable Wave Source** **Mo-POS-65**

Isao Yoshimine; Masatsugu Yamashita; Hiromichi Hoshina; Mikiko Saito; Hiroaki Minamide; Chiko Otani
RIKEN Center for Advanced Photonics, Japan

High-power terahertz pulse generation by optical rectification with organic nonlinear crystals was reported. Terahertz pulses up to 730 nJ/pulse was generated from a DAST crystal pumped by 250 μJ light pulses with a central wavelength of 1500 nm. The generated terahertz pulses had a spectrum which can be applied to material science. With terahertz modulation of pump pulses, control of frequency and polarization of the generated terahertz pulses can be obtained, which leads to selective excitation of materials as molecules or spins.

18:00 **THz-range Emission Based On Transformation Of Plasma Waves Pumped By High-current Relativistic Electron Beam** **Mo-POS-66**

Andrey Arzhannikov[1]; Vladimir Annenkov[2]; Vladimir Burmasov[2]; Ivan Ivanov[2]; Aleksandr Kasatov[2]; Sergey Kuznetsov[1]; Maksim Makarov[2]; Konstantin Mekler[1]; Sergey Polosatkin[2]; Vladimir Postupaev[2]; Andrey Rovenskikh[2]; Denis Samtsov[1]; Stanislav Sinitsk[2]; Vladislav Sklyarov[2]; Vasili Stepanov[2]; Igor Timofeev[2]; Evgenia Volchok[2]; Manfred Thumm[1]
[1]Novosibirsk State University, Russian Federation; [2]Budker Institute of Nuclear Physics, Russian Federation

The original project of a THz-range generator (0.1÷1 THz) based on transformation of plasma waves pumped by a high-current relativistic electron beam is developed at the GOL-PET facility. In this facility, a kA-current electron beam excites plasma upper-hybrid waves in a long plasma column, which are transformed into electromagnetic waves via two different physical processes. As the result of the first one the direct conversion of the plasma waves on strong plasma density gradients produces electromagnetic upper-hybrid frequency waves. Secondly, the merging of two upper-hybrid waves into an electromagnetic wave results in radiation with double frequency of upper-hybrid waves. Results of recent experimental studies,

theoretical analysis and computer simulations on this generation scheme are presented in the paper.

18:00 **Super-intense Solid-state Terahertz Sources** **Mo-POS-67**

xiaojun wu
Beihang University, China
Tabletop super-intense terahertz sources covering 0.1-15 THz with peak electric field towards 10 MV/cm are proposed. Tilted pulse front technique is employed to generate intense low frequencies of 0.1-1 THz while femtosecond spin-current is for 1-15 THz generation with 800 nm, 25 fs, 0.5 J Ti:sapphire laser pulses.

18:00 **Enhancement Of THz EO Sampling Signal By Polarization Filtering** **Mo-POS-68**

Hiroyuki Kato[1]; Hideaki Kitahara[1]; Takuro Yasumoto[1]; Daiki Goto[1]; Masaki Shiihara[1]; Jessica Afalla[1]; Valynn Mag-usara[1]; Dmitry Bulgarevich[1]; Clare Escaño[1]; Kohji Yamamoto[1]; Takashi Furuya[1]; Michael Bakunov[2]; Elmer Estacio[3]; Masahiko Tani[1]
[1]Res. Center for Dev. of FIR Region, Univ. Fukui, Japan; [2]Univ. Nizhny Novgorod, Russian Federation; [3]National Institute of Physics, Univ.Philippines, Philippines
To improve the detection efficiency of electro-optic(EO) sampling of terahertz waves, we propose to suppress the main polarization component of the probe optical beam after the EO crystal. Experimentally, we achieved a factor of 2.4 increase in the EO sampling signal.In the experiment, a mode-locked Ti:sapphire laser was used as a light source (wavelength ~ 800 nm, rep-rate 82 MHz, pulse width ~ 100 fs). A dipole PCA, biased by an AC voltage of 70 Vpp (96.8 kHz), was used for generating THz pulses. The average power of the pump beam incident on the PCA was about 10 mW. The THz beam was collimated and focused to an <110>-cut ZnTe EO crystal of thickness tZnTe = 1 mm by a pair of off-axis parabolic mirrors. The probe beam was focused to the EO crystal collinearly with the THz beam through a hole in the focusing parabolic mirror. We used glass plates of thickness tPCE = 0.12 to 0.17 mm, oriented at the Brewster angle, as PCE. The plates were successively inserted, one at a time, in the optical path of the probe beam to suppress the vertical polarization component.

18:00 **Terahertz Emission Enhancement Of I-/n-Gallium Arsenide Thin Film On A Porous Silicon Distributed Bragg Reflector Designed At 800nm** **Mo-POS-69**

Ameera Jose[1]; Anthony Montecillo[1]; Joybelle Lopez[1]; Alexander De los Reyes[2]; Miguel Bacaoco[2]; Maria Angela Faustino[1]; Arven Cafe[2]; John Daniel Vasquez[2]; Karl Cedric Gonzales[2]; Gerald Angelo Catindig[2]; Armando Somintac[2]; Arnel Salvador[2]; Elmer Estacio[2]
[1]Materials Science and Engineering Program, University of the Philippines Diliman, Philippines; [2]National Institute of Physics, University of the Philippines Diliman, Philippines
A bare semiconductor Terahertz (THz) emitter based on an i-/n-GaAs layer integrated on a porous silicon distributed Bragg reflector (PSi-DBR) is presented. PSi-DBR acts as a reflector substrate for the excess 800nm transmitted photoexcitation, as is the case for a very thin GaAs film. For a 0.55 micron GaAs, this novel design exhibited a stronger THz emission (67% increase) compared to a similar GaAs film on Silicon (Si) substrate. The enhancement can be attributed to the increased light absorption and multiple reflections in the active layer.

18:00 **Physical Design Of The Pre-bunched THz FEL At NSRL** **Mo-POS-70**

Ruixuan Huang; Heting Li; Weiwei Li; Zhouyu Zhao; Zhigang He; Yalin Lu; Qika Jia; Lin Wang
University of Science and Technology of China, China
A new high throughput material characterization system is under development at National Synchrotron Radiation Laboratory (NSRL), University of Science and Technology of China. It is a multiple light source which will supply a time resolved pump laser, a broad-band terahertz source and a pre-bunched terahertz free electron laser. We are introducing the physical design results of the project.

18:00 **Finite-difference Time-domain Simulation Of Terahertz Pulse Generation By Non-collinear Phase Matching Using Obliquely Crossed Optical Pulses** **Mo-POS-71**

Ken Morita; Yuta Osumi; Yoshihiro Ishitani
Chiba University, Japan
THz pulse generation for the obliquely crossed optical pump pulses in optical

rectification based on the lithium niobate crystal is simulated by finite-difference time-domain method. We simulated the THz pulse generation in oprical rectification based on lithium niobate crystal which has a large nonlinear coefficient with the different group and phase refractive index between optical and THz regions. We assume the 100 fs optical laser pulse with the center wavelength of 800 nm. The cases for the three different beam widths 10, 40, and 80 μm are calculated at the obliquely crossed angle 3 degree.The beam diameter dependence clearly shows that Cherenkov type radiation with the broad band spectrum is dominant for the beam diameter smaller than 10 μm, while the non-collinear phase matching with narrow spectrum is dominant for the beam diameter larger than 40 μm.

18:00 **Enhancement Of THz-QTDS Performance By Pulsed Laser Operation** **Mo-POS-72**

Arno Rehn[1]; Mikhail Mikerov[1]; Sascha Preu[2]; Martin Koch[1]; Jan Balzer[3]
[1]Philipps University Marburg, Germany; [2]Technical University Darmstadt, Germany; [3]University of Duisburg-Essen, Germany

We present a straightforward method for enhancingthe performance of a low-cost terahertz quasi time-domain spectroscopy (THz-QTDS) system regarding thebandwidth.THz-QTDS is similar to conventional terahertz time-domain spectroscopy (THz-TDS), but instead of an expensive femtosecond pulse laser, a cheaper multi-mode laser diode is employed.Compared to THz-TDS, a typical drawback of THz-QTDS is the smaller bandwidth. In our experiment, the bandwidth of the THz-QTDS signal is improved by modulation of the injection current of the laser diode. The roll-off of the THz spectrum is decreased by 55 dB/THz.

18:00 **Asymmetric Terahertz Radiation From A Thin Foil Irradiated By Ultrashort Relativistic Laser Pulse** **Mo-POS-73**

Shota Tajima
Osaka university, Japan

We have observed the asymmetric THz radiation from the thin foil target irradiated by the ultrashort relativistic laser pulse. The distribution of the THz radiation was observed to depend on the distribution of the escaped electrons. These results imply that the THz radiation can be a powerful diagnosis to study the temporal evolution of the plasma sheath.

18:00 **A Compact Terahertz CW HCN Dual Laser And Its Stability Control** **Mo-POS-74**

Jiaxing Xie[1]; Haiqing Liu[1]; Junjie Shen[2]
[1]ASIPP, China; [2]Tianjin University of Technology, China

A compact terahertz continuous wave (CW) discharge-pumped Hydrogen cyanide (HCN) dual laser has been developed for better signal to noise ratio and higher time resolution, with active power and intermediate frequency (IF) control. The output power of about 1~10 mW on the 0.89 THz line has been obtained with 1 m long and 50 mm inner diameter dual discharge-pumped wave-guides laser. A power and frequency feedback control system is applied to the HCN dual laser. This feedback system consists of two stepping motors, a piezoelectric ceramics (PZT), a PLC, a supervisory computer and the corresponding control program. The whole feedback control system is successful in stabilizing the power of the laser around 1~10 mW and the IF at around 1MHz in several hours

18:00 **Properties Of Terahertz Wave Emission From Nano-porous GoldExcited By Femtosecond Laser Pulses** **Mo-POS-75**

Kosaku Kato[1]; Takashi Kashihara[1]; Thanh Nhat Khoa Phan[1]; Keisuke Takano[2]; Marjan Akbari[3]; Teruya Ishihara[3]; Masashi Yoshimura[1]; Makoto Nakajima[1]
[1]Osaka University, Japan; [2]Shinshu University, Japan; [3]Tohoku University, Japan

We studied properties of terahertz wave emission from gold film with random nano-porous structures excited by femtosecond laser pulses. The dependence of emitted terahertz power on excitation laser power shows higher nonlinear order with 800-nm laser excitation than with 400-nm laser excitation. This result indicates the contribution of multiphoton ionization to the terahertz generation.

18:00 **High Efficient Dichroic Beam Splitter For Terahertz Gas Laser** **Mo-POS-76**

Chuang Liu[1]; Lijuan Li[1]; Qingmao Zhang[2]; Jianjun Xiong[2]; Ping Huang[2]; Jianchuan Li[3]; Longgang Qin[3]
[1]Changchun University of Science and Technology, China; [2]Chengdu Aircraft Design Institute, China; [3]Chengdu Aircraft Industrial (Group) Co., Ltd, China

A high efficient dichroic beam splitter in FIR/IR band is presented. With a thin Ge

plate coated by multilayer dielectric coating, high reflectance at 100~500μm (0.6~3THz) and high transmittance performance at 9~11μm is obtained simultaneously. When using this dichroic beam splitter in a terahertz gas laser for separating the pump CO2 laser and the generated THz laser, the energy conversion efficiency is improved, which indicates high efficient THz laser can be obtained with different wavelengths.

18:00 **(Withdrawn)** **Mo-POS-77**

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18:00 **Development Of The Cyclotron Radiation Source With Vortex Property** **Mo-POS-78**

Yuki Goto[1]; Shin Kubo[2]; Tohru Tsujimura[2]
[1]Nagoya University, Japan; [2]National Institute for Fusion Science, Japan
Recently, it was shown that the radiation from a charged particle with spiral motion has vortex property. Cyclotron radiation, synchrotron radiation from the helical undulator and inverse Compton scattering by intense circularly polarized laser also has vortex property. We are developing the cyclotron radiation source with vortex property by controlling the multi-electron. The electrons which have cyclotron motion around magnetic field can be phase-matched by interaction with the external high power circularly polarized gyrotron beam. The coherent radiation can be obtained from these phase matched electrons.

18:00 **Monocycle Terahertz Vortex Generation By Tsurupica Spiral Phase Plate** **Mo-POS-79**

Katsuhiko Miyamoto[1]; Bong Joo Kang[2]; Yuta Sasaki[1]; Won Tae Kim[2]; Takahiro Miyakawa[1]; Fabian Rotermund[2]; Takashige Omatsu[1]
[1]Chiba University, Japan; [2]KAIST, Korea, Democratic People's Republic of
Optical vortex beams, showing an annular intensity profile, a spiral wavefront and orbital angular momentum characterized by a topological charge *l*, have been investigating in a variety of research field, such as ultra-high speed optical communication, advanced optical manipulation, and chiral materials fabrication. Furthermore, they enable us to develop super-resolution microscopes (with a high spatial resolution beyond the diffraction-limit) based on fluorescence depletion via simulated emission. A vortex beam in a terahertz (THz) frequency region, in which eigen modes of the intramolecular (or cluster-cluster) interactions exist, will potentially allow us to develop THz imaging systems with a micrometer-scale spatial resolution beyond the diffraction-limit by applying it to materials with terahertz nonlinearities such as graphene. To date, we have demonstrated the generation of monochromatic picosecond THz vortex beam at topological charge of l = 1, 2 by a spiral phase plate formed of a Tsurupica polymer (Tsurupica-SPP). In this presentation, we extend our previous work to generate a monocycle THz vortex pulse generation by utilizing the Tsurupica-SPP. Furthermore, we address unique nonlinear transmission behaviors of bilayer graphene induced by illumination of monocycle THz vortex.

18:00 **Theory For High-Field Narrowband THz Generation Via Colliding At An Oblique Angle Plasma Wakefields** **Mo-POS-80**

Evgeniia Volchok; Igor Timofeev; Vladimir Annenkov
Budker Institute of Nuclear Physics, Russian Federation
The analytical theory for the generation of high-field and narrowband THz radiation is presented. The generation mechanism is based on the nonlinear interaction of two colliding at an oblique angle plasma wakefields results in electromagnetic radiation at the double plasma frequency. Optimal parameters of the "proof of principle" experiment in the most effective regime is obtained. Proposed mechanism allows to produce high-field (~10-20 MV/cm) tunable (in range 0.4-40 THz) and powerful terahertz radiation with a narrow line width and efficiency 10^{-3}-10^{-4}.

18:00 **Enhancement Of THz Energy Generated From Two Colour Laser Induced Air Plasma Using Chirped Pulses** **Mo-POS-81**

Sonal Saxena[1]; Suman Bagchi[2]; M. Tayyab[2]; J. A. Chakera[2]
[1]Raja Ramanna Centre for Advanced Technology, India; [2]RAJA RAMANNA CENTRE FOR ADVANCED TECHNOLOGY, India
We have characterized the two-colour laser induced plasma in ambient air as an efficient terahertz source with chirp in the laser pulse duration. Larger THz flux has been observed for positively chirped 200 fs laser pulses, with the transform-limited pulse duration being 45 fs.

18:00 **Enhancing The Energy Of THz Emission From Air Plasma Using Two-color nonlinearly Chirped Laser Pulses** **Mo-POS-82**

Morteza Karimi; Fazel Jahangiri; Ali Reza Niknam; Reza Massudi
Shahid Beheshti Univ., Iran

Terahertz (THz) radiation produced by the interaction of two-color ultra-short nonlinearly chirped laser pulses with the air plasma is investigated. In this interaction, a nonlinear net current density is induced that depend on the frequency modulation of the laser pulses. Our results indicate that applying nonlinear chirp effect could improve the nonlinear current density and result in significantly enhanced THz energy.

18:00 **Development Of An Highly Distributed Photoconductor For CW THz Generation** **Mo-POS-83**

Fuanki Bavedilla; Vincent Magnin; Joseph Harari; Dmitri Yarekha; David Troadec; Sylvie Lepilliet; Vanessa Avramovic; Guillaume Ducournau; Jean-François Lampin; Emilien Peytavit
IEMN CNRS/Lille University, France

In this communication, we propose a new architecture of photomixer in order to develop a wideband and powerful photomixing THz source. It is achieved by a velocity-matched distributed photoconductor (VMDP), in which the pump optical power is guided in a dielectric optical guide and slightly coupled to a low-temperature grown GaAs 1-mm-length photoconductor. We present the fabrication and the characterization of the dielectric optical guide and the THz waveguide which form the VMDP

18:00 **Toward Optimum Conversion Efficiency In 1550-nm THz PC Switches** **Mo-POS-84**

W-D Zhang[1]; Andrea Mingardi[2]; Elliott Brown[3]
[1]TeraPico LLC, United States; [2]Wright State University, United States; [3]Department of Physics, United States

Optical-to-THz conversion efficiencies have been steadily improving in 1550-nm photoconductive switches for the past decade, still under 1% but already exceeding the Manley-Rowe limit of coherent down-conversion. This paper addresses the issue of optimum efficiency and achieving this efficiency with lower laser power levels.

18:00 **Recent Developments And Applications Of Multi-Extreme THz ESR** **Mo-POS-85**

Hitoshi Ohta[1]; Susumu Okubo[2]; Eiji Ohmichi[2]; Takahiro Sakurai[2]; Hideyuki Takahashi[2]; Shigeo Hara[2]
[1]Kobe University, Molecular Photoscience Research Center, Japan; [2]Kobe University, Japan

Due to the advantages of high spectral resolution, ESR measurement beyond the zero field splitting or the magnetic phase transition, THz electron spin resonance (ESR) measurement has been a powerful means to study novel magnetic systems. We have been developing this THz ESR system since 1988, and we are now extending to the multi-extreme THz ESR. Here the multi-extreme corresponds to the high magnetic field, the high pressure, the low temperature and the micro-mechanically detected ESR. Recent new developments, and the application of the high pressure THz ESR will be shown.

18:00 **Light-induced Conformational Changes Of Transmembrane Proteins Probed By Tip-enhanced Mid-infrared Differential Nanospectroscopy** **Mo-POS-86**

Valeria Giliberti[1]; Raffaella Polito[2]; Eglof Ritter[3]; Alessandro Nucara[2]; Paolo Calvani[2]; Matthias Broser[3]; Peter Hegemann[3]; Ljiljana Puskar[4]; Ulrich Schade[4]; Leonetta Baldassarre[2]; Michele Ortolani[2]
[1]Istituto Italiano di Tecnologia, Center for Life Nanoscience, Italy; [2]Department of Physics, Sapienza University of Rome, Italy; [3]Humboldt-Universität zu Berlin, Institut für Biologie, Berlin, Germany; [4]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany

Vibrational mid-infrared spectroscopy is widely applied to transmembrane protein receptors in order to gain insight on the dynamics and conformational changes that are at the base of their function as ion pump or channel. Here we apply for the first time mid-infrared tip-enhanced absorption nanospectroscopy to investigate the light-induced conformational changes of bacteriorhodopsin at the nanoscale. Difference spectra of the protein acting as a proton pump under illumination at 565 nm are obtained on 10 nm-thick cell membrane bilayers with an area of less than 1 μm^2. The data are benchmarked to the difference spectra obtained by Fourier

transform infrared spectroscopy on thick films of unoriented cell membranes containing bacteriorhodospin.

18:00 **Verification Of The Non-thermal Effects Of THz-wave On Human Cells** **Mo-POS-87**

Noriko Yaekashiwa[1]; Sato Otsuki[1]; Hisa Yoshida[1]; Shin'ichiro Hayashi[2]; Kodo Kawase[3]
[1]RIKEN, Japan; [2]RIKEN and NICT, Japan; [3]RIKEN and Nagoya University, Japan
A 0.3-THz or 0.6-THz wave was applied to human cells using a uni-traveling carrier photodiode (UTC-PD) source. We also examined the effects of the exposure of broadband THz pulses emitted from a photo conductive antenna (PCA) on cells. To investigate the non-thermal effects of THz waves, a human skin fibroblast cell line was exposed to continuous and pulse waves. There was no change between the metabolic activity and morphology of the exposed and sham-exposed cells.

Tuesday, September 11, 2018

08:45 - 09:00 **Announcements** **Shirotori Hall**

Session Type: Others

09:00 - 10:30 **Tu-A1-S Plenary Session** **Shirotori Hall**

Session Type: Plenary
Chair(s)/Convenor(s)/Facilitator(s): Franz X. Kaertner
Discussant(s):

09:00 **Millimeter-Wave Technologies For Body-Centric Applications** **Tu-A1-S-1**

Maxim Zhadobov
IETR / CNRS, France
Body-centric wireless networks constitute an attractive next-generation wireless technology representing a cognitive interface to higher-level networks. Recently, the 60 GHz band has been identified as highly promising for body-centric wireless communications including body-area network technologies. A massive deployment of wireless devices equipped with 60 GHz Tx / Rx modules is foreseen in coming years. The corresponding new usages and services will involve near-field interaction of radiating devices with the human body, both in terms of the body impact on wireless device performances as well as in terms of user exposure. This presentation will provide an overview of main features and recent advances in the field of antenna / human body interactions in the 60 GHz band.

09:45 **Active THz Devices Using Hybrid Lead-Halide Perovskites** **Tu-A1-S-2**

Ajay Nahata
University of Utah, United States
The ability to control the propagation properties of THz radiation holds great promise for creating the next generation of active optoelectronic devices and systems. Among the various approaches that have been developed to control the THz response of a device, the use of an optical radiation is highly desirable, because it does not require special device characteristics, such as electrical leads. In the case of semiconductor-based devices, optical radiation allows for straightforward generation of photocarriers, Using silicon wafers that are coated with thin films of two-dimensional methyl ammonium lead iodide (MAPbI3) perovskites, we demonstrate complete extinction in the transmission properties of broadband terahertz radiation. While similar demonstrations have previously been shown using high fluence ultrafast lasers, we show that this can be accomplished using a commercial halogen lamp. Moreover, 2D perovskites offer the ability to tune the band-gap by varying the number of electrically connected layers (n) [3]. This section is the Introduction. II. RESULTSWe used conventional THz time-domain spectroscopy to measure the THz transmission properties through high resistivity silicon wafers that were coated with thin films (typically ~60 nm thick) of 2D perovskites. In Figure 1, we show a schematic of the experimental setup and the corresponding transmission properties.Perovskites allow for variation in the band gap of the material by simply changing the number of layers for 2D perovskites or the composition of 3D perovskites. To demonstrate this, we cast different 2D perovskites onto silicon wafers and varied the excitation spectrum using color filters. We observed extinction peaks in broadband terahertz radiation just above the band-gap of the corresponding 2D perovskites. These extinction peaks in THz correspond to exciton absorption peaks in 2D perovskite associated with 2D arrangement. We utilize this capability to demonstrate a 3 color metamaterial

structure based on plasmonic aperture arrays. In this device, three separate aperture arrays with different periodicities were fabricated in aluminum films deposited on a single silicon substrate. Each section was then coated with a different 2D perovskite (n=1,2 or 3). By exciting the device with different colors from the halogen lamp, different resonances associated with the three different aperture array sections could be modulated (Fig 2). When illuminated using white light excitation, all three resonances can be modulated simultaneously.

11:00 - 12:30 Tu-A2-R1 Spectroscopy and Material Properties IV — **Shirotori Hall**

Session Type: Oral

11:00 **[Keynote] THz Near-field Imaging And Spectroscopy With Nanoscale Resolution** — **Tu-A2-R1-1**

Aina Reich; Andreas Huber; Max Eisele
neaspec GmbH, Germany

Scattering-type near-field microscopy can overcome the limits in spatial resolution present in conventional THz imaging and spectroscopy techniques. This talk shows how THz near-field imaging and THz-TDS with a spatial resolution <20 nm can be realized with our neaSNOM microscope and some of the possible applications.s-SNOM has shown its strength in different applications of THz near-field nanoscopy. Monochromatic and broadband THz near-field imaging contrasts can be used to map the free charge carrier concentration in 1D wires, 2D graphene and 3D semiconductor structures. The integration of THz-TDS also enables a look at the carrier dynamics.The recent integration of our microscope into a closed-cycle cryostat is the latest development towards new opportunities in the research of low energy transitions.

11:30 **Visualization Of Plasmons In Zero-Dimensional Graphene With Near-Field Infrared Microscopy** — **Tu-A2-R1-2**

Takuya Okamoto[1]; Akira Sasagawa[1]; Yota Harada[2]; Satsuki Nakano[2]; Wataru Norimatsu[2]; Michiko Kusunoki[2]; Yukio Kawano[1]
[1]Tokyo Institute of Technology, Japan; [2]Nagoya University, Japan

Because of unique plasmonic features, nanostructured graphene such as graphene nanoribbons (GNRs) and quantum dots (GQDs) is attracting much interests. In this work, we investigated real-space characterization of surface plasmon polariton (SPP) in GQDs on SiC substrate by utilizing a scattering-type scanning near-field optical microscope (s-SNOM) in the mid-infrared (MIR) band. Nanoscale near-field images revealed that the SPP in GQDs was excited in a strongly frequency-dependent manner, which is significantly different from two-dimensional (2D) graphene. The present findings provide not only a deeper understanding of the SPP in graphene nanostructures, but also a first step for exploring new plasmonic functionalities impossible with conventional 2D graphene.

11:45 **Semiconductor Energy Band Structure Characterized By Terahertz Excitation Spectroscopy** — **Tu-A2-R1-3**

Andrius Arlauskas; Vaidas Pačebutas; Renata Butkutė; Ričardas Norkus; Bronislovas Čechavičius; Evelina Pozingytė; Arūnas Krotkus
Center for Physical Sciences and Technology, Lithuania

A new method for semiconductors band structure characterization is presented. THz excitation spectroscopy is a versatile tool for the investigation of semiconductor band structure. In the present contribution it is used for determination of the subsidiary valley energy position and for heterojunction band off-sets.

12:00 **Extraction Of THz Absorption Signatures Obscured By Rough Surface Scattering Using Discrete Wavelet Transform** — **Tu-A2-R1-4**

Mahmoud Ebrahimkhani; Hassan Arbab
Stony Brook University, United States

We employ discrete wavelet transform (DWT) to extract THz absorption signatures obscured by rough surface scattering. DWT decomposes a signal into wavelet coefficients associated with changes in weighted averages on different scales of a wavelet so-called mother filter. Therefore, it is capable of extracting resonant signatures obscured by noise and scattering contributions and represent them as prominent sharp peaks. We address the effect of non-zero phase function of wavelet filters that can result in representing erroneous signature positions. We provide analytical phase corrections for this non-zero-phase function problem to provide a complete DWT analysis method which can retrieve exact resonant frequencies in the presence of high rough surface scattering effects. We apply LA(8), C(6) and Db(4) wavelet filters to the normalized THz reflection spectrum

acquired from lactose/PE pellets with different grades of surface roughness inscribed to them using sandpapers of different grit sizes. The experimental results show that the resonance peaks in normal DWT coefficients are shifted in frequency, and therefore do not align with the dielectric resonance of the materials. However, by applying phase correction factors calculated exactly from the analytical phase function solutions of the transform, these resonances with appear in exact alignment with reported absorption peaks of the material.

12:15 **Intra-Excitonic Terahertz Emission From Semiconductors** **Tu-A2-R1-5**

Alexey Zakhar'in; Alexander Andrianov
Ioffe Institute, Russian Federation
We report on experimental observation and investigation of intra-excitonic terahertz emission from semiconductors. The experiments were carried out on high-purity silicon crystals at low temperatures and interband photoexcitation. THz emission spectra demonstrate narrow lines corresponding to optical transition between excited and ground states of free excitons.

11:00 - 12:30 **Tu-A2-1b High-Field THz Wave Generation and Nonlinear THz Physics IV** **Room 131+132**

Session Type: Oral

11:00 **[Keynote] Terahertz Field Emission Of Femto-Coulomb Electron Bunches** **Tu-A2-1b-1**

David Cooke; Dominique Matte; Lauren Gingras; Mark Sutton; Bradley Siwick
McGill University, Canada
We have demonstrated femtosecond electron wave packets emitted from a tungsten nanotip illuminated by a strong field THz pulse. The bunch charge of these electron pulses has been measured to be as high as 12 femtoCoulombs, or approximately 8×10^5 electrons in the bunch. This THz driven nanotip a potentially interesting next generation electron source for ultrafast electron diffraction experiments, due to the high brightness, perfect synchronization with a laser source, deterministic energy spectrum from acceleration in the measured temporal THz field profile, and (presumably) high transverse coherence. The emission is shown to be well described by Fowler-Nordheim tunnelling directly from the metal nanotip Fermi level, leading to an initial narrow energy distribution (10's of meV) relative to typical photocathodes possessing an energy spread on the order of 1 eV. Extraction of the tungsten nanotip work function is possible through fitting our data with the Fowler-Nordheim tunnelling rate, giving a work function of 4.5 eV in excellent agreement with bulk polycrystalline values. This is due to dramatic tip reshaping observed under strong field illumination that serves to both clean the tip and narrow the radius leading to improved emission over time. We envision THz driven nanotip cold field emission as a first step towards an all-THz driven ultrafast electron scattering system with vastly improved characteristics over existing instruments, potentially even operating in the single shot regime.

11:30 **[Keynote] Extreme Nonlinear Optics In Transition Metal Dichalcogenide Monolayers** **Tu-A2-1b-2**

Koichiro Tanaka
Department of Physics/Kyoto University, Japan
We have succeeded in observing several nonlinear optical phenomena such as high-harmonic generation and high-sideband generation with femtosecond mid-infrared lasers in monolayer transition metal dichalcogenides. Physical mechanism will be discussed.

12:00 **Direct Injection Of Ultrashort Electron Bunches Into A Solid Material Using Terahertz-driven Electron Field Emission** **Tu-A2-1b-3**

Simon Lehnskov Lange; Lars René Lindvold; Peter Uhd Jepsen
Technical University of Denmark, Denmark
We present here how terahertz (THz)-driven electron field emission from gold antennas can be directly injected into a solid material. Simulations show that an ultrashort sub-ps driving THz laser pulse results in even shorter sub-ps electron bunches with up to 420 eV energies under vacuum conditions. An experiment shows that these electron bunches can interact with the bulk of a solid, scintillating material under standard laboratory conditions (SLC). Our result is a key step towards building a novel platform for femtochemistry driven by ultrashort electron bunches.

12:15 **Demonstration Of 0.6mJ Multicycle THz Pulses Via Chirp-and-delay Down Conversion Of Broadband Lasers With Precise Spectral Phase Tuning And** **Tu-A2-1b-4**

Large PPLN

Nicholas Matlis[1]; Spencer Jolly[2]; Frederike Ahr[1]; Vincent Leroux[1]; Timo Eichner[1]; Anne-Laure Calendron[1]; Koustuban Ravi[1]; Takunori Taira[3]; Hideki Ishizuki[3]; Andreas Maier[1]; Franz Kaertner[1]
[1]DESY (Deutches Elektronen Synchrotron), Germany; [2]University of Hamburg, Germany; [3]Institute for Molecular Science, Japan

Multicycle THz pulses with millijoule level energies can provide high fields with narrow bandwidths opening up new possibilities in fields including relativistic electron acceleration and ultrafast current manipulation in materials. Generation of such high energies via nonlinear down conversion requires specialized laser pulses with energies in the Joule range as well as extremely precise control of phase matching conditions. Critical to using the full laser pulse energy without damaging the conversion medium is scaling to large crystals and beam sizes. We demonstrate efficient THz generation by difference-frequency conversion in a periodically-poled lithium niobate crystal with a centimeter scale aperture. Two Joule-scale broadband chirped pulses were combined with a delay and their spectral phases were precisely tuned to satisfy phase-matching. The resultant THz pulses exceeded 0.6 mJ at 361 GHz with a 1% bandwidth and a peak power of ~ 3 MW, exceeding previous results by over an order of magnitude.

11:00 - 12:30 Tu-A2-1c Laser Driven THz Sources III — **Room 133+134**

Session Type: Oral

11:00 **[Keynote] Generation Of 4 THz Radiation From Lithium-Niobate Off-axis THz Parametric Oscillator** — **Tu-A2-1c-1**

Yen-Chieh Huang[1]; Yu-Chung Chiu[2]; Tsong-Dong Wang[3]; Gang Zhao[4]
[1]Institute of Photonics Technologies, National Tsinghua University, Taiwan; [2]Institute of Photonics Technologies, National Tsing Hua University, Taiwan; [3]Chung-Shan Institute of Science and Technology, Taiwan; [4]Institute of Heavy Ion Physics, Peking University, China

Stimulated polariton scattering (SPS) in lithium niobate (LN) is an effective means to generate the THz radiations. All the previously reported THz SPS from LN shows a stand-alone gain peak near 1.8 THz, resulting from the lowest A_1-symmetry vibration mode near 250 cm^{-1}. Generation of THz radiation from LN with frequencies higher than 2.5 THz has been considered inefficient due to sharply increased material absorption. Since LN is relatively low-cost and high-quality, it is desirable to extend the useful THz radiation bandwidth of LN to higher frequencies. By using the so-called off-axis THz parametric oscillator (OTPO), we report the discovery of a phase-matched SPS gain peak near 4 THz from LN.We also demonstrated a signal-seeded LN OTPO that generates 1.4 nJ pulse energy at 4 THz wit 17.5 mJ pump energy at 1064 nm.

11:30 **Laser-Plasma Method For Generation Of Few- And Subcycle Pulses In A Broad Spectral Range** — **Tu-A2-1c-2**

Vasily Kostin; Nikolay Vvedenskii
Institute of Applied Physics, Russian Academy of Sciences, Russian Federation

Generation of strong few- and sub-cycle radiation in a broad range (from terahertz to infrared and above) at combination frequencies during plasma production by multicolor femtosecond pulses is studied analytically and numerically.

11:45 **Coherent Terahertz Radiation Emitted By Wide-angle Electron Beams From Laser-Wakefield Accelerators** — **Tu-A2-1c-3**

xue yang[1]; Enrico Brunetti[2]; Dino Jaroszynski[2]
[1]Capital Normal University, China; [2]Univeristy of Strathclyde, United Kingdom

The generation of terahertz radiation from wide-angle electron beams produced by a laser-wakefield accelerator is studied. An intense laser pulse propagating in an underdense plasma can generate ultrashort duration, MeV-GeV electron bunches over millimetres. In addition, a sub-picosecond duration, 1-2~MeV electron beams with nC-level charge is emitted obliquely into a cone of 30°-60° opening angle around the laser propagation axis. Here we perform simulations to characterise the coherent transition radiation (CTR) emitted by these beams if passed through a thin metal foil, or directly at the plasma-vacuum interface. We have shown that wide-angle electron beams produced by LWFAs can deliver 10s μJ to mJ-level, single-cycle radiation in the 0.1-5 THz spectral region, depending on the radiator size and location. At the vacuum-plasma boundary, the spectrum of CTR is peaked at about

2-3 THz, with the low frequency part suppressed because of the small transverse size of the radiator, which is typically about 20-30 μm. As the electron beam leaves the plasma, the longitudinal and transverse size increase quickly and a foil inserted at a distance of about 0.1-1 mm from the accelerator exit would produce CTR with spectrum shifted to approximately 0.1-1 THz. With this method, coherent terahertz radiation with 10s μJ to mJ-level energy can be produced with an optical to terahertz conversion efficiency up 10^-3 to 10^-4.

12:00 **Terahertz Pulses With Strong DC Precursors** **Tu-A2-1c-4**

Michael I. Bakunov[1]; Evgeny Efimenko[2]; Maxim Tsarev[3]; Sergey Sychugin[1]
[1]University of Nizhny Novgorod, Russian Federation; [2]Institute of Applied Physics, Russian Academy of Sciences, Russian Federation; [3]Ludwig-Maximilians-Universität München, Germany

Concurrent processes of optical rectification and multiphoton absorption of high-intense ultrashort laser pulses in electro-optic crystals can generate terahertz pulses with strong DC precursors. We explore this phenomenon by numerical modeling and propose ways to maximize the precursor fields. In particular, we demonstrate that chirped-pulse pumping can compensate for the pump depletion, whereas tilted-pulse-front pumping allows one to increase the precursor fields by orders of magnitude.

12:15 **Two-color Femtosecond Plasma Backward Terahertz Emission** **Tu-A2-1c-5**

Pavel Chizhov[1]; Alexandr Ushakov[2]; Vladimir Bukin[1]; Nikolay Panov[2]; Daniil Shipilo[2]; Olga Kosareva[2]; Andrei Savel'ev[2]; Sergey Garnov[1]
[1]A.M. Prokhorov General Physics Institute of the Russian Academy of Sciences, Russian Federation; [2]M.V. Lomonosov Moscow State University, Russian Federation

We provide comparison between backward and forward THz emission from two-color femtosecond plasma in air. Plasma is created under tight focusing conditions. Spectral properties of backward/forward THz radiation are investigated. Emission efficiency dependence on laser pump energy is measured.

11:00 - 12:30 Tu-A2-1a Sources, Detectors, and Receivers I — Room 141+142

Session Type: Oral

11:00 **[Keynote] Field Effect Transistors Based Terahertz Detectors 25 Years History, State Of The Art And Future Directions** **Tu-A2-1a-1**

Wojciech KNAP
CNRS & University of Montpellier, France

A overview of main results concerning THz detection related to plasma nonlinearities in nanometer field effect transistors will be presented. In particular, the physical limits of the responsivity, speed and the dynamic range of these detectors will be discussed. We will also present applications of the FET THz detectors for construction of focal plane arrays and based on them nondestructive quality control and security screening scanners. Finally, possible future developments will be discussed.

11:30 **Coupling Of 2D Plasmons In Grating-Gate Plasmonic THz Detector ToTHz Wave With Lateral Polarization** **Tu-A2-1a-2**

Masaya Suzuki[1]; Tomotaka Hosotani[1]; Taiichi Otsuji[1]; Tetsuya Suemitsu[2]; Yuma Takida[3]; Hiromasa Ito[3]; Hiroaki Minamide[3]; Akira Satou[1]
[1]Research Institute of Electrical Communication ,Research Organization of Electrical Communication ,T, Japan; [2]Center for Innovative Integrated Electronic Systems ,Research Organization of Electrical Communicati, Japan; [3]RIKEN Center for Advanced Photonics, RIKEN, Japan

We have developed the so-called asymmetric dual-grating-gate high-electron-mobility transistors (A-DGG HEMTs) as terahertz (THz) detectors based on two-dimensional (2D) plasmons in their channels. The grating gates enable broadband, direct coupling between incident THz waves and 2D plasmons. However, for linearly-polarized THz wave, the A-DGG HEMT can only detect its electric-field component parallel to the source-to-drain direction, i.e., perpendicular to the grating-gate fingers. This is because (1) only the electric field in that direction can be coupled to 2D plasmons by the grating gates and (2) only 2D plasmons oscillating in that direction can generate the nonzero net photovoltage output at the drain port. To make the detector sensitive to the THz wave with the "lateral"

polarization, a component that enables the coupling between the lateral THz electric field and 2D plasmons oscillating perpendicular to it is necessary. In this paper, we introduced a "2D diffraction grating," i.e., 2D rectangular patches, in place of one of the dual grating gates. We measured the polarization-dependent photovoltage upon the THz-wave irradiation and demonstrated that the polarization characteristic can be altered by the 2D diffraction grating from that of a standard A-DGG HEMT.To do that experiment, we fabricated an InP-based A-DGG HEMT and a new detector with the 2D diffraction grating. To verify the effect of the 2D diffraction grating, the active area, gate length, gate spacings, and shape of electrode pads were designed identical for those detectors. We used an injection-seeded THz-wave parametric generator as a THz source that emits a pulsed cw THz wave with linear polarization; the center frequency was set at 0.8 THz. We varied the polarization angle using two wire-grid polarizers between 0 to 90 degrees with respect to the direction of the grating-gate fingers. The pulsed output signal from the drain port of a detector, which is connected to an RF probe, was measured by a digital storage oscilloscope. Here, we took the peak of the output signal as the photovoltage.In this experiment, we obtained polarization characteristics of photovoltages of the A-DGG HEMT and the new detector, respectively. Comparing them, it is clearly seen that the polarization characteristic is significantly altered by the introduction of the 2D diffraction grating. The significant differences in the polarization characteristics, especially at the angle equal to 0 degree, indicate that the lateral electric field with respect to the source-to-drain direction excites 2D plasmons oscillating perpendicular to it due to the presence of the 2D diffraction grating.This result can be utilized to control the polarization characteristics. Furthermore, it can stimulate further investigation of the full use of two-dimensionality of the 2D plasmons for THz devices.

11:45 **Organics-based Phase Modulator For Terahertz Detection Up To 1.25 THz** **Tu-A2-1a-3**

Ileana Cristina Benea Chelmus[1]; Tianqi Zhu[1]; Francesca Fabiana Settembrini[1]; Christopher Bonzon[1]; Elena Mavrona[1]; Delwin Elder[2]; Wolfgang Heni[3]; Juerg Leuthold[3]; Larry Dalton[2]; Jérôme Faist[4]
[1]Quantum Optoelectronics Group, Switzerland; [2]Department of Chemistry, University of Washington, Seattle, United States; [3]Institute of Electromagnetic Fields (IEF), ETH Zurich, Switzerland; [4]Quantum Optoelectronics Group, ETHZ, Switzerland

We present a three-dimensional phase modulator at telecom wavelength acting as a Terahertz detector with an electro-optic bandwidth of 1.25 Terahertz. The detector exploits the r33 coefficient in the organic chromophore-host mixture JRD1:PMMA, combined with a high field enhancement provided by a metallic antenna structures. At an interaction length of only 4 μm, its sensitivity reaches the few photons limit.

12:00 **Sensitivity Enhancement Of Photothermoelectric Terahertz Detectors With Series Combination Between Carbon Nanotubes And Metals** **Tu-A2-1a-4**

Kou Li; Daichi Suzuki; Yuki Ochiai; Yukio Kawano
Tokyo Institute of Technology, Japan

This paper presents highly flexible terahertz (THz) detectors based on single-walled carbon nanotube (SWNT) films. Based on detection mechanism of the photothermoelectric effect, the effective Seebeck coefficient between the SWNT film and the electrode metal is a key parameter for sensitive THz detection. We proposed and demonstrated that the effective Seebeck coefficient was increased by employing the combination with the electrode in series, and achieved raising the sensitivity of THz detection. Particularly utilizing a metal (nickel) with negative Seebeck coefficient for the series electrode led the sensitivity enhancement by a factor of 11 compared to conventional parallel combination.

12:15 **Terahertz Receivers For Time-domain Spectroscopy Made Of Transition Metal Doped InGaAs: Up To 105 DB Dynamic Range** **Tu-A2-1a-5**

Robert Kohlhaas[1]; Björn Globisch[1]; Steffen Breuer[1]; Simon Nellen[1]; Lars Liebermeister[1]; Martin Schell[1]; Philipp Richter[2]; Martin Koch[2]; Mykhaylo Semtsiv[3]; William Ted Masselink[3]
[1]Fraunhofer Heinrich-Hertz-Institute, Germany; [2]Philipps-Universität Marburg, Germany; [3]Humboldt Universität Berlin, Germany

Transition metal doped photoconductors are investigated as terahertz (THz) receivers in time-domain spectroscopy (TDS). Compared to state-of-the-art receivers based on low-temperature-grown InGaAs/InAlAs, rhodium-doped InGaAs

receivers allow for an improvement in dynamic range (DR) of 15 dB over the whole spectral range, resulting in a peak DR of 105 dB. This improvement increases the resolution in non-destructive testing applications of thin films with THz TDS.

11:00 - 12:30 **Tu-A2-R2 Applications in Biology and Medicine III** **Reception Hall**

Session Type: Oral

11:00 **[Keynote] THz-TDS Measurements Of Hydration State Of Bio Related Materials And Data Analysis By Machine Learning** **Tu-A2-R2-1**

Hitoshi Tabata
The University of Tokyo, Japan

We have evaluated the hydration properties of bio related materials by a terahertz spectroscopy. In particular, we have focused on ions and water-soluble polymers which have potential use for a basic understanding and practical applications in bio-medical fields. The dielectric loss of samples obtained by the terahertz spectroscopy is found to strongly depend on the molecular weight of the polymers and the density of the solution. We have revealed that the hydration number per monomer depends on the molecular weight of the polymer. Experimental results are evaluated by a machine learning analysis to discussed details of hydration.

11:30 **Investigation Of Water-free Biotissue Phantoms In Terahertz Frequency Range** **Tu-A2-R2-2**

Tianmiao Zhang[1]; Mikhail Khodzitsky[1]; Petr Demchenko[1]; Aleksander Bykov[2]; Alexey Popov[2]; Igor Meglinski[2]
[1]ITMO University, Russian Federation; [2]University of Oulu, Finland

The research proves that the presented phantoms with ZnO nanoparticles, Si nanoparticles and the phantom with no nanoparticles can mimic human hand skin, paraffin-embedded glioma and paraffin-embedded healthy brain tissue, respectively, in THz frequency range.

11:45 **Detection Of Human Tumor Markers With THz Metamaterials** **Tu-A2-R2-3**

Christian Weisenstein[1]; Dominik Schaar[2]; Merle Schmeck[1]; Anna Katharina Wigger[1]; Anja Katrin Bosserhoff[2]; Peter Haring Bolívar[1]
[1]High Frequency and Quantum Electronics/University of Siegen, Germany; [2]Biochemistry and Molecular Medicine/Friedrich-Alexander-University Erlangen-Nürnberg, Germany

THz bioanalytical techniques are already proven as a viable tool for the label-free detection of biomolecules. But still, significant improvement of THz sensing techniques is needed to reach application relevant sensitivity levels. We present the label-free THz sensing of human tumor markers using a highly sensitive metamaterial based THz biosensor. High affinity binding of the specific protein to DNA is utilized for localized functionalization to further enhance the detection sensitivity.

12:00 **Terahertz Microfluidic Metamaterial Biosensor For Tiny Volume Liquid Samples** **Tu-A2-R2-4**

Rui Zhang[1]; Qingming Chen[2]; Kai Liu[1]; Zefeng Chen[1]; Kaidi Li[1]; Emma Pickwell-MacPherson[1]
[1]The Chinese University of Hong Kong, China; [2]The Hong Kong Polytechnic University, China

We present a novel multi-microfluidic-channel metamaterial biosensor (MCMB) for highly sensitive terahertz (THz) sensing of tiny volume liquid samples. The multi-channels are set mainly in the strong electric field enhancement area of the metamaterial, which significantly decreases the liquid amount and enhances interaction between the sensing targets and the THz wave (thus increasing the sensitivity). The water sensing results demonstrate the effectiveness of this proposed design and the great potential in THz biosensing.

12:15 **Development Of PDMS Microchannel Integrated Type Terahertz Chip** **Tu-A2-R2-5**

Ryohei Taie[1]; Kazunori Serita[1]; Keiko Kitagishi[1]; Takayuki Kawai[2]; Iwao Kawayama[1]; Hironaru Murakami[1]; Masayoshi Tonouchi[1]
[1]Institute of laser engineering, Japan; [2]RIKEN Center for Biosystems Dynamics Research, Japan

We developed a PDMS microchannel integrated type terahertz chip for trace analysis of liquid solution. By utilizing near-field interactions between of local

terahertz source with, a few arrays of metaterials and the liquid solution flowing inside the PDMS microchannel, we showed the possibility of high-sensitive and quantitative sensing of the trace amount of liquid solution with different concentration.

11:00 - 12:30 **Tu-A2-4 Devices, Components, and Systems IV** **Room 432**
Session Type: Oral

11:00 **High-power Pulsed Terahertz Spectrometer** **Tu-A2-4-1**
Ivan Tzibizov; Grigory Kropotov; Dmitry Tsypishka
Tydex LLC, Russian Federation
Here we presented the commercially available THz spectroscopic complex PTS-1 with an average output power of 300 μW and an optic-to-THz conversion factor of 10^-4.

11:15 **Real-time Continuous Wave Terahertz Spectroscopy With 2 THz Bandwidth** **Tu-A2-4-2**
Lars Liebermeister; Simon Nellen; Robert Kohlhaas; Martin Schell; Björn Globisch
Fraunhofer Heinrich Hertz Institute, Germany
Until now, real-time acquisition of terahertz (THz) spectra has been an unique feature of time-domain spectroscopy (TDS) systems. However, fast acquisition of broadband THz signals can be a strength of continuous-wave (cw) THz as well, when a fast frequency tunable laser source is used. In this paper, we present a new continuous wave THz spectrometer capable of acquiring 2 THz-wide spectra with 1 GHz resolution at 8 Hz continuous update rate. To our knowledge, this is the first demonstration of a phase-sensitive cw THz spectrometer able to perform broadband acquisition in real-time.

11:30 **1.5 Port Vector Spectrometer For Terahertz Time Domain Spectroscopy** **Tu-A2-4-3**
Fahd Rushd Faridi; Uttam Nandi; Sascha Preu
Institut für Mikrowellentechnik und Photonik, Technische Universität Darmstadt, Germany
We demonstrate a spectrometer capable of executing terahertz time domain transmission and reflection spectroscopy simultaneously in a single setup. This facilitates highly accurate determination of optical material parameters by taking advantage of both geometries. The system is also suitable for parameter extraction for materials when transmission data cannot be extracted and for characterizing non-time-invariant devices such as optical isolators.

11:45 **Pure Phase Terahertz Wave Front Modulator** **Tu-A2-4-4**
Yan Zhang; Jingying Guo
Department of Physics, Capital Normal University, China
A kind of optically controlled pure phase terahertz wave front modulator is proposed. The modulator is based on the dynamic metasurface generated on a super thin silicon wafer. Several devices based on this technology are implemented. Experimental results demonstrate the validity of this approach.

12:00 **[Keynote] High-speed Terahertz Waveform Measurement For Intense Terahertz Light Using 100-kHz Yb-doped Fiber Laser** **Tu-A2-4-5**
Masaaki Tsubouchi; Keisuke Nagashima
National Institutes for Quantum and Radiological Science and Technology, Japan
We have demonstrated a high-speed terahertz (THz) waveform measurement for intense THz light generated by an amplified pump laser. Although, the high-speed measurements have been realized with a weak oscillator output, the low repetition rate of the amplified pump laser system limits the scan rate much less than 1 Hz for intense THz light. The fast measurement for intense THz light will extend the THz application, e.g. an optical pump-THz probe time-resolved spectroscopy for the study of the photo-induced dynamics with high-accuracy, the time-of-flight THz tomography for thick layers with high absorbance, the high-speed THz imaging system with simultaneous measurement in the one- or two-dimensional space, and so on. In this study, we have developed the high-speed measurement with intense THz light by employing a high-speed shaker with a vibration frequency of 50 Hz to quickly scan the time delay between THz and electro-optic sampling pulses. In addition, to achieve a high data sampling rate, we have developed a Yb-doped fiber laser with a repetition rate of 100 kHz optimized for the intense THz light generation. The output from the Yb fiber laser with a wavelength of 1040 nm and a pulse energy of 13 μJ was introduced into a small tip "contact grating device" originally designed in our previous study. In the conventional method, the pump pulse front was tilted by a diffraction grating and imaged onto an LN prism. Our device employed "contact grating setup" in which the diffraction grating was placed in contact with the input surface of the LN substrate which realized downsizing of

the THz light source drastically. Output THz pulse has a peak electric field of 1 kV/cm and a peak frequency of 0.6 THz.In the presented system, we have obtained the THz waveform with a scan rate of 100 Hz, which drastically reduces the measurement time from several minutes in the conventional methods to 10 ms. The THz waveform consists of 1000 data points in the time range of 15 ps with 15 fs intervals. The dynamic range of the spectrum was 10^4 even without averaging and went up to 10^6 with 1 second (100 scans) averaging.

14:00 - 16:00 **Tu-P1-R1 Spectroscopy and Material Properties V** **Shirotori Hall**

Session Type: Oral

14:00 **[Keynote] Structure And Dynamics Of Bound Water In Polymer Film Studied By THz Spectroscopy** **Tu-P1-R1-1**

Hiromichi Hoshina[1]; Yoh Iwasaki[1]; Takuro Kanemura[1]; Eriko Kometani[2]; Makoto Okamoto[2]; Chiko Otaani[1]
[1]RIKEN, Japan; [2]Kuraray Co., Ltd, Japan

THz absorption spectra of polymer films (EVOH and Nylon-6) under different humidity conditions were studied to obtain information about the bound water. Subtracting absorption coefficient of vacuum dried polymer from humid samples, spectral feature of bound water was obtained. In the EVOH films, a blue-shifted intermolecular stretching mode of bound water was observed but the libration mode was very weak, which indicates that water is frozen as amorphous ice. In the spectra of Nylon-6, the drastic change of absorption spectra was observed at lower humidity, indicating that bound water assists structural change of the crystalline Nylon-6.

14:30 **Active Bidirectional Control Hybrid Based On Organic Materials For Terahertz Waves** **Tu-P1-R1-2**

Wei Wang; Bo Zhang; Hongyu Ji; Jingling Shen
Capital Normal University, China

Controlling the transmission properties of terahertz waves in organic/inorganic hybrid holds vast promise for the novel material structure. Organic polymers were used in many products and had excellent performance. Most THz modulators was usually unidirectional modulation, such as coupling of metamaterials with incident waves results in transmission decreasing in terahertz, two-dimensional electron gas of semiconductor heterojunction absorb terahertz, VO2 phase transition reduces terahertz transmission, and electronically controlled BiFeO3/Si structure improves transmission power. However, one-way modulation limits the application in terahertz functional devices. With optical and electrical excitations, we experimentally demonstrated an active bidirectional amplitude modulation in organic/inorganic hybrid for terahertz consisting of a MEH-PPV/Pedot:Pss/Si/Pedot:Pss multiple structure. In the external CW optical excitation, transmitted terahertz was enhanced when biased with a low positive voltage while attenuated under negative voltage. We obtained a bidirectional transmission modulation from -54% to 60%. The result exhibits great potential for applications in designing active broadband terahertz devices.

14:45 **THz-TDS On Polymers: Monitoring Thermo-oxidative Ageing And Crystallization Kinetics** **Tu-P1-R1-3**

Sebastian Engelbrecht[1]; Kai-Henning Tybussek[2]; Bernd Michael Fischer[1]; Stefan Sommer[3]
[1]French-German Research Institute of Saint Louis, France; [2]French-German Research Institute of Saint-Louis, France; [3]Philipps Universität Marburg, Germany

THz-TDS is used to non-destructively study the behavior of different polymers under thermo-oxidative ageing conditions. Furthermore, it is also possible to monitor the crystallization kinetics in amorphous polyethylene terephthalate. The definition of an optical Avrami equation allows to obtain the crystallization rate as well as the time constant of the crystallization.

15:00 **Boson Peak And Fracton Of Sodium Carboxymethyl Starch Detected By Terahertz Time-Domain And Low-Frequency Raman Spectroscopies** **Tu-P1-R1-4**

Wakana Terao[1]; Tatsuya Mori[2]; Karolina Kaczmarska[3]; Beata Grabowska[4]; Yasuhiro Fujii[5]; Akitoshi Koreeda[5]; Jae-Hyeon Ko[6]; Seiji Kojima[1]
[1]Graduate School of Pure and Applied Sciences University of Tsukuba, Japan; [2]Division of Materials Science, University of Tsukuba, Japan; [3]AGH - University of Science and Technology, Faculty of Foundry Engineering, Poland; [4]AGH - University

of Science and Technology, Faculty of Foundry Engineering, Poland; [5]Department of Physical Sciences, Ritsumeikan University, Japan; [6]Department of Physics, Hallym University, Korea, Republic of
We successfully detected boson peak of CMS-Na using terahertz time-domain spectroscopy. The spectral difference of BP plot of the CMS-Na from the vitreous glucose suggests that the existence of the fracton region. In the lecture, comparison with the result of low-frequency Raman scattering will also be discussed.

15:15 **Investigation Of Aggregation-induced emission Molecules With Terahertz Spectroscopy** **Tu-P1-R1-5**

Harunobu Takeda[1]; Yuji Oki[1]; Hiroaki Minamide[2]
[1]Kyushu university, Japan; [2]RIKEN, Japan
Aggregation-induced emission materials were attractive because of its unique emission fluorescent mechanisms.In this research, tetraphenylethylene derivatives as a group of the aggregation-induced emission fluorophores were investigated by terahertz-wave spectroscopic measurement with the cryogenic cooling system and density functional theory based calculations. From the 1.0 -- 2.2 THz spectroscopic results, we obtained novel intramolecular rotational motions which inspire the molecular aggregation causes the restriction of intramolecular motions.

15:30 **Experimental Characterization Of Artificial Human Skin With Melanomas For Accurate Modelling And Detection In Healthcare Application** **Tu-P1-R1-6**

Rui Zhang[1]; Qammer Abbasi[2]; Najah Abed AbuAli[3]; Akram Alomainy[1]
[1]Queen Mary University of London, United Kingdom; [2]University of Glasgow, United Kingdom; [3]United Arab Emirates University, United Arab Emirates
A preliminary investigation is carried out on the artificial human skin tissues with and without metastatic melanomas using Terahertz Time Domain Spectroscopy (THz-TDS) in transmission mode. Two duplicate samples of each case were tested and each sample was scanned three times. We obtain the statistical mean and standard deviation of the refractive indexes and absorption coefficients in a THz band from 0.2 THz to 1.6 THz are presented. The refractive indexes and absorption coefficients of artificial skin with melanomas are higher than the normal artificial skin samples over the entire frequency range. The reason is that tumor cells have a reduced capacity to contract lattices. It means that less water is squeezed out from the malignant tissues in the contraction process. The results are in accordance with the lattice contraction and high sensitivity of THz signal to water. This study quantifies the impact of melanomas on the optical parameters of artificial skin tissue and can help in techniques that will diagnose and prevent tumors at the early stage.

15:45 **Terahertz Conductivity In Proteins** **Tu-P1-R1-7**

Jens Neu; Sophia M. Yi; Yangqi Gu; Nikhil S. Malvankar; Charles A. Schmuttenmaer
Yale University, United States
Most proteins are electrical insulators or poor conductors. We present the first observation of metallilc-like conductivity in proteins. Temperature-resolved THz spectroscopy was used as a contact free method to measure the conductivity. DC and THz-measurements each found an increasing conductivity with decreasing temperature. This correlation is typical for metals and the results are well described with a quasi 1D-metal model.

14:00 - 16:00 **Tu-P1-1b High-Field THz Wave Generation and Nonlinear THz Physics V** **Room 131+132**

Session Type: Oral

14:00 **[Keynote] Generating And Shaping Light In The THz Frequency Range** **Tu-P1-1b-1**

Karl Unterrainer; Christian Derntl; Sebastian Schoenhuber; Moritz Wenclawiak; Martin Kainz; Benedikt Limbacher; Juraj Darmo
Technische Universität Wien, Austria
I will show a few experiments with semiconductor nanostructures and quantum cascade lasers where the phase information allows observing physical processes directly; this includes population transfer, amplification, and short pulse formation. In addition to the phase information, down conversion and quantum cascade lasers provide us with very large bandwidth- spanning more than one octave. Handling these bandwidths is an interesting challenge and also extremely attractive for new optical methods like frequency comb sensing.

14:30 **Dressing Intersubband Transitions At Terahertz Frequencies** **Tu-P1-1b-2**

Johannes Schmidt; Stephan Winnerl; Emmanouil Dimakis; Manfred Helm; Harald Schneider
Helmholtz-Zentrum Dresden-Rossendorf, Germany
We combine intense, spectrally narrow THz pump pulses from a free-electron laser with broadband THz probe pulses and electro-optic sampling for highly nonlinear THz spectroscopy. We exploit this approach for dressing intersubband transitions in a wide GaAs quantum well and for investigating the associated coherent phenomena with added spectral resolution. We observe pump-induced spectral broadenings and attribute them to the Autler-Townes effect.

14:45 **Nonlinear THz Plasmonics In Bi2Se3 Topological Insulator** **Tu-P1-1b-3**

Paola Di Pietro[1]; Nidhi Adhlakha[1]; Federica Piccirilli[2]; Alessandra Di Gaspare[3]; Seongshik Oh[4]; Andrea Perucchi[1]; Stefano Lupi[5]
[1]Elettra Sincrotrone Trieste, Italy; [2]CNR-IOM Trieste, Italy; [3]NEST, Istituto Nanoscienze, CNR, Scuola Normale Superiore, Italy; [4]Department of Physics and Astronomy Rutgers, United States; [5]CNR-IOM Dip. di Fisica, Università di Roma Sapienza, Italy
We report evidence of the nonlinear response of the Dirac surface plasmon on a patterned film of Bi2Se3 topological insulator. A redshift of the plasmon peak is induced by the strong THz electric field provided by the TeraFERMI beamline at the Free Electron Laser Fermi at Elettra in Trieste (Italy). The nonlinear plasmonic behavior on a topological insulator has been unveiled for the first time.

15:00 **Subcycle Nonlinear Terahertz Optics In Doped Semiconductor Thin Film** **Tu-P1-1b-4**

Xin Chai[1]; Xavier Ropagnol[1]; S. Mohsen Raeis-Zadeh[2]; Matthew Reid[3]; Safieddin Safavi-Naeini[2]; Tsuneyuki Ozaki[1]
[1]INRS-EMT, Canada; [2]University of Waterloo, Canada; [3]University of Northern British-Columbia, Canada
We study the nonlinear ultrafast carrier dynamics in n-doped In0.53Ga0.47As using terahertz (THz) time-domain spectroscopy (THz-TDS). We observed a significant subcycle pulse truncation and the generation of high-frequency THz photons.

15:15 **Ultrafast Control Of Even-Order Harmonic Generation From Solids By An Intense Terahertz Field** **Tu-P1-1b-5**

Haoyu Huang[1]; Liwei Song[1]; Nicolas Tancogne-Dejean[2]; Nicolai Klemke[1]; Angel Rubio[2]; Franz Kaertner[1]; Oliver Muecke[1]
[1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Germany; [2]Max Planck Institute for the Structure and Dynamics of Matter, Germany
Nonperturbative even-order harmonics, physically forbidden in centrosymmetric crystals, are observed from both insulator (diamond) and semiconductor (silicon) samples driven by IR pulses, when in addition an intense THz electric field is applied to the solid. The time-resolved study of the high-harmonic spectra with the temporal profile of the THz electric field suggests a transient THz-field-induced symmetry reduction. We also investigate the harmonics' yields depending on the angles of the linear IR and THz polarizations with respect to the crystal axes. This work might pave the way for THz-based symmetry control in solids with important ramifications for petahertz electronics.

15:30 **[Keynote] Giant Terahertz Nonlinearity Of Graphene** **Tu-P1-1b-6**

Dmitry Turchinovich
Fakultät für Physik, Universität Duisburg-Essen, Germany
In this presentation we will demonstrate that graphene possesses an enormous THz-range optical nonlinearity, resulting from the collective response of Dirac fermions to incident THz fields. In particular, efficient upconversion of electron and photon energy in single layer graphene becomes possible under ambient conditions.

14:00 - 16:00 **Tu-P1-1c Laser Driven THz Sources IV** **Room 133+134**

Session Type: Oral

14:00 **Tilted Pulse-Front Phase-matching In Three Dimensions: Overcoming The Cherenkov Angle Restrictctions.** **Tu-P1-1c-1**

Steven Jamison[1]; David Walsh[2]; Edward Snedden[2]
[1]Lancaster University, United Kingdom; [2]STFC, United Kingdom
We consider the non-linear generation of THz with tilted pulse fronts in three dimensions and show that, contrary to the widely held expectations, coherent phase matching can be obtained for pulse-front tilt angles other the Cherenkov angle.

14:15 **Optical Rectification Of A 100W Average Power Ultrafast Thin-disk Oscillator** **Tu-P1-1c-2**

Frank Meyer; Negar Hekmat; Samira Mansourzadeh; Martin Hoffmann; Clara Saraceno
Ruhr-Universität Bochum, Germany
We demonstrate THz generation by optical rectification in GaP crystals using excitation average power levels exceeding 100 W. The laser source is a state-of-the-art diode-pumped Yb:YAG modelocked Thin-Disk oscillator, capable of generating 120 W at 13.4 MHz directly from a one-box oscillator, without the need for any amplification stages. In this first demonstration, we measured an average power of 78 μW at a central frequency of 0.8 THz. This first result shows that optical rectification of high average power (100 W class) ultrafast sources is within reach, and paves the way towards Watt-level, ultrafast laser pumped THz sources.

14:30 **[Keynote] Pulse Front Tilt Derived From A Digital Micromirror Device Andits THz Application** **Tu-P1-1c-3**

Kosuke Murate[1]; Mehraveh Javan Roshtkhari[2]; Xavier Ropagnol[2]; Francois Blanchard[2]
[1]Nagoya University, Canada; [2]Département de génie électrique, École de technologie supérieure (ETS), Université du Québec, Canada
We report a new method to temporally and spatially manipulate the pulse front tilt (PFT) intensity profile of an ultrashort optical pulse using a commercial microelectromechanical system (MEMS), also known as a digital micromirror device (DMD). For our demonstration, we show terahertz (THz) generation in a lithium niobate crystal using the PFT pumping scheme derived from a DMD chip. The adaptive functionality of the DMD could be a convenient alternative to the more conventional grating required to generate a laser beam with a PFT intensity profile that is typically used for efficient optical rectification in noncollinear phase matching conditions. In contrast with a grating, PFT using DMD does not suffer from wavelength dispersion, and exhibits overlap properties between grating and a stair-step echelon mirror. Our results open the door for THz emissions with a subwavelength controllable spatial pump beam pattern in a collinear or non-collinear phase matching geometry. They show a clear THz wave generation via the PFT pumping scheme in lithium niobate derived from a DMD chip. As well, they confirm that echelon mirror equation can be used for DMD in zero-order reflection mode. Using the Littrow configuration, the zero-order reflection from a DLP3000 chip in combination with a 11× demagnification factor produced the required PFT intensity profile at the LN crystal position to generate THz waves efficiently. In comparison with gratings, reflections from micromirrors have the benefit of being dispersion-free; however, diffraction still occurs because of the small mirror size w and step height h. To avoid this situation, a custom DMD chip with a larger micromirror size and height would enable maximizing the efficient reflection in the zero order while reducing the diffraction effect, in a manner similar to a stair-step echelon mirror. We anticipate that the versatility of DMD to modify electronically the spatial intensity distribution of PFT intensity beams will spark novel applications that extend beyond THz-related domains.

15:00 **Thin-Disk Laser Oscillator Driving THz Generation Up To 6 THz** **Tu-P1-1c-4**

Clément Paradis[1]; Norbert Modsching[2]; Olga Razskazovskaya[2]; Jakub Drs[1]; Frank Meyer[3]; Christian Kränkel[4]; Clara J. Saraceno[3]; Valentin J. Wittwer[1]; Thomas Südmeyer[1]
[1]Université de Neuchâtel, Switzerland; [2]Université de Neuchatel, Switzerland; [3]Ruhr Universität Bochum, Germany; [4]Leibniz Institute for Crystal Growth, Germany
We present a proof-of-principle demonstration of THz generation driven by a short-pulse thin-disk laser (TDL) oscillator. The laser source is based on a directly diode-pumped Yb:Lu_2O_3 gain crystal delivering 4 W average power in 50-fs pulses at 61 MHz repetition rate. Broadband THz radiation up to 6 THz is generated by optical rectification and detected with electro-optical sampling in GaP crystals. Our

experiment shows the high potential of this power-scalable technology for driving MHz-repetition-rate broadband THz systems.

15:15 **[Keynote] Plasmonic Resonances Affecting Terahertz Generation In Laser-induced Gas-plasmas** **Tu-P1-1c-5**

Korbinian J. Kaltenecker[1]; Illian Thiele[2]; Binbin Zhou[3]; Alisee Nguyen[4]; Evgeniya Smetanina[5]; Rachel Nuter[6]; Pedro Gonzalez de Alaiza[6]; Jeremy Dechard[7]; Luc Berge[7]; Peter Uhd Jepsen[3]; Stefan Skupin[8]
[1]Technical University of Denmark, Denmark; [2]Univ. Bordeaux / Chalmers University, Sweden; [3]DTU, Denmark; [4]CEA/DAM Ile-de-France, France; [5]Univ. Bordeaux / Univerity Gothenborg, Sweden; [6]Univ. Bordeaux, France; [7]CEA/DAM, France; [8]Universite de Lyon, France

We demonstrate that plasmonic resonances can be used to broaden the terahertz emission spectrum from two-color laser-driven gas-plasmas. This effect can be controlled by changing the polarization properties of elliptically shaped driving laser-pulses.

15:45 **A Mirrorless Terahertz-Wave Parametric Oscillator** **Tu-P1-1c-6**

Kouji Nawata; Yu Tokizane; Yuma Takida; Takashi Notake; Zhengli Han; Andreas Karsaklian.Dal.Bosco; Mio Koyama; Hiroaki Minamide
RIKEN, Japan

We demonstrated a mirrorless terahertz (THz)-wave parametric oscillator (TPO) based on backward optical parametric oscillation. The mirrorless TPO has no cavity mirrors because of inhibit feedback effect inside a periodically poled lithium niobite (PPLN). The oscillator offered wide tunability, mode-hop free tuning, narrow linewidth, and high conversion efficiency. Prototype of mirrorless TPO has the dimension of 80 mm with 30 mm square and the weight was about 110 g. The prototype indicates that mirrorless TPO realizes compact and robust THz-wave sources with excellent features based on nonlinear wavelength conversion.

14:00 - 16:00 **Tu-P1-1a Sources, Detectors, and Receivers II** **Room 141+142**

Session Type: Oral

14:00 **Tuneable Optical Frequency Comb Generator For THz Spectroscopy** **Tu-P1-1a-1**

Lalitha Ponnampalam; Martyn Fice; Haymen Shams; Cyril Renaud; Alwyn Seeds
University College London, United Kingdom

We present an optical frequency comb generator with a record span of 3.8 THz suitable for high resolution THz spectroscopy, based on a single phase modulator system. The line spacing, exactly referenced to a microwave synthesizer, can be continuously tuned from 17.5 GHz to 20 GHz overcoming the limitation otherwise imposed by the free spectral range of the fibre loop, making the system capable of generating a continuously tuneable electrical signal from 122.5 GHz to >2.7 THz. The system noise has been measured up to a record frequency of 300 GHz, and shown to be limited by the multiplied phase noise of the reference synthesizer.

14:15 **Continuous Wave Terahertz Generation From Photodiode-based Emitters With Up To 200 µW Terahertz Power** **Tu-P1-1a-2**

Simon Nellen; Robert Kohlhaas; Lars Liebermeister; Steffen Breuer; Björn Globisch; Martin Schell
Fraunhofer HHI, Germany

The output characteristics of an optoelectronic terahertz (THz) transmitter based on a high-speed, waveguide integrated photodiode is demonstrated. THz power measurements are performed with a calibrated pyroelectric detector and 1.4 µW at 1 THz and up to 200 µW at 52 GHz are obtained. When the optical illumination power is increased up to 35 mW no saturation of the THz output is observed whereas the bias voltage of the device has to be adjusted for maximum THz output.

14:30 **Broadband Spectrum From A Photoconductive Emitter Spanning Up To 13 THz** **Tu-P1-1a-3**

Abhishek Singh; Alexej Pashkin; Stephan Winnerl; Manfred Helm; Harald Schneider
Helmholtz Zentrum Dresden Rossendorf, Dresden, Germany, Germany

We demonstrate here ultra-broadband THz emission from a Ge based photoconductive emitter with the gapless spectrum extending up to ~ 13 THz, twice as far as what has been previously achieved with other materials. Being a non-polar semiconductor, Ge does not possess infrared-active TO phonons and, therefore, it has almost flat transmission up to more than 20 THz. Hence we

observe THz radiation from Ge PC emitter substrate that is free from absorption dips and spans beyond the TO phonon frequency of conventional polar semiconductors. THz emission properties of Ge based emitter are compared with that of GaAs based emitter.

14:45 **High-Power Terahertz Generation From Telecommunication-Compatible, Bias-Free Photoconductive Nano-Antennas** **Tu-P1-1a-4**

Deniz Turan[1]; Nezih Tolga Yardimci[1]; Zixuan Rong[1]; Dingkun Ren[1]; Hyunseok Kim[1]; Diana Huffaker[2]; Mona Jarrahi[1]

[1]University of California, Los Angeles, United States; [2]Cardiff University, United Kingdom

We present a telecommunication-compatible, bias-free photoconductive terahertz source with arrays of plasmonic nano-antennas. We demonstrate pulsed terahertz radiation with powers up to 72 μW, enabling time-domain terahertz spectroscopy over a 3 THz bandwidth with a 100 dB dynamic range.

15:00 **Optimization Of Terahertz Emission Spectra Of Electrically Pumped 2DEG Plasmonic AlGaN/GaN Heterostructures** **Tu-P1-1a-5**

Ignas Grigelionis; Vytautas Jakstas; Vytautas Janonis; Irmantas Kasalynas

Center for Physical Sciences and Technology, Lithuania

In this work the radiative processes which deteriorate the performance of electrically pumped 2DEG plasmonic GaN/AlGaN heterostructures are identified and optimized in the THz frequency range. The emission spectroscopy of GaN/AlGaN heterostructures grown on different substrates was investigated in the temperature range 20-300 K. A thermal radiation of the lattice and hot electrons, as well as impurity electroluminescence was found largely contributing to the emission spectrum. The lower lattice thermal radiation intensity is observed for the SiC-based GaN/AlGaN samples providing an optimal solution for plasmonic-based THz sources.

15:15 **Feedback Effects And Nonlinear Dynamics In Resonant Tunneling Diodes** **Tu-P1-1a-6**

Andreas Karsaklian Dal Bosco[1]; Safumi Suzuki[2]; Masahiro Asada[3]; Hiroaki Minamide[1]

[1]RIKEN Center for Advanced Photonics, Japan; [2]Tokyo Institue of Technology, Japan; [3]Tokyo Institute of Technology, Japan

This experimental study of a Resonant Tunnelling Diode (RTD) with optical feedback and electro-optical feedback unveils that, according to the feedback properties, RTD are capable of showing harmonic oscillations, pulsing dynamics and other complex fluctuations of their intensity versus time. These dynamics can be generated, controlled and suppressed by the effect of the feedback which proves to be a simple and effective tool to generation of nonlinear dynamics in such compact THz systems. We identify harmonic oscillations at frequencies perfectly defined by the temporal properties of the external feedback, intermittent dynamics constituted of bursts of periodic oscillations interspersed by regions of constant power and other more complex fluctuations.This fundamental analysis of the effects of the feedback on the RTD dynamics is a further step on the direction of unlocking dynamical properties for developing THz sources for THz wireless communication technologies. We expect that associating the wealthy dynamical possibilities of RTDs with their compactness and ease of use will set the way to the future THz communication technology in the coming years.

15:30 **[Keynote] The Route To Nanoscale Terahertz Technology: Nanowire-based Terahertz Detectors And Terahertz Modulators** **Tu-P1-1a-7**

Jessica Louise Boland[1]; Kun Peng[2]; Sarwat Baig[3]; Djamshid Damry[2]; Patrick Parkinson[4]; Lan Fu[5]; Hark Hoe Tan[5]; Chennupati Jagadish[5]; Laura Herz[2]; Hannah Joyce[3]; Michael Johnston[2]

[1]University of Regensburg, Germany; [2]University of Oxford, United Kingdom; [3]University of Cambridge, United Kingdom; [4]University of Manchester, United Kingdom; [5]Australian National University, Australia

Research in the terahertz (THz) region of the electromagnetic spectrum is undergoing major advances driven by its promise in numerous applications, ranging from non-destructive evaluation and security to ultrafast computing and biomedical imaging. In the past 20 years, advanced THz sources and detectors have therefore been developed at a rapid pace, yet if ultrafast THz communication and table-top THz spectrometers are to be realized, THz nanoscale components are essential. In this work, we demonstrate novel THz detectors and modulators based on semiconductor nanowires. We show that single nanowire photoconductive THz

receivers exhibit excellent sensitivity, high SNR of 40, and a broad detection bandwidth up to 2 THz, comparable to the bulk InP photoconductive receivers. We also demonstrate ultrafast THz modulation by GaAs nanowire polarisers with a less than 5ps switching time and a modulation depth of -8dB, We show an extinction of over 13% and dynamic range of -9dB, comparable to microsecond-switchable graphene- and metamaterial-based THz modulators. The high performance of these nanowire-based THz components thereby opens up a route for development of table-top THz spectrometers and ultrafast wireless communication at the nanoscale.

14:00 - 16:00 **Tu-P1-R2 Applications in Biology and Medicine IV** **Reception Hall**

Session Type: Oral

14:00 **Concentration Dependence Of IgG Immobilized On A Sensing Plate for Higher Sensitivity Of A Terahertz Chemical Microscope** **Tu-P1-R2-1**

Masahiro Iida; Tatsuki Kamiya; Sakai Kenji; Kiwa Toshihiko; Tsukada Kenji
Okayama University, Japan
We have developed a terahertz chemical microscope for measuring immune reactions without any label. Here, to evaluate the relation between the concentration of IgG immobilized on the sensing plate and the sensitivity of the system, the concentration dependence of the IgG was evaluated.

14:15 **THz Anisotropy Identification Using Tunable Compact Narrow Band THz Sources** **Tu-P1-R2-2**

Deepu George[1]; Andrea Markelz[2]; Ian McNee[3]; Patrick Tekavec[3]; Vladimir Kozlov[3]; Peter Schunemann[4]
[1]University at Buffalo, United States; [2]SUNY Buffalo, United States; [3]Micro Tech, United States; [4]BAE Systems, United States
We demonstrate THz anisotropy signature detection for a protein crystal model using newly developed compact tunable narrow band THz sources for turn-key spectroscopic systems. Narrowband THz pulses are generated by optical rectification in quasi phase matched 'Orientation Patterned Gallium Arsenide' (OP-GaP) crystals, pumped with a high power 1064 nm fiber laser. The frequency of the generated THz pulse is tuned by varying the periodicty of the crystals. The sources are chareterized using an FTIR. We demonstrate the viability of this spectroscopic approach through anisotropic spectroscopic signature detection of molecular crystals. Molecular crystals provide an excellent environmentally insensitive model system for developing Anisotropic Terahertz Microscopy (ATM) methods for protein and RNA characterization. Change in THz absorption as a funtion of the sample orientation with respect to the direction of source polarization provides a measure of both the anisotropy as well as the directionality of individual vibrational modes.

14:30 **Measurement Of Protein Conformational Fluctuation In Ice By Passive Millimeter-wave Microscopy** **Tu-P1-R2-3**

Akio Kishigami[1]; Tatsuo Nozokido[2]
[1]Gifu Women's University, Japan; [2]University of Toyama, Japan
Thermal radiation emitted from an aqueous solution of bovine serum albumin (BSA) was measured and analyzed by passive millimeter-wave microscopy at a temperature range low enough to freeze water and to trap conformational intermediates in BSA. Experiments were performed at a millimeter-wave frequency of 50 GHz in a temperature range from 130 K to 270 K for a 20 % BSA aqueous solution, showing a displacement between two conformational states of BSA at a boundary temperature of approximately 190 K. Our microscope system using this freeze-trapping method is expected to provide noninvasive thermal images to enable novel high-throughput calorimetry useful for the analysis of protein functions.

14:45 **[Keynote] Detection Of Ions In Solutions With Sub-micro Liter Volumes using A Terahertz Chemical Microscope** **Tu-P1-R2-4**

Yuki Maeno; Tatsuki Kamiya; Toshihiko Kiwa; Kenji Sakai; Keiji Tsukada
Okayama University, Japan
Abstract--A terahertz chemical microscope (TCM) has been proposed and developed for measuring the small volume of the ion concentrations in solutions. By fabricating the small solution wells and the ion selective membranes on the sensing plate, the concentration of the sodium ions in the solution of 450 nL could be measured.

15:15 **Study On The Membrane Electroporation Threshold With The Applied Terahertz Electric Field** **Tu-P1-R2-5**

Jingchao Tang; Hairong Yin; Jialu Ma; Wenfei Bo; Yang Yang; Jin Xu; Yubin Gong

University of Electronic Science and Technology of China, China
The terahertz (THz) electric field is an efficient tool with unique advantages in the fields of biology and medicine. To make better use of this tool, a series of molecular dynamics (MD) simulations are performed to study the electroporation threshold with the applied THz electric field. Results show that the electroporation threshold increases with the THz electric field frequency increasing. And this phenomenon can be explained from the view of the polarization of water dipoles.

15:30 **Characterization Of Water Content In Organ Tissues By Using THz Pulses** **Tu-P1-R2-6**

Seung Jae Oh[1]; Young-Bin Ji[2]; Yuna Choi[3]; Young-Min Huh[3]; Hyeyoung Son[3]; Jin-Suck Suh[3]
[1]Medical Convergence Research Institute, Yonsei University, Korea, Republic of; [2]Gimhae Biomedical Center, Korea, Republic of; [3]Yonsei University, Korea, Republic of
We determined the water content in the liver, spleen, kidney, and brain of rats by using a terahertz (THz) spectroscopic imaging system. The water content in the tissues was obtained using simple equations involving complex optical constants of fresh and freeze-dried tissues. The water content in organs before and after freeze drying was compared with the difference in tissue mass before and after lyophilization. The water content obtained by THz spectroscopy and mass measurement were almost identical, except those for the kidneys.

15:45 **Propagation Dynamics Of The THz Radiation Through A Dehydrated Tissue By The Pulse Time Domain Holography Method** **Tu-P1-R2-7**

Olga Smolyanskaya[1]; Evgeniy Odlyanitskiy[1]; Maksim Kulya[1]; Kirill Zaytsev[2]
[1]ITMO University, Russian Federation; [2]Bauman Moscow State Technical University, Prokhorov General Physics Institute of RAS, Russian Federation
Optical clearing immersion method provides temporal and reversible tissue transparency for optical diagnostics and therapy. The immersion solution creates an osmotic pressure on the tissue collagen matrix and cells membranes, thus activates tissue dehydration and partial replacement of interstitial water and cell cytoplasm by a biocompatible agent. This technique has been widely used to improve different optical imaging and spectroscopic methods for more than two decades and only few studies were done for terahertz (THz) waves. In particular, in our previous work we observed an enhancement of the THz wave penetration into biological samples after their treatment with the glycerol solutions, which induce changes of the dielectric properties of tissues. In this work, we applied a computational approach, which relies on the angular spectrum (AS) and Rayleigh-Sommerfeld convolution (RSC) methods and allows for describing the propagation of a complex amplitude of electromagnetic wave through the dispersive homogeneous medium, to demonstrate a time- and spatial-domain evolution of the THz pulse in a tissue. In numerical simulation, we used experimentally registered reference THz pulse without interaction with the sample and we calculated its propagation through the tissue sample considering two cases -- before and after the tissue dehydration by glycerol. Pulse slope is caused by the phase shift on the temporal axis due to the wavefront propagation through the dispersive media. Considering the THz pulses in 1D view for the incident and transmitted radiation one can see that dehydration leads to an absorption decrease and an additional phase shift due to increase of the sample width from 430 to 435 μm. Simulation has provided a support that propagation distance increases due to sample shrinkage in transverse direction. We used experimentally obtained data about the thickness increasing of the sample after dehydration. Moreover, the index of refraction and absorption coefficient dependencies were also considered for non-glycerol and 70% glycerol cases. We observed a good agreement between the measured and simulated THz waveforms, where experimental and calculated pulses passed through the skin sample coincide for both non-dehydrated and dehydrated cases.

14:00 - 16:00 **Tu-P1-4 Devices, Components, and Systems V** **Room 432**
Session Type: Oral

14:00 **Design, Analysis And Implementation Of Quarter-Wave Absorber Structure For Uncooled Infrared Detectors With High Fill Factor** **Tu-P1-4-1**

RAMAZAN CETIN; OZAN ERTURK; TAYFUN AKIN
METU MEMS Research and Application Center, Turkey
This study presents design, analysis, optimization, and fabrication of umbrella structures as an efficient quarter wave absorber within Long Wave Infrared (LWIR)

range for uncooled IR detectors. The umbrella topology consists of a mirror layer of Titanium/Gold at the bottom and an umbrella body layer of silicon nitride (Si_xN_y) holding the ni-chrome (NiCr) based absorbing layer at a distance from the bottom mirror with a post formation to meet Quarter-Wave Impedance Matching (QWIM) requirements. An optimization for maximum LWIR absorption is done over air gap thickness, seperating the mirror layer from the body, the body layer thickness itself, and the sheet resistance (R_S) of the absorbing metal layer through Cascaded Transmission Line (CTL) modeling. An average absorption of 96% within the LWIR range is obtained for an optimized air gap thickness of 2.3μm when absorbing layer with Rs=400Ω/square is employed. Both the effect of the NiCr layer and effect of varying pixel pitch sizes on the IR absorption performance are examined. Broadband characteristics introduced by the existence of NiCr absorbing layer is proved experimentally. It is also observed that varying pitch sizes do not affect absorption performance greatly for the optimized case.

14:15 **High Numerical Aperture Diffractive Optics For Imaging Applications At 0.6 THz Frequency** **Tu-P1-4-2**

Linas Minkevicius; Domas Jokubauskis; Vytautas Janonis; Simonas Indrisiunas; Gediminas Raciukaitis; Vincas Tamosiunas; Irmantas Kasalynas; Gintaras Valusis
Center for Physical Sciences and Technology, Lithuania

High numerical aperture diffractive lenses such as conventional and combined zone plates, silicon based multilevel phase Fresnel zones were developed for boosted THz imaging at the frequency range of 0.6 THz. Spectral features, spatial profiles, and focal depth characteristics are discussed, demonstrating the results to be in a good agreement with simulation data. In addition, new technique of the bifocal THz imaging is proposed.

14:30 **Terahertz Artificial Dielectric Stepped-refractive-index Lens** **Tu-P1-4-3**

Enrique Castro-Camus[1]; Arturo Hernandez-Serrano[1]; Rajind Mendis[2]; Kimberly Reichel[2]; Wei Zhang[2]; Daniel Mittleman[2]
[1]Centro de Investigaciones en Optica, Mexico; [2]Brown University, United States

In this work we theoretically and experimentally demonstrate a stepped- refractive-index convergent lens made of a parallel stack of metallic plates for terahertz frequencies based on artificial dielectrics technology. The theoretical and experimental results show that this structure is capable of focusing a 1 cm diameter beam to a line focus of less than 4 mm for the design frequency of 0.18 THz.

14:45 **Resonant Dielectric Structure As A Lens For Super-resolution Imaging** **Tu-P1-4-4**

Alexander Chernyadiev; Anna Vozianova; Mikhail Khodzitsky
ITMO University, Russian Federation

In this article the generalized results of full width at half-maximum intensity (FWHM) of "terajets" are presented for a parallelepiped and cubic structures made of five different photopolymers in 0.05-0.35 THz frequency range. The best resolution 0.244 λ for the parallelepiped structure and 0.198 λ for the cubic structure was achieved. The results give us an instruction about choosing the working frequency for these types of photopolymers for achieving the resolution beyond the diffraction limit. This work could lead to the development of THz narrow-band devices for microscopy, spectroscopy, imaging purposes. A great advantage of these future devices based on this effect is cheap and simple fabrication.

15:00 **Paper-based Optical Components For The THz Region** **Tu-P1-4-5**

Rhiannon Lees; Polina Stefanova; Andreas Klein; Claudio Balocco; Andrew Gallant
Durham University, United Kingdom

Laser-cut paper patterns which are suitable for focusing terahertz radiation are presented. Such designs provide an extremely low-cost route for the prototyping and production of terahertz optical components. Conventional binary Fresnel diffractive designs have been extended to produce multi-focal spots, and further approximations of the Fresnel design have been made to demonstrate lenses with unconventional shapes (e.g. hexagonal).

15:15 **Chirality Plasmonic Lens Induced Terahertz Super-focusing** **Tu-P1-4-6**

ZHU YIMING[1]; XIAOFEI ZANG[2]; Yan Peng[2]; Lin Chen[2]
[1]UNIVERSITY OF SHANGHAI FOR SCIENCE AND TECNOLOGY, China; [2]University of Shanghai for Science and Technology, China

In summary, we have theoretically proposed and experimentally demonstrated a novel plasmonic lens that owns THz super-focusing beyond diffraction limit. The density of the focal spot is sensitivity to the polarization of the incident waves. The

THz super-focusing demonstrated in this report may open up a new avenue to THz super-resolution imaging.

15:30 **[Keynote] Demonstration Of Computational THz Diffractive Optical Elements Enabled By A Modified Direct Binary Search Technique** **Tu-P1-4-7**

Sourangsu Banerji; Ashish Chanana; Hugo Condori-Quispe; Sara Arezoomandan; Ajay Nahata; Berardi Sensale-Rodriguez
University of Utah, United States

Computational diffractive optics is a robust tool for designing optical elements. A gradient-descent based modified search algorithm enables us to find optimal solutions 10-100X faster than what is possible by employing traditional direct binary search algorithm. The proposed algorithm cannot just enable a faster convergence, but also allows us to increase the dimension of the search space, thus the number of degrees of freedom on the problem, which can lead to much better design performance. Using this approach, we demonstrate a series of efficient THz optical elements including (i) large NA 1D and 2D lenses for aberration-rectified narrow and broadband focusing and (ii) the THz equivalent of an optical spectrometer, i.e. a structure focusing different THz frequencies at different points in space. We present experimental results performed using 3D printed structures, which are backed by full wave simulations.

16:30 - 18:30 Tu-P2-R1 Gyro-Oscillators and Amplifiers I — Shirotori Hall

Session Type: Oral

16:30 **Progress On 1 MW Operation Of Japan Gyrotron For ITER EC System** **Tu-P2-R1-1**

Ryosuke Ikeda; Yasuhisa Oda; Ken Kajiwara; Takayuki Kobayashi; Taku Nakai; Masayuki Terakado; Koji Takahashi; Shinichi Moriyama; Keishi Sakamoto
National Institutes for Quantum and Radiological Science and Technology, Japan

High-power operations of Japan ITER-gyrotron are underway in the QST. Two ITER-gyrotrons was manufactured and these short-pulse tests were completed. Similar beam profiles at the output window and MOU outlet were identified. The output power of 1 MW in 1 ms was achieved for both gyrotrons. Conditioning of one of the gyrotrons has being carried out and the operation of 1.0 MW-100 s was achieved. In addition, full-power modulation of 5 kHz for 10 s was demonstrated.

16:45 **Developments Of Equipment For Sub-THz Collective Thomson Scattering In LHD** **Tu-P2-R1-2**

Teruo Saito[1]; Shunsuke Tanaka[1]; Ryuji Shinbayashi[1]; Takumi Hirobe[1]; Yuusuke Yamaguchi[1]; Masafumi Fukunari[1]; Yoshinori Tatematsu[1]; Kunizo Ohkubo[1]; Shin Kubo[2]; Takashi Shimozuma[2]; Kenji Tanaka[2]; Masaki Nishiura[3]
[1]University of Fukui, Japan; [2]National Institute for Fusion Science, Japan; [3]The University of Tokyo, Japan

Equipment for sub-THz collective Thomson scattering diagnostics in the Large Helical Device has been developed. The probe beam source is a 303 GHz Gyrotron. It operates in a pulse mode. No parasitic mode is excited during the whole pulse width including the turn-on and turn-off phases. Single mode oscillation at several frequencies has been confirmed. For power transmission, a 3.5 inch corrugated waveguide line installed for electron heating with lower frequency gyrotrons will be used. The test with the 303 GHz gyrotron has shown a sufficiently low transmission loss.

17:00 **Terahertz-range High-order Cyclotron Harmonic Planar Gyrotrons With Transverse Energy Extraction** **Tu-P2-R1-3**

Naum Ginzburg[1]; Vladislav Zaslavsky[1]; Toshitaka Idehara[2]; Vladimir Manuilov[1]; Ilya Zheleznov[1]; Andrey Kuftin[1]; Andrey Malkin[1]; Irina Zotova[1]; Alexander Sergeev[1]; Mikhail Glyavin[1]
[1]Institute of Applied Physics, Russian Federation; [2]University of Fukui (FIR UF), Japan

We develop the new concept of terahertz gyrotrons with planar geometry and transverse diffraction radiation output. The advantage of this scheme comparing to the conventional cylindrical gyrotrons is the possibility of providing the radiation coherence at larger oversize factors by using the diffraction mode selection mechanism with respect to the "open" transverse coordinate. Planar gyroton can operate as at fundamental as at high order cyclotron harmonics. The equidistant mode spectrum is beneficial for frequency multiplication.

17:15 **Overview Of Recent Gyrotron R&D At KIT In View Of The EU DEMO** **Tu-P2-R1-**

Konstantinos Avramidis[1]; Gaetano Aiello[1]; Philipp Thomas Bruecker[1]; Thomas Franke[2]; Gerd Gantenbein[1]; Marc George[1]; Giovanni Grossetti[1]; Stefan Illy[1]; Zisis Ioannidis[1]; Jianbo Jin[1]; Parth Kalaria[1]; Alexander Marek[1]; Ioannis Pagonakis[1]; Sebastian Ruess[1]; Tobias Ruess[1]; Tomasz Rzesnicki[1]; Theo Scherer[1]; Martin Schmid[1]; Dirk Strauss[1]; Manfred Thumm[1]; Minh Quang Tran[3]; Chuanren Wu[1]; Andy Zein[1]; John Jelonnek[1]
[1]Karlsruhe Institute of Technology, Germany; [2]EUROfusion Consortium, Germany; [3]École Polytechnique Fédérale de Lausanne, Switzerland
A large part of the gyrotron R&D activities at Karlsruhe Institute of Technology focus on addressing challenging requirements posed on gyrotrons by the European concept for a demonstration fusion reactor (EU DEMO). This paper reports on the progress of these activities and on the recent results.

17:30 **Development Of A Second Harmonic Multi-Frequency Gyrotron With Gaussian Beam Output** **Tu-P2-R1-5**

Yoshinori Tatematsu; Kyoya Takayama; Yuto Maeda; Tatsuya Ueyama; Taisei Ogura; Masafumi Fukunari; Yuusuke Yamaguchi; Teruo Saito
University of Fukui, Japan
A sub-THz second harmonic multi-frequency gyrotron with Gaussian beam output is under development. This gyrotron can change the frequency stepwise in the range from 270 to 420 GHz. For multi-frequency Gaussian-beam output, all design modes should be converted to Gaussian beams with one mode converter. To achieve this, nine oscillation modes with close values of the transverse propagation angle were selected. Oscillation test of the selected modes was carried out with a linear type gyrotron equipped with the designed cavity. Oscillations of seven second-harmonic modes were successfully observed among the nine selected modes. Operation condition for each mode was experimentally investigated. An internal mode converter to radiate Gaussian beam from each mode was designed.

17:45 **Possibilities Of Mode Selection In Double-Beam Gyrotrons With Additional Absorbing Beam** **Tu-P2-R1-6**

Vladimir Manuilov[1]; Vladislav Zaslavsky[2]; Irina Zotova[2]; Ivan Osharin[2]; Andrey Savilov[2]; Toshitaka Idehara[3]; Andrey Fokin[2]; Mikhail Glyavin[2]
[1]Insitute of Applied Physics RAS, Russian Federation; [2]Institute of Applied Physics RAS, Russian Federation; [3]FIR UF, Japan
The concept of a double-beam gyrotron is known as a promising solution of the mode competition problems (especially in the tubes operating on high harmonics of the cyclotron frequency) since it provides an additional means for mode selection (besides the usually used electronic and electrodynamic selection), namely a selection by the transverse index of the operating mode. Such improved selectivity is achieved by adjusting properly the injection radii of both electron beams inside the resonant cavity with respect to the maxima of the coupling factors of the operating and the competing modes. Generally, there are two possible schemes of double-beam gyrotrons. In the first one, two generating beams are used while in the second one the second beam is used as an absorber in order to suppress the development of the neighboring parasitic mode. First experimental results with gyrotron of centimeter wavelength have shown that both ways allow improve the mode selection and increase the output power of the tube significantly. But the most important task is to provide good enough efficiency and output power of the double-beam gyrotrons in millimeter and submillimeter wavelength range. First theoretical and experimental investigations of the tube with two generating beams have proved that even for the frequency close to 1 THz it is possible to achieve good enough parameters of the gyrotron in CW regime. At the same time till now the theory of double-beam gyrotrons is not completed and so the potentialities of such tubes for different types of the additional electron beam in different frequency ranges are not compared. Simple analytical model for estimation of the cavity length and ratio of the currents in generating and absorbing beams are developed. It is shown that the characteristic ratio between the generating beam current and the current in the absorbing beam required for significant improving the selectivity Igen/Iabs is proportional to parasitic fundamental-harmonic wavelength to cavity length (wl/L). Thus, this approach is effective if the cavity length L is short enough. Calculations have shown that for centimeter wavelength experimental W-band gyrotron the selectivity is improved dramatically even if the absorbing beam current is 5 times smaller than the generating beam current, that is in a good agreement

with the experimental data. At the same time, for submillemeter wavelengths harmonic gyrotrons the ratio Iabs/Igen usually needs in the range about 10 (due to relatively long cavity for harmonic operation), that make difficult the development of the corresponding electron gun. External position of the absorbing beam is more preferable. Numerical simulations (EPOS code was used) show that it is possible to form the absorbing beam with very low pitch-factor about 0.05 that is 3-4 times lower than minimal value providing the conditions of the energy absorption by that beam.

18:00 **[Keynote] Terahertz Large-orbit High-harmonic Gyrotrons At IAP RAS Features** **Tu-P2-R1-7**

Andrei Savilov; Ilya Bandurkin; Vladimir Bratman; Yuriy Kalynov; Vladimir Manuilov; Ivan Osharin; Nikolay Zavolsky
Institute of Applied Physics of Russian Academy of Sciences, Russian Federation

We describe high-harmonic gyrotrons with axis-encircling electron beams developing on the basis of two (80 keV pulsed and 30 keV CW) experimental setups. Selective operation at the second (0.267 THz) and at the third (0.394 THz) cyclotron harmonics were observed in the 30 keV gyrotron. Quasi-regular cavities with periodic phase correctors are designed to improve the operation at the third harmonic, as well as to achieve the fourth-harmonic operation at frequencies of up to 0.65 THz. At the pulsed gyrotron setup, a sectioned cavity with a decreased diffractive Q-factor was experimentally tested.

16:30 - 18:15 Tu-P2-1b Metamaterial Structures and Applications I — Room 131+132

Session Type: Oral

16:30 **Active And Ultrafast Terahertz Metamaterials** **Tu-P2-1b-1**

Caihong Zhang; Biaobing Jin; Jingbo Wu; Jian Chen; Peiheng Wu
Research Institute of Superconductor Electronics, Nanjing University, China

Recently, with the development of artificial electromagnetic medium, metamaterials offer people the ability to subjectively control electromagnetic wave and provide a promising solution for scarce terahertz (THz) functional devices. More and more terahertz system gradually become integration and miniaturization that we urgently need the active terahertz functional devices. Among these devices, tunability of transmission is desirable for many applications. In this paper, we report our recent development of nonlinear tunability and ultrafast dynamics from Nb5N6 metamaterials at THz region measured by intense THz pump THz probe system. Also, the temperature dependent nonlinearity is characterized.

16:45 **Detection Of EGFR Protein Using Terahertz Metamaterial Biosensor** **Tu-P2-1b-2**

Kai Liu; Rui Zhang; Xuequan Chen; Emma Pickwell-MacPherson
The Chinese University of Hong Kong, Hong Kong

Increasing the detection specificity and sensitivity of the epidermal growth factor receptor (EGFR) will benefit the diagnosis of a number of cancers. Terahertz metamaterial biosensors are very sensitive and able to detect trace biomolecules. In this work, we fabricated a bow-tie THz metamaterial biosensor and functionalized it with EGFR antibody for specific EGFR detection. The results demonstrate that the proposed strategy can achieve EGFR detection with high specificity and sensitivity. This has the potential to be introduced into clinical use for the fast diagnosis of EGFR related diseases.

17:00 **Metallic Periodic Surface Lattice Enhanced High-Power MM-wave Sources** **Tu-P2-1b-3**

Amy MacLachlan; Huabi Yin; Liang Zhang; Craig Robertson; Kevin Ronald; Adrian Cross; Alan Phelps
University of Strathclyde, United Kingdom

The design and construction of metallic Periodic Surface Lattices (PSLs) to enable oversized cylindrical interaction volumes to be excited efficiently by annular electron beams is presented. Construction methods include metallic electrodeposition and "additive manufacturing", or "3D printing".

17:15 **Ultrasensitive THz Sensing With Corrugated Hyperbolic Metamaterials** **Tu-P2-1b-4**

Guangyuan Li; Yuanfu Lu; Wenquan Liu; Guohua Jiao; Jiancheng Lv
Shenzhen Institues of Advanced Technology, Chinese Academy of Sciences, China

We show that ultrasensitive THz sensors can be achieved based on corrugated hyperbolic metamaterials. For the proposed sensor the sensitivity of the proposed

sensor reaches 1 THz/RIU (9.3 x10^3 nm/RIU), which is orders of magnitude larger than those based on metasurfaces.

17:30 **Terahertz Thin-Film Sensing With Angle-Susceptable Metasurface** **Tu-P2-1b-5**

Nazar Nikolaev[1]; Sergei Kuznetsov[2]; Miguel Beruete[3]
[1]Institute of Automation and Electrometry, Siberian Branch of the Russian Academy of Sciences, Russian Federation; [2]Novosibirsk State University, Russian Federation; [3]Universidad Pública de Navarra, Spain

Tthin-film structures and coatings are widely applied in various state-of-the-art technologies both of industrial and scientific purposes that makes the tasks of thin-film sensing highly demanded in practice. Last decade, stimulated by a rapid progress in terahertz (THz) instrumentation, a keen interest has been attracted to the THz spectral range to develop its potential for detecting and measuring properties of thin films. The THz radiation serves as an advantageous alternative to visible and IR waves when examining optically opaque coatings. Meanwhile, due to a relatively large wavelength λ, the conventional spectroscopic methods (TDS-, FDS-, FTIR-, BWO-based) are ill-suited for direct characterization of thin films deposited on unpatterned substrates when the film thickness d is 2-4 orders of magnitude smaller than λ. This obstacle, however, can be overcome with metamaterials, in particular, with plasmonic metasurfaces (PMSs). Owing to strong field localization in the vicinity of the PMS, the latter exhibits high sensitivity of its spectral response to dielectric environment that makes feasible sensing of analyte layers satisfying d << λ condition. Traditionally, THz thin-film sensing with PMSs is based on measuring a frequency shift of the PMS resonance when the analyte is deposited onto the PMS. In this work we elaborate an idea to substitute THz spectral measurements for tracking the PMS response at a fixed wavelength upon changing the incidence angle θ of the exciting THz beam. This concept works well for the PMS with a narrowband resonance sensitive to θ. We present the results of the numerical investigations and experimental study of such a PMS, which was designed as a single-layer array of hexagon-shaped annular slots with θ-susceptible resonant transmission near 0.85 THz. The proposed approach paves the way to novel compact thin-film sensing devices utilizing the principle of single-wavelength multiangle photometry.

17:45 **[Keynote] Critical Mode Softening In Ultra-strong Coupling Of Landau Level Transitions To THz Metamaterials Beyond The Hopfield Model** **Tu-P2-1b-6**

Janine Keller[1]; Giacomo Scalari[1]; Felice Appugliese[1]; Shima Rajabali[1]; Curdin Maissen[1]; Johannes Haase[2]; Christian A. Lehner[1]; Werner Wegscheider[1]; Michele Failla[3]; Maksym Myronov[3]; David R. Leadley[3]; James Lloyd-Hughes[3]; Pierre Nataf[1]; Jérôme Faist[1]
[1]ETH Zürich, Switzerland; [2]Paul Scherrer Institute, Switzerland; [3]University of Warwick, United Kingdom

We study the ultra-strong light-matter coupling of THz metamaterials to Landau level transitions in heavily non-parabolic strained Ge quantum wells (QWs) and InSb QWs. We systematically scale the frequency of the THz metamaterial and observe a clear deviation of the polariton energies from the standard Hopfield model. The lower polariton frequency is strongly below the expected frequency from a standard Hopfield model.

16:30 - 18:30 **Tu-P2-1c Imaging and Remote Sensing I** **Room 133+134**

Session Type: Oral

16:30 **[Keynote] A Solid-State 0.56 THz Near-Field Array For µM-Scale Surface Imaging** **Tu-P2-1c-1**

Philipp Hillger[1]; Ritesh Jain[1]; Janusz Grzyb[1]; Laven Mavarani[1]; Thomas Bücher[1]; Gaetan Mac Grogan[2]; Patrick Mounaix[3]; Jean-Paul Guillet[3]; Ullrich Pfeiffer[1]
[1]University of Wuppertal, Germany; [2]Institut Bergonié, France; [3]IMS CNRS 5218, France

We demonstrate a fully-integrated 0.56 THz 128-pixel near-field 1-D sensor array that makes use of a dielectric permittivity-based imaging contrast and has 10-15 µm lateral resolution. The sensor comprises THz illumination, evanescent field sensing, detection, and a video-rate analog and digital read-out on a single silicon chip. Thus, it enables rapid THz near-field image acquisition of planar and soft

surfaces. As an example test case, this work demonstrates THz near-field sensing as a tool for biometric fingerprint reading for the first time.

17:00 **Non-scanning Terahertz Near-field Imaging With Spatial Resolution Of ~λ/100** **Tu-P2-1c-2**

Liguo Zhu; Sichao Chen; Zeren Li
China Academy of Engineering Physics, China

Introduction:The long wavelength of THz waves limits the resolution down to millimeter in conventional imaging scheme, due to far-field diffraction limitation. To obtain sub-diffraction THz images, two approaches for THz imaging in near field via tiny aperture and tip-enhanced scattering, have been demonstrated. But both methods rely on mechanical scanning the target point by point, which has inherent drawbacks of mechanical structures and raster scheme, such as invasive detection, long sampling time, low signal noise ratio and inflexible system. More recently, sing-pixel camera with compressive imaging in THz regime has been demonstrated. And compressing the near-field THz wave has been proven with spatial resolution of λ/4. Further improving the resolution is still challenging, and by more it works only in transmission mode, which restricts itself only for micrometer-thick samples imaging.In this talk, we'll present an experimentally demonstrated novel non-scanning near-field THz imaging with resolution of better than ~λ/100 (@0.5 THz), which operates both in transmission and reflection modes. It was further been used to spatially mapping semiconductor-based metasurfaces in transmission geometry and living bio tissues in reflection geometry. Compared with previously published methods which is limited for ultrathin (~μm) samples, it opens a way for real object deep-subwavelength imaging.Results:A novel non-scanning THz near-field imaging layout. A digital micro-mirror device (DMD) was used to spatially code the 800nm fs-laser pulses with designed patterns (Hadamard masks), and the patterned fs-laser pulses further spatially modulate THz pulse through exciting 100nm thick vanadium dioxide (VO2) thinfilm. The Phase transition material VO2 was utilized as spatial light modulator. A single-pixel detector recorded the intensities of the patterned THz pulses transmitted through or reflected from objects. Owing to VO2 film with 100nm thickness, we can detect the high spatial frequency THz information of the object in a very near distance (tens of μm) where evanescent waves dominate. In reflection geometry, THz wave reflected from the interfacial between VO2 thin film and living bio tissues. To spatially mapping metasurfaces, we used transmission geometry since the thickness of metasurface is of 10s of μm. By applying single-pixel imaging technique with Hadamard sequence measurements, we spatially resolved a metal wheel (32Ãƒâ€"32) with pixel size of 6 μm (λ/100 @ 0.5 THz). More detailed results, along with subwavelength reflectively imaging of living myelin-deficit mouse brain and fs-machining VO2 based metasurface, will be presented.

17:15 **Towards Polarization-resolved THz-nanoscopy** **Tu-P2-1c-3**

Stephan Schäffer; Anna Katharina Wigger; Peter Haring Bolívar
University of Siegen High Frequency and Quantum Electronics, Germany

We report on a 600 GHz scattering-type THz nanoscope (THz-s-SNOM) with independent electronic emitter and detector unit. This system is capable of measuring the in-plane and out-of-plane near-field components independently of the polarization of the emitter. An approach curve is shown which verifies the functionality of our system, paving the way towards polarization-resolved THz-nanoscopy.

17:30 **Scanning THz Noise Microscopy Of Operating Nano-devices** **Tu-P2-1c-4**

Le Yang[1]; Ruijie Qian[1]; Qianchun Weng[2]; Xue Gong[1]; Pingping Chen[3]; Susumu Komiyama[2]; Wei Lu[3]; Zhenghua An[1]
[1]Fudan University, China; [2]The University of Tokyo, Japan; [3]Shanghai Institute of Technical Physics, China

Electrical currents in operating nano-devices generate terahertz noise emission due to the rich ultrafast interactions of flowing charges with hosting lattices. With a newly developed scanning noise microscope, we present here real-space imaging of hot carrier dissipation dynamics in long-channel GaAs operating nano-devices and discuss the associated nonequilibrium relaxation mechanisms.

17:45 **Sub-wavelength Imaging In The Terahertz Domain Through Optical Rectification** **Tu-P2-1c-5**

Jean-Louis Coutaz; Federico Sanjuan; Gwenael Gaborit

IMEP-LAHC, France
We record a sub-wavelength THz image of a caster sugar grain by performing optical rectification in the grain and scanning the grain surface. We obtain a spatial resolution equal to 30 µm, i.e. ~ λ_{THz} / 7.

18:00 **[Keynote] Imaging On The Nanoscale With THz Time-Domain, Emission And Pump-Probe Microscopy** **Tu-P2-1c-6**
Pernille Klarskov
Aarhus University, Denmark
We demonstrate an experimental platform based on an scattering-type scanning near-field optical microscope (s-SNOM) with the ability to perform Laser Terahertz Emission Microscopy (LTEM), Terahertz Time-Domain Imaging (THz-TDI) and optical-pump terahertz probe back-to-back in the same configuration. We illustrate this by imaging a metal-semiconductor interface with all three methods.

16:30 - 18:30 **Tu-P2-1a Sources, Detectors, and Receivers III** **Room 141+142**

Session Type: Oral

16:30 **A Tunable Optical Cavity For Enhancement Of Nb5N6 Microbolometer THz Detector Absorption** **Tu-P2-1a-1**
Xuecou Tu; lin kang; Peng Xiao; chengtao Jiang; shiming zhai; xinle guo; xiaoqing jia; jian chen; peiheng wu
Nanjing University, China
Based on substrate cavity effect, an asymmetric coupled Fabry-Pérot (FP) cavity is constituted by simply placing a movable metallic planar mirror in the back of the silicon substrate. The incident THz radiation onto the Nb5N6 microbolometer can be effectively manipulated by changing the substrate-mirror distance to modulate the phase relation between the reflect wave and the incident wave. The distinct responsivity control can be observed and the experiments are well explained by numerically analyzing the radiation dynamics that highlights the role of FP cavity effect. All results discussed here can be extended to broad range of frequency and other type of THz detectors.

16:45 **Ultra-Broadband Schottky Diode Balanced Envelope Detector For W-Band High-Data Rate Communication Systems** **Tu-P2-1a-2**
Angel Blanco Granja[1]; Roland Reese[1]; Rolf Jakoby[1]; Andreas Penirschke[2]
[1]Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Darmstadt 6428, Germany; [2]Technische Hochschule Mittelhessen, Friedberg, 61169, Germany, Germany
We present an outright W-Band (75-110 GHz) receiver, composed by a Schottky diode based balanced Envelope Detector (ED), built in microstrip technology with SMA output and a microstrip to hollow waveguide WR-10 transition at its input. Simulations show that is able to demodulate amplitude shift keying (ASK) signals with data rates up to 15 Gbps in the whole W-Band. This ED shows an outstanding broadband operational bandwidth together with its compact design compared to other balanced ED's.

17:00 **[Keynote] Fermi-Level Managed Barrier Diode: Room-Temperature Low-Noise Terahertz-Wave Detector** **Tu-P2-1a-3**
Hiroshi Ito[1]; Tadao Ishibashi[2]
[1]Kitasato University, Japan; [2]NTT Electronics Techno Corporation, Japan
We present our recent results on a room-temperature THz-wave detector called Fermi-level managed barrier (FMB) diode. The FMB diode has a very low barrier height, which is the key for achieving low noise characteristics. The fabricated FMB diode module could detect signals at frequencies from 160 GHz to 1.4 THz with very low noise-equivalent powers of 3.0 pW/Hz^0.5 in the square-law detection mode and 16 aW/Hz in the homodyne detection mode with a very low local oscillator power of 500 nW, both at 300 GHz.

17:30 **New InGaAs THz Schottky Detectors With Nanowire Contact For Zero-bias Operation** **Tu-P2-1a-4**
Ahid S. Hajo; Oktay Yilmazoglu; Franko Küppers
Technische Universität Darmstadt, Germany
In this paper we report a new THz Schottky detector based on vertically contacted high doped (1 x 1018 cm-3) indium gallium arsenide (InGaAs) by using a small diameter (100 nm) silver nanowire (NW) as air-bridge contact. Compared to Schottky diodes based on gallium arsenide (GaAs) it has better zero-bias operation of 100 µA at 0.05 V raising to more than 1 mA at 0.27 V for lower noise application.

17:45 **Semiconducting Y-Ba-Cu-O Uncooled Detectors: Feasibility Of THz Pyroelectric Sensing** **Tu-P2-1a-5**

Annick Dégardin[1]; Manjakavahoaka Razanoelina[2]; Xavier Galiano[3]; Yvan Méautte[1]; Masayoshi Tonouchi[2]; Alain Kreisler[3]
[1]Sorbonne Universite, France; [2]Institute of Laser Engineering - Osaka University, Japan; [3]CentraleSupelec - GeePs, France

Introduction. Since the demonstration of pyroelectric properties in oxygen depleted semiconducting $YBa_2Cu_3O_{6+x}$ oxides ($x < 0.5$), the interest of the amorphous phase (*a*-YBCO) has been demonstrated for thermal near infrared (NIR) detection sensing. Highly competitive performances have been reported for metal contact / *a*-YBCO, both planar and trilayer structures. These exhibit similar or higher sensitivity than commercially available pyroelectric sensors, with much faster response (two to four orders of magnitude shorter time constant). Moreover, we have interpreted the fast response of *a*-YBCO devices by means of an analytical model (without adjustable parameters). We shall first summarize our achievements in the NIR with both planar and trilayer structures, then consider the feasibility of extending the operation at THz frequencies, supported by the knowledge of *a*-YBCO conductivity to have access to impedance matching with a THz planar antenna.

a-YBCO pyroelectric detector performance. The amplitude response as a function of modulation frequency *f* of the NIR source is reported for planar and trilayer structures. The f^{+1} behavior at lower frequencies is typical of the pyroelectric capacitance current, and the $f^{-1/2}$ decay at higher frequencies is due to thermal diffusion across the silicon substrate. The - 3 dB cutoffs are f_{cP} = 84 kHz (time constant τ = 1.9 µs) for the planar device and f_{cT} = 1.3 MHz τ = 0.12 µs) for the trilayer device. The best noise equivalent power (*NEP*) and detectivity *D** were observed at *f* = 10 kHz for both planar (trilayer) devices: *NEP* = 2.0 (2.6) pW/Hz$^{1/2}$, *D** = 6.6x10^9 (5.7x10^9) cm.Hz$^{1/2}$/W.

Feasibility in the THz: *a*-YBaCuO conductivity. To migrate towards the THz range, the main issue to be overcome is a proper knowledge of *a*-YBaCuO absorption at THz frequencies. Previous studies evidenced the low *a*-YBaCuO THz absorption, suggesting the use of micro-antenna coupling. Time-domain spectroscopy measurements of the complex permittivity led to have access to the THz electrical conductivity, so allowing to design the antenna geometry for optimal matching with *a*-YBaCuO structures. First results have shown *a*-YBaCuO to exhibit THz conductivity in the 0.5 to 2 S/cm range. It therefore seems that impedance matching to trilayer devices, which exhibit a few tens of ohms THz impedance, is achievable with conventional antennas (such as wide band log-periodic). Planar devices, however, which exhibit a few kΩ input impedance, will require specific high impedance antennas.

Acknowledgment. The devices were processed at the CTU-Minerve facility, Universite Paris-Sud, Orsay, France.

18:00 **[Keynote] An Ultra-Compact 520-600 GHz/1100-1200 GHz Receiver With <10 W Power Consumption For High-Spectral Resolution Spectroscopy From Small-Sat Pl** **Tu-P2-1a-6**

Jose V. Siles[1]; Jonathan Kawamura[1]; Darren Hayton[1]; Jonathan Hoh[2]; Christopher Groppi[2]; Imran Mehdi[1]
[1]NASA Jet Propulsion Laboratory, United States; [2]Arizona State University, United States

Water, chemistry and energy/heat are three key aspects to consider to address habitability in planetary bodies. Many key species such as salts (NaCl, KCl, MgCl, NaOH, KOH, MgO), carbon molecules (CO, CN, HCN, H2C, CH3CN, CH3OH), water (H20, H218O, H217O, HDO), and sulfur molecules (H2S, SO2) fall in the submillimeter-range, especially in the 216-290 GHz, 510-580 GHz and 1080-1200GHz bands. These receiver needs to be capable of high-resolution (<100 kHz) molecular spectroscopy to measure line shapes and Doppler-shifts of molecular emissions from gases in environments as harsh as the Jupiter system. This is accomplished using Schottky diode heterodyne receivers, which offer high spectral resolution based on their temporal stability and dynamic range. These kinds of receivers will also be able to detect/map plumes remotely, from at least 200,000 miles in Europe or Enceladus. With current state-of-the-art (SOA), a dedicated

receiver was needed for each band due to the limited bandwidth/power of locals oscillator sources. Here we report on a room-temperature dual-band single channel receiver operating simultaneously in the 520-600 GHz and 1100-1200 GHz range, which allows velocity resolved remote water detection and mapping in planetary bodies at 557 GHz and 1124GHz. Due to the efficiency of the new generation of frequency multiplied LO sources recently demonstrated, together with the use of CMOS-based W-band synthesizers and spectrometers, this receiver can operate with a dc power consumption of less than 10 W, which makes it suitable for deployment in Small Satellite platforms. The dual-band operation is enabled by an on-chip power combined 520-600 GHz frequency single-chip tripler that is able to generate two independent outputs with 2-3.5 mW output power each, 4- 7 mW total (each mixer requires only 1.5 mW LO power. These output power levels are enough to drive both mixer simultaneously and obtain state-of-the-art performance with a reduction of 5 to 10 times in dc power, mass and size. The back-end features SiGe LNAs and ultra-low power CMOS-based spectrometers (<1.5 W dc power consumption each. The current mixers exhibits performances of Tmix<1000 K DSB for the 520-600 GHz band and Tmix<4000 K DSB for the 1100-1200 GHz band at room temperature (300K). New mixer chips are currently under fabrication using an optimized epi-structure to further improve the mixer performance. The single-channel operation avoids the need of polarizing grids to separate the telescope beam into multiple receivers, reducing RF losses and improving the overall receiver performance.

16:30 - 18:30 **Tu-P2-R2 Astronomy, Planetary and Environmental Science** **Reception Hall**

Session Type: Oral

16:30 **[Keynote] Submm Astronomy From Ground And Space: Evolution And Future Perspectives** **Tu-P2-R2-1**

Thijs de Graauw
ESO/ASC-LPI, Chile

An overview is give on the successful interaction between mm/sub-mm science and technology and submm astronomy over the last 50 years. Development of enabling innovations are summarized with resulting astronomical investigations and discoveries. An outlook to further technical advances, possible applications and scientific objectives for future observations from ground and space will be presented.

17:00 **The 1200GHz Receiver Frontend Of The Submillimetre Wave Instrument Of ESA Jupiter Icy Moons Explorer** **Tu-P2-R2-2**

Alain Maestrini[1]; Lina Gatilova[1]; Jeanne Treuttel[1]; Yong Jin[2]; Antonella Cavana[2]; Diego Moro Melgar[1]; Thibaut Vacelet[1]; Alexandre Féret[1]; Sylvain Caroopen[1]; Grégory Gay[1]; Frédéric Dauplay[1]; Jean-Michel Krieg[1]; Bertrand Thomas[3]; Peter De Maagt[4]; Christophe Goldstein[5]
[1]Observatoire de Paris, France; [2]C2N-Marcoussis, France; [3]Radiometer Physics GmbH., Germany; [4]ESTEC, Netherlands; [5]CNES, France

The Sub-millimetre Wave Instrument (SWI) of ESA JUpiter ICy moons Explorer (JUICE) is built by an international consortium lead by the Max Planck institute for solar system research in Gottingen. SWI will investigate the temperature structure, composition and dynamics of Jupiter's stratosphere and troposphere, and the exospheres and surfaces of the icy moons. It will be the first planetary instrument to feature 1200GHz and 600GHz heterodyne receivers capable of observing spectral lines with a relative resolution of 1E7 and a frequency accuracy of 1E8. Due to stringent mass and power limitations of JUICE payload, SWI receivers are based of passively cooled Schottky receiver frontends working at 120K to 150K. SWI 1.2THz receiver sensitivity specification is a double side band receiver noise temperature below 4000K with a goal at 3000K.This paper will present the current design and status of SWI 1080-1280GHz Schottky receiver frontend, which is developed at LERMA-Observatoire de Paris in partnership with C2N-Marcoussis (formerly LPN). A double side band receiver noise temperature of 1600K has been recorded at 1114GHz at an ambient temperature of 150K, with a maximum double side band noise temperature of 2570K, an average of 1950K and a standard deviation of 220K across the entire band. This is believed to be the best performance of Schottky receiver in this frequency range.

17:15 **The Bench Test Of A High Temporal Resolution HCN Interferometry ForAtmospheric Pressure Air Plasmas** **Tu-P2-R2-3**

jibo zhang; Haiqing Liu; Yinxian Jie
ASIPP, China
A heterodyne interferometer operating at the frequency f = 0.89 THz has been designed for measuring electron density of atmospheric pressure air plasmas. The system is configured as a Mach-Zehnder type interferometer and the bench test has been finished. The light source is hydrogen cyanide (HCN) laser with wavelength of 337 microns, which the power is up to 100 mW. The intermediate frequency, shifted by 500 kHz, is generated by the Doppler shift with a high speed rotating grating (HSRG), which is installed in a vacuum vessel. The frequency shift is one order higher than the conventional rotating grating. With this novel technology, to measure the electron density profile and high frequency density fluctuation simultaneously in plasmas becomes possible with a single far-infrared laser source.

17:30 **A Compact Integrated 675-693 GHz Polarimeter** **Tu-P2-R2-4**

Eric Bryerton
Virginia Diodes, Inc., United States
The design of a single-sideband 675-693 GHz integrated polarimeter is presented here. The compact module, measuring 1.5" x 1.5" x 0.75" includes the OMT, RF LNAs, image-reject filters, mixers, IF LNAs, and LO active multiplier chain. Total power dissipation is expected to be approximately 6W. Receiver noise temperature is expected to be approximately 6000K SSB. The polarimeter has been machined and is currently in assembly with measurements to be presented at the conference.

17:45 **Axion Haloscopes: Moving From Microwaves To Mm-Waves** **Tu-P2-R2-5**

Samantha Lewis
University of California, Berkeley, United States
The axion is a well-motivated dark matter candidate particle. In the primary detection scheme, axions convert to photons in the presence of a strong magnetic field. This photon signal can be enhanced using resonant electromagnetic cavities. Current experiments are searching for axions in the microwave regime, but the possible axion mass range extends to much higher frequencies. This work will discuss the use of microwave cavities in current experiments as well as the challenges and possible approaches to moving to the mm-wave and THz regimes in the future.

18:00 **[Keynote] Atacama Large Millimeter/submillimeter Array (ALMA): Scientific Achievements And Developments For Future** **Tu-P2-R2-6**

Tetsuo Hasegawa
National Astronomical Observatory of Japan, Japan
ALMA has completed its first 5 years of full science operations and has produced more than a thousand refereed research papers worldwide. In parallel with the science operations, future enhancements of the ALMA capabilities are being discussed and prepared. We review highlights of the scientific achievements of ALMA that have transformed our view of the universe and of the ALMA enhancement plans for the future.

16:30 - 18:15 **Tu-P2-4 Devices, Components, and Systems VI** **Room 432**
Session Type: Oral

16:30 **THz Pump-probe Setup For Experiments In High Magnetic Fields** **Tu-P2-4-1**

Bence Bernáth[1]; Dmytro Kamenskyi[1]; Britta Redlich[2]; Lex van der Meer[2]; Peter Christianen[1]; Hans Engelkamp[1]; Jan Kees Maan[1]
[1]High Field Magnet Laboratory, Netherlands; [2]FELIX Laboratory, Netherlands
The combination of high power, pulsed THz radiation and high magnetic fields is very promising from a scientific perspective. We present the design of a THz single-color pump-probe setup inside a high-field Bitter magnet, using components that are not within the scope of regular quasi-optical THz setups. We use special waveguides and a prism geometry to spatially separate the pump and the probe beams, which allows us to work in a cryogenic environment in a small bore magnet. Our test results show that this pump-probe insert enables studying the fast carrier dynamics in semiconductors using cyclotron resonance.

16:45 **Experimental Demonstration Of 20dB Nonreciprocity Around 1.5THz On A InSb Magnetoplasmonic Grating Mirror At 77K** **Tu-P2-4-2**

Oleksandr Stepanenko[1]; Tomas Horak[1]; Romain Peretti[1]; Sergey Mitryukovskiy[1]; Jan Chochol[2]; Kamil Postava[2]; Jean-François Lampin[1]; Mathias Vanwolleghem[1]
[1]CNRS IEMN, France; [2]Nanotechnology Centre, VSB Ostrava, Czech Republic

In our work we present a design and an experimental demonstration of a nonreciprocal magnetoplasmonic InSb mirror for 1.5 THz radiation. The transverse magneto-optic Kerr effect (TMOKE) provides the nonreciprocal behaviour. TMOKE manifests itself as a nonreciprocal reflectivity of p-polarized light when incident on a gyrotropic material that is magnetized perpendicular to the incidence plane. At THz frequencies, a straightforward way to induce gyrotropic response is by exploiting cyclotron effects in magnetized free carrier plasmas. As the gyrotropy is governed by the cyclotron frequency which is inversely proportional to the carrier effective mass, intrinsic semiconductors with a low effective free carrier mass, such as InAs and InSb, exhibit strong gyrotropy at reasonably low applied magnetic fields. Moreover due to their low bandgap, their plasma frequency is in the THz range. Strong THz TMOKE under low magnetic fields can therefore already be expected on InSb substrates near their intrinsic plasma frequency. We have numerically shown how this effect can be further enhanced and controlled by combining it with surface plasmon excitations on gratings etched in such semiconductors. Our calculations predict nonreciprocal reflectivity isolation of the order of 20dB. In previous work we have already demonstrated experimentally a nonreciprocal magnetoplasmonic mirror that achieves room temperature isolation with a rejection of 10dB. These were characterized using a 2.5 THz gas laser coupled to a reflective setup with variable incidence angle and incorporated in an electro-magnet.In this work we demonstrate a drastic improvement of this THz isolator by using a reflective THz time-domain spectrometer (Menlo systems), that is in-house customized with an external permanent magnet of 0.5T and a liquid nitrogen cooled substrate holder. At 77K our model predicts an improved quality factor for the InSb surface plasmon polariton due to the lower scattering losses and fully exploiting the high electron mobility typical of this semiconductor. As a result the nonreciprocal reflectivity near the InSb SPP resonances is drastically more pronounced. InSb gratings with 70μm period and varying depths between 5 and 9 μm have been fabricated using ebeam lithography and wet etching. The measured TM TDS reflectivity spectra under opposite magnetic fields exhibit THz isolation rejection up to 20dB, i.e. a 10dB improvement with respect to room temperature operation. Up to our knowledge this is the first report of competitive isolation for THz frequencies at an operation temperature that is fully compatible with typical THz QCL temperatures. Moreover the operating frequency of this compact isolator can be tuned by the geometric parameters of the grating and does not need any special coupling mechanisms (such as a prism) to excite the nonreciprocal surface plasmon polaritons.

17:00 **Subwavelength Fiber: Enhanced THz Magnetic Source** **Tu-P2-4-3**

Shaghik Atakaramians[1]; Ilya Shadrivov[2]; Andrey Miroshnichenko[3]; Alessio Stefani[4]; Heike Ebendorff-Heidepriem[5]; Tanya Monro[6]; Shahraam Afshar[6]
[1]UNSW Sydney, Australia; [2]Australian National University, Australia; [3]UNSW Canberra, Australia; [4]The University of Sydney, Australia; [5]The University of Adelaide, Australia; [6]University of South Australia, Australia

We experimentally demonstrate that an enhanced THz magnetic source can be achieved by placing a sub-wavelength fiber in front of a sub-wavelength aperture illuminated by a THz plane wave. This hybrid system can be considered as a unit cell of metasurfaces for THz wave manipulation and can also be scaled to optical frequencies opening up avenues for developing fiber based optical devices such as nanoantenna and laser.

17:15 **Ultra-Precise Processing And Maker Fringe Measurements Of Organic N-Benzyl-2-Methyl-4-Nitroaniline Crystal** **Tu-P2-4-4**

Takashi Notake; Masahiro Takeda; Takuya Hosobata; Yutaka Yamagata; Hiroaki Minamide
RIKEN, Japan

Accurate Maker fringe measurements of nonlinear optical coefficients for as-grown or cleaved organic crystals have been difficult ever. We applied an ultra-high-precision lathe and single crystalline diamond blade to process brittle organic crystals precisely to perform appropriate Maker fringe measurements. 2nd-order nonlinear optical coefficient and the associated wavelength-dispersion of organic BNA crystal can be measured properly by using the precisely processed parallel thin BNA plate samples.

17:30 **Influence Of Two-photon Absorption Anisotropy On Terahertz Generation In <111> Zinc Blende Crystals** **Tu-P2-4-5**

jean-louis COUTAZ; Federico Sanjuan; Gwenaël Gaborit
IMEP-LAHC, France

We report on an unexpected anisotropy of THz generation by optical rectification in <111> ZnTe crystal, which is due to the anisotropy of THz absorption by free carriers excited through two-photon absorption of the pump laser beam.

17:45 **[Keynote] Synchronized Plasma Wave Resonances In Ultrathin-membrane GaN Heterostructures** **Tu-P2-4-6**

Hugo Condori[1]; Ashish Chanana[1]; Jimy Encomendero[2]; Mingda Zhu[2]; Nicole Trometer[3]; Ajay Nahata[3]; Debdeep Jena[2]; Huili Grace Xing[2]; Berardi Sensale-Rodriguez[1]

[1]UNIVERSITY OF UTAH, United States; [2]Cornell University, United States; [3]University of Florida, United States

In this work we report on synchronized plasma wave resonances in ultrathin-membrane GaN heterostructures. In contrast to commonly employed grating-gate configurations, the analyzed structure contains periodically-patterned ohmic contacts to the two-dimensional electron gas (2DEG), which are laid-out parallel to the gate fingers. Our work demonstrates that the proposed approach allows: more efficient excitation of high order plasmon modes, and superior overall coupling, even in configurations having less number of devices per unit area.

18:30 - 20:00 **Tu-POS Poster Session** **Event Hall**

Session Type: Poster

18:30 **Paraffin Embedded Cancer Tissue 2D Terahertz Imaging And Machine Learning Analysis** **Tu-POS-01**

Yury Kistenev[1]; Alexey Borisov[1]; Anastasya Knyazkova[1]; Eleonora Ilyasova[1]; Ekaterina Sandykova[2]; Ludmila Spirina[3]; Alexey Gorbunov[3]

[1]Tomsk State University, Russian Federation; [2]Siberian State Medical University, Russian Federation; [3]Tomsk National Research Medical Center of the RAS, Russian Federation

Absorption spectra of paraffin-embedded prostate and adenocarcinoma cancer tissues and healthy tissues have been measured in the 0.3-3 THz range. Absorption were measured using of Time-domain THz spectrometer (EKSPLA, Estonia) with tuning range 0.3-3 THz. A spatial 2D absorption spectra scanning with averaging over scans at every spatial point (1024 scans) was carried out. The spatial step of scanning was varied from 0.1 mm to 1.0 mm. The Principal Component Analysis was applied to separate informative features in measured THz spectra. The Support Vector Machine classifier was created which allows to distinguish the tumor tissues from healthy tissues, including classification of prostate cancer tissue stage according to the Gleason scale.

18:30 **Simulations Of The Penetration Of 60-300 GHz Radiation Into The Human Ear** **Tu-POS-02**

Zoltan Vilagosh; Alireza Lajevardipour; Andrew Wood

Swinburne University of Technology, Australia

Human tissues have a high coefficient of absorption in the 60-300 GHz range. This focuses the study of human radiation exposure in this band on the skin and the cornea. The capacity of 60-300 GHz radiation to access the deeper parts of the ear has not been studied. Simulations show that up to 80% of the radiation that is presented parallel to the ear canal penetrates to 20mm into the canal at 90 GHz. At 300 GHz, the canal develops areas of up to 190% of the incident intensity. The structures of the outer ear are highly protective, reducing penetration to below 10% for radiation directed at a 450 angle. These findings have important implications for the design of devices emitting 60-300 GHz radiation.

18:30 **Nano-scale Infrared Imaging Of β-sheet Structures In Synaptic Junctions Of Primary Neuraons Isolated From Transgenic Mice.** **Tu-POS-03**

Anders Engdahl[1]; Oxana Klementieva[2]; Katarina Willen[3]; Gunnar Gouras[2]; Per Uvdal[4]; Raul Freitas[5]; Jeremie Mathurin[6]

[1]MAX IV laboratory, Lund University, Sweden; [2]Experimental Dementia Research Unit, Department of Experimental Medical Science, Lund University, Sweden; [3]1Experimental Dementia Research Unit, Department of Experimental Medical Science, Lund University, Sweden; [4]Chemical Physics, Chemical CenterLund University, Sweden; [5]4Brazilian Synchrotron Light Laboratory, CNPEM, Campinas, Brasil, Brazil; [6]Université Paris-Sud Laboratoire de Chimie Physique d'Orsay, France

Abstract--Aβ is a class of aggregation-prone proteins, which may misfold into stable, β-sheet rich fibrils. Aβ is linked to the development of synaptic pathology in Alzheimer's disease (AD). However, a main question in the AD field is how Aβ

contributes to AD neuropathology? Up to now there is little evidence for protein structural changes in diseased neuron. Our aim is to study the distribution of β-sheet structures in AD transgenic neurons in order to uncover sub-cellular mechanism(s) by which amyloid β-sheet structures are involved in AD pathology.I. INTRODUCTION.AÃŽÂ² is a class of aggregation-prone proteins, which may misfold into stable, ÃŽÂ²-sheet rich fibrils. AÃŽÂ² is linked to the development of synaptic pathology in Alzheimer's disease (AD). However, a main question in the AD field is how AÃŽÂ² contributes to AD neuropathology? Up to now there is little evidence for protein structural changes in diseased neuron. Our aim is to study the distribution of ÃŽÂ²-sheet structures in AD transgenic neurons in order to uncover sub-cellular mechanism(s) by which amyloid ÃŽÂ²-sheet structures are involved in AD pathology.II. RESULTSUsing synchrotron-based infrared micro-spectroscopy imaging we have studied the secondary structure of proteins in cultured neurons at the nanolevel. For the first time, the hyperspectral maps of protein structures in AD transgenic neurons were performed and ÃŽÂ²-sheet distribution in AD transgenic neurons with nano-scale spatial resolution (~ 40 nm) were mapped. The of ÃŽÂ²-sheet in AD transgenic cultured neurons expressing AD mutant APP compared to wild-type neurons, suggesting that the abnormal (ÃŽÂ²- sheet rich) protein structures distributed along the AD neurites

18:30 **Terahertz Spectroscopic Identification Of Ligusticum Chuanxiong Hort And Ligusticum Chuanxiong Hort. Cv. Fuxiong** **Tu-POS-04**

Jun Zhou[1]; Junhong Tian[1]; Lin Zhou[1]; Xiaoxiao Zheng[2]; Guihua Jiang[2]; Yuying Ma[2]
[1]University of Electronic Science and Technology of China, China; [2]Chengdu University of Traditional Chinese Medicine, China

In this work, 240 herbal medicine samples of Ligusticum chuanxiong Hort and Ligusticum chuanxiong Hort. cv. Fuxiong were measured by terahertz time-domain spectroscopy and analyzed by the sparse autoencoder and the LargeVis algorithm. The results show that the advanced algorithm used in this paper can get a classification accuracy rate of 100% with good visualization. This technology can be used to qualitatively identify similar herbal medicines.

18:30 **Device For Light-matter Interaction Enhancement In The Full THz Range For Precise Spectroscopy Of Small Volume Samples** **Tu-POS-05**

Romain Peretti[1]; Sergey Mitryukovskiy[2]; Flavie Braud[2]; Emilien Peytavit[3]; Emmanuel Dubois[2]; Jean-Francois Lampin[2]
[1]IEMN, CNRS, Univ. Lille, France; [2]CNRS IEMN, France; [3]IEMN CNRS, France

We designed, fabricated, characterized and performed the first experimental uses of a device assembling a waveguide and two antennas. The goal of our device is to confine the broadband pulse of a time-domain spectroscopy setup in the slot of the waveguide with the minimum losses and dispersion and with the thinnest slot. With this device, we aimed at analysis a bio sample of the volume below 200 µl.

18:30 **Towards Pathogenic Fungal Detection Using THz Metamaterial Biosensors** **Tu-POS-06**

Anna Katharina Wigger[1]; Deborah Amazu[1]; Andreas Neuberger[1]; Nadja Regner[2]; Nico Vieweg[2]; Patrick Leisching[2]; Peter Haring Bolívar[1]
[1]High Frequency and Quantum Electronics, University of Siegen, Germany; [2]TOPTICA Photonics AG, Germany

The rapid and early detection of pathogenic fungi with mortality rates up to 85 % is crucial in order to improve the therapeutic procedures. THz bioanalytical techniques are already proven as a promising tool for the detection of biomolecules. Here, we present THz measurements of penicillium on nanoporous substrates and propose a metamaterial based THz biosensor for early analysis of invasive fungal infections.

18:30 **Theoretical Modeling Of THz Heating Effects On The Cornea** **Tu-POS-07**

Wenquan Liu; Yuanfu Lu; Guangyuan Li; Guohua Jiao; Rongbin She; Jiancheng Lv
Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, China

Due to the abundance of water in the cornea and the high THz absorption coefficient of liquid water, THz beams will create heat under interaction with a given sample during an experiment. If the sample is not kept at a constant temperature, the increase in temperature could induce uncertainties in the extracted parameters or potential damage. Therefore, it is important to know how THz radiation might heat the corneal tissue, from both fundamental and practical point of view. To date, there is still little information available about THz heating effects on the corneal tissue in the literature. In this work, we present a theoretical model for the simulation of temperature distribution in the corneal tissue during THz heating and

consider the effect of different parameters such as the exposure time, the applied THz power level, the tear film thickness and corneal thickness.The temperature distribution in the tissue, which was obtained by solving the bio-heat equation, was calculated using FEM and the COMSOL commercial software was used for the computer simulations. The results show that the THz power level has a much significant effect on the temperature increase in the cornea while either the tear film thickness or corneal thickness couldn't have a significant effect. It indicates that about 30 min exposure of a 1 THz beam (the diameter of 5 mm and the power density of 5000 W/m2) could result in a temperature increase of over 60 degrees Celsius;. Thus, this highlights the need to take appropriate precautions. Besides, our model can also be generalized to study the THz heating effects on other biological object by choosing appropriate parameters.

18:30 **Complex Permittivity Calculation Of Tiny Biological Materials Using Cavity Perturbation Method At Millimeter Wave Frequency** **Tu-POS-08**

Jialu Ma; Jingchao Tang; Wenfei Bo; Yang Yang; Jin Xu; Baoqing Zeng; Yubin Gong
Vacuum Electronics National Laboratory,University of Electronic Science and Technology of China, China

A method for measuring dielectric parameters of high-loss tiny biological materials at millimeter-wave frequency are proposed. The real and imaginary parts of the high loss material dielectric parameters can be well calculated. With the utilization of Maxwell Garnett mixing equation for spherical particles, the CP of a single cell can be calculated by measuring the CP of the mixture.

18:30 **Modelling Neuronal Activity Alterations Caused By MMW-THz Mediated Melting Of Lipid Membrane** **Tu-POS-09**

Sergii Romanenko[1]; Peter H Siegel[2]; Livia Hool[1]; Alan R Harvey[1]; Vincent Wallace[1]
[1]The University of Western Australia, Australia; [2]California Institute of Technology, United States

Heating is the most obvious effect that exposure to millimeter-wave-to-terahertz (MMW-THz) radiation has on living tissue. It is expected that the resulting increase in temperature causes up-regulation of cellular mechanisms, e.g. increased rate of action potential (AP) generation. However, some studies have demonstrated the opposite. Here we show, using a simple computer model of a neuron, the passive cell parameters (affected by MMW exposure) that might be responsible for the suppression of action potentials (AP) even with temperature increases of as much as 10 °C.

18:30 **Spectroscopic Measurement Of Birefringent Materials By Simultaneous Acquisition Of Two-polarization State THz Pulse Responses** **Tu-POS-10**

Yoichi Kawada[1]; Katsumasa Yoshioka[2]; Yusuke Arashida[2]; Ikufumi Katayama[2]; Jun Takeda[2]; Hironori Takahashi[1]
[1]Hamamatsu Photonics K.K., Japan; [2]Yokohama National University, Japan

Measurement of optical-birefringent materials using THz waves is widely applied in several fields. The birefringent property in a THz regime has been observed in organic and inorganic crystals, expanded polymers, the orientation of fiber reinforced plastic, anisotropic metamaterials, and aligned protein samples. Changes in the polarization state due to the birefringent material can be easily detected because not only the amplitude but also the phase of the THz pulse can be measured using THz-time domain spectroscopy (TDS).In this study, we demonstrate a novel spectroscopic technique for acquiring optical parameters of birefringent materials: frequency-dependent, complex-refractive indices of an ordinary and extraordinary axis, and the direction of the optic axis. To obtain these five parameters, two responses to different polarization states of THz pulses are required. Several temporal sweeps are normally needed to measure the temporal waveforms of two different polarized THz pulses. However, we obtained two temporal waveforms of electric-field *vectors* using only a single temporal sweep.A femto-second (fs) laser pulse passes through a half-wave plate, a Pockels cell, and a quarter-wave plate in order and is converted into THz pulses by a ZnTe (111) crystal. The Pockels cell works as a transient quarter-wave plate when a rectangular high-voltage electric pulse is applied. In this configuration, orthogonal linearly polarized THz pulses are alternately generated. These THz pulses are converted into right-handed and left-handed circularly polarized THz pulses using a prism-shaped THz quarter-wave plate.Temporal waveforms of circularly polarized THz pulses were measured using THz electric field vectors while simultaneously measuring orthogonal electric fields of the THz pulses. We used a ZnTe (111) crystal for detection and probed the THz electric field using circularly polarized fs laser pulses.

The state of the THz electric-field vector was coverted to a change in the polarization state of the probe pulses. A rotating-polarizer technique, which is generally used in ellipsometry, was applied for analyzing the change in the probe pulses. To use the double lock-in scheme, we simultaneously obtained two temporal waveforms of THz electric-field vectors. We measured a sample of birefringent material and a quartz disc to test the validity of our technique. The expected results were obtained.

18:30 **Sub-mm Wave Transmission And Reflection Response In Low Dose Radiation Damaged Silicon** **Tu-POS-11**

Biswadev Roy[1]; Branko Pivac[2]; Branislav Vlahovic[1]; Marvin Wu[1]
[1]North Carolina Central University, United States; [2]Ruder Boskovic Institute, Croatia

Time-resolved millimeter wave conductivity (TRmmWC) experiment at various laser fluences is used to study p-doped crystalline silicon (100) that were irradiated with 3 dose of 1.2 MeV Co60 gamma, and 2 ion fluxes each of 2 MeV proton and 0.75 MeV chlorine beams respectively. These samples were used to produce transmission and reflection geometry responses. We report a systematic relationship between ratio of millimeter wave bulk transmitted transient peak to surface reflected transient peak and non-radiative recombination lifetimes with the total displacements (total vacancy) per ion calculated using Stopping and Range of Ions in Materials (SRIM). Frequency spectra of power reflectance and transmittance (d.c response of detector) of gamma irradiated silicon samples have also been discussed in some detail.

18:30 **THz Dynamics Of Hydrated Phospholipid Studied By Broadband Dielectric Spectroscopy** **Tu-POS-12**

Yu Kadomura[1]; Naoki Yamamoto[1]; Keisuke Tominaga[2]
[1]Graduate School of Science, Kobe University, Japan; [2]Molecular Photoscience Research Center, Kobe University, Japan

Cell membrane is mainly formed from self-assembled phospholipid bilayer. Phospholipid bilayer plays an important role in biochemical functions such as ion and molecule transportation. In addition, the functions are observed under certain temperature and hydration condition. Therefore, it is important to investigate effects of thermal excitation and hydration on dynamics of phospholipid bilayer in order to understand biological functions.Broadband dielectric spectroscopy (BDS) has been used for investigation of dynamics of materials because complex dielectric constant reflects microscopic properties such as intermolecular interactions and molecular motions. By this method, we can mainly investigate rotational relaxation modes, vibrational modes, and conductivity of the material.Recently, we reported BDS studies of lysozyme and purple membrane from the sub-GHz region to the THz region to show effects of hydration and thermal excitation on the low- frequency dynamics of proteins. In our previous work we found a fast relaxational mode in the THz region for hydrated lipid bilayer. However, details of this mode remains to be clarified. In this work we studied dynamics of DMPC in a broad frequency region including the THz region. We have performed broadband dielectric spectral measurements on 1,2-dimyristoyl-sn-glycero-3-phosphocholine (DMPC) to investigate dynamics of phospholipid bilayer in the THz frequency region. Measurements were performed with changing hydration level and temperature of the sample in the frequency region of 0.50 GHz to 2.0 THz. The spectra of the dehydrated sample (R = 3.4) do not have a relaxational mode and can be analyzed by 2 vibrational components. For the hydrated samples (R = 7.1, 7.9) 2 or 3 relaxational components were needed in addition to the vibrational components. The observed relaxational modes in the GHz region are slow and broad compared to that of liquid water. This suggests that the relaxational modes are caused by coupling of water with the lipid head-groups. One of the slow relaxational mode have an intensity in THz region, which is overlapped with the high-frequency underdamped vibrational modes. In addition, a fast relaxational mode was observed in sub-THz region as we reported before.

18:30 **Phase Transitions In SnSe Probed By Far Infrared Spectroscopy** **Tu-POS-13**

Ulrich Schade[1]; Ljiljana Puskar[2]; Matthias Berg[2]; Eglof Ritter[3]; Ilias Efthimiopoulos[4]; Augusto Marcelli[5]; Michele Ortolani[6]; Yong Liu[7]; Li-Dong Zhao[8]; Wei Xu[9]
[1]HZB/BESSY II, Germany; [2]Helmholtz-Zentrum Berlin für Materialien und Energie, Germany; [3]Humboldt-Universität zu Berlin, Experimentelle Biophysik, Germany;

[4]Deutsches GeoForschungsZentrum Potsdam, Germany; [5]INFN, Laboratori Nazionali di Frascati, and RICMASS, Rome International Center for Materials Science, Italy; [6]Universita di Roma La Sapienza, Dipartimento di Fisica, Italy; [7]AECC-Beijing Institute of Aeronautical Materials, China; [8]School of Materials Science and Engineering, Beihang University, China; [9]Institute of High Energy Physics, Chinese Academy of Sciences, China
SnSe exhibits a layered anisotropic crystal structure and was extensively investigated in the 60ies and 70ies on the quest of metal chalcogenide semiconductors for electronic and optoelectronic devices.Very recently an ultralow thermal conductivity and a surpassing high thermoelectric figure of merit were reported in SnSe which makes this material very attractive for electrical energy harvesting. In this paper we follow the evolution of the low-energy phonons with doping, temperature and pressure and compare the experimental results with ab initio calculations to help understanding better the low thermal conductivity in SnSe and may provide a route for developing highly efficient thermoelectrical materials.

18:30 **Terahertz Optical Transmission Of Charged Ge/Si Quantum Dots** **Tu-POS-14**

Dmitry Firsov[1]; Roman Balagula[1]; Anton Sofronov[1]; Leonid Vorobjev[1]; Alexander Tonkikh[2]; David Hayrapetyan[3]; Hayk Sarkisyan[3]; Eduard Kazaryan[3]
[1]Peter the Great Saint Petersburg Polytechnic University, Russian Federation; [2]OSRAM Opto Semiconductors GmbH, Regensburg, 93055 Germany, Germany; [3]Russian-Armenian University, Yerevan, 0051 Armenia, Armenia
Terahertz optical transmission of doped Ge/Si quantum dots has been studied. The absence of the lowest interlevel transition energy dependence on the number of holes in the quantum dot is experimentally observed and explained theoretically. Specific geometry of the studied quantum dots allows the implementation of the adiabatic confining potential and, as a result, proves the applicability of the generalized Kohn theorem to such quantum dot systems.

18:30 **Giant Thermal Effect Of Vibration Modes Of Single-Crystalline Alanine** **Tu-POS-15**

Zenjiro Mita; Hiroshi Watanabe; Shin-ichi Kimura
Osaka University, Japan
Amino acids are the most basic molecules of living bodies. The temperature dependence of the polarized optical conductivity [σ(ω)] spectrum of single-crystalline L-alanine, which has the simplest molecular structure among amino acids having chirality, has been measured in the photon energy region of 1 meV -- 30 eV. The polarized σ(ω) spectra suggest the strong anisotropy of vibration modes owing to the strong anisotropic crystal structure. Peaks of these vibration modes have been observed to show extremely strong temperature dependence. The thermal effect can be explained by a temperature-dependent anharmonic potential model.

18:30 **Optical Parameter Extraction Of Plastic Materials Based On THz-TDS** **Tu-POS-16**

Dandan Zhang[1]; Jiaojiao Ren[1]; Lijuan Li[1]; Qingmao Zhang[2]; Yiming Zhang[2]; Ping Huang[2]
[1]Changchun University of Science and Technology, China; [2]Chengdu Aircraft Design & research Institute, China
This paper has proposed a high-precision extraction technology for the optical parameters of engineering plastics materials by taking use of terahertz time domain spectroscopy system. We choose parallel plates of different plastic materials as the experimental samples. We use the transmission-type terahertz time domain spectroscopy system to detect the refractive index, extinction coefficient and other optical parameters on the plastic material. Firstly, we acquire the measurement waveform of terahertz signal passing through plastic material samples. Then we analyze the terahertz waveform of the sampling points through time domain and frequency domain, obtain the corresponding frequency spectral information by Fourier transform, then corresponding amplitude and phase information of the waveform can be calculated. Finally, we get the curve of the refractive index and extinction coefficient about the plastic material depending on the simplex optimization method in the frequency range of 0.1~1.3 THz, through analyzing the optical parameter extraction model.In the experimental results, the optimized refractive index and extinction coefficient of the samples are more close to the theoretical values, and the extraction error is between positive and negative 0.01 which has improved the accuracy of the extracted optical parameters. The

experimental result shows that the extraction technology of optical parameter based on terahertz time-domain spectroscopy can help to extract the optical parameters of engineering plastics, the technology has higher extraction accuracy according to the optical parameters extracted we can know the defects of the material through analyzing the terahertz time-domain and frequency-domain imaging, which is of significance for the research of terahertz nondestructive testing of engineering plastics.

18:30 **Temperature And Substrate Dependent Conductivities Of CVD Graphene Measured By Terahertz Time-Domain Spectroscopy** **Tu-POS-17**

Iwao Kawayama[1]; Shohei Ohashi[1]; Shohei Kameo[1]; Filchito Bagsican[1]; Manjakavahoaka Razanoelina[1]; Hironaru Murakami[1]; Junichiro Kono[2]; Robert Vajtai[2]; Pulickel Ajayan[2]; Masayoshi Tonouchi[1]
[1]Osaka University, Japan; [2]Rice University, United States

Graphene has recently attracted a substantial amount of attention because of its excellent electrical properties such as very high carrier mobility compared with conventional semiconductors [1-3]. The electrical and optical properties of graphene are susceptible to its environment, such as adsorbed molecules, temperatures and substrates that support graphene [4, 5]. Terahertz time-domain spectroscopy (THz-TDS) is a powerful tool that is able to characterize the free carrier response of graphene and can in particular probe intra-band transition of excited carriers of graphene with sub-ps time resolution. However, there haven't been any systematic studies regarding temperature and substrate dependence of carrier responses in graphene with THz-TDS. In this study, we measured the temperature dependence of the THz conductivity of graphene prepared on Si, SiO2 and MgO substrates in a wide temperature range between 80K and 600 K using THz-TDS. We found that the THz conductivity of graphene shows qualitatively different behaviors depending on the substrate, in particular above room temperature. The result indicates that the conductivity change of graphene on Si and SiO2 can be mainly explained by desorption of oxygen molecules, however, a carrier doping effect by substrates should be considered in case that MgO is used as a substrate.

18:30 **Spectroscopy Of Temperature-driven Single Valley Dirac Fermions In HgTe/CdHgTe Quantum Wells** **Tu-POS-18**

Aleksandr Kadykov[1]; Sergey Krishtopenko[2]; Benoit Jouault[2]; Wilfried Desrat[2]; Michal Marcinkiewicz[2]; Sandra Ruffenach[2]; Christophe Consejo[2]; Jeremie Torres[3]; Sergey Morozov[1]; Vladimir Gavrilenko[1]; Nikolay Mikhailov[4]; Sergey Dvoretckii[4]; Wojciech Knap[2]; Frederic Teppe[2]
[1]Institute for Physics of Microstructures RAS, Russian Federation; [2]Laboratoire Charles Coulomb UMR 5221 CNRS-UM, France; [3]Institut d'Electronique et des Systemes, UMR 5214 CNRS, France; [4]A.V.Rzhanov Institute of Semiconductor Physics, Siberian Branch of RAS, Russian Federation

We report on the temperature-dependent magnetoabsorption and magnetotransport spectroscopy of HgTe/CdHgTe quantum wells above the critical well thickness dc. Our results, obtained in magnetic fields up to 16 T and temperature range from 1.7 to 150 K, clearly indicate a change in the band-gap energy with temperature. A topological phase transition between quantum spin Hall and trivial insulator states, revealing appearance of single-valley Dirac fermions at T = 27 and 90 K for 6.5 and 8 nm QWs respectively, was clearly observed in our magnetospectroscopy measurements.

18:30 **Ferromagnetic Resonance In Hexagonal Ferrite BaFe12O19 At The EHF Frequency Range** **Tu-POS-19**

Alexander Badin; Grigorii Kuleshov; Kirill Dorozhkin; Grigorii Dunaevskii; Valentin Suslyaev; Victor Zhuravlev; Kirill Bilinskii
National Research Tomsk state University, Russian Federation

Due to the large values of the magnetocrystalline anisotropy fields (Ha) and the saturation magnetization the hexaferrite with M-type crystal structure BaFe12O19 (Ba-M) are widely used as permanent magnets and radar-absorbing materials. Maximum absorbance of these compounds is observed within the range of natural ferromagnetic resonance (NFMR) which is defined by a magnitude of anisotropy field and size/shape of ferrimagnetic powders grains. According to Refs. the NFMR frequency of the polycrystalline Ba-M sample is close to 47 GHz. Thus, this material is promising for the development of radar-absorbing materials and coatings for the millimeter wavelength range. The five samples of the composite based on epoxy

resin with different content of Ba-M powders in the form of plane-parallel polished plate 1.13-1.21 mm thick was prepared for researches. The particle sizes were from 90 to 160 μm. The concentration of Ba-M powders in the composites was 15, 30, 45, 60 and 75 mass. %. Researches of electromagnetic response of the samples were carried out by use quasioptical Mach-Zehnder interferometer at room temperature.Analysis of the frequency dependences of the transmission coefficients in the frequency range of 34 - 250 GHz showed the presence of the absorption region with a maximum at the frequency ~52 GHz (Figure 1). Approximation of the transmission index with permeability μ calculated by model of ferromagnetic resonance with parameters from Table 1 shows agreement with the measured results. The increasing of concentration of BaFe12O19 in the composite increases saturation magnetization and permeability at the resonant frequency at room temperature.Thus, in this study we observed and studied resonant absorption region near the frequency of 50 GHz, which is well described by magnetic resonance model. The estimations of the NFMR parameters were performed.

18:30 **Understanding The Formation Of Midgap States In GaAs(001)--β2(2x4) With Surface Defects Based On Density Functional Theory** **Tu-POS-20**

Dhonny Bacuyag[1]; Mary Clare Escaño[2]; Melanie David[1]; Masahiko Tani[3]
[1]Physics Department, De La Salle University, Philippines; [2]Department of Applied Physics, University of Fukui, Japan; [3]Research Center for Development of Far-Infrared Region, University of Fukui, Japan

Understanding the defect feature of GaAs(001) in the formation of midgap state is significant in gaining new insights for its applications in efficient photoconductive detection and emission in terahertz (THz) technology. In this work, we investigate the role of surface point defects in the structural and electronic properties of GaAs(001)--β(2x4) based on density functional theory (DFT). Midgap states were found even on surfaces with high formation energies relative to the clean surface as seen in their band structures. The formation of these states is attributed to the redistribution of charges and supports the observed two-step photon absorption in experiments.

18:30 **Quantitative Impurity Measurement In Organic Crystals By Precise Measurements Of THz Absorption Frequencies** **Tu-POS-21**

Tetsuo Sasaki[1]; Tomoaki Sakamoto[2]; Makoto Otsuka[3]
[1]Shizuoka University, Japan; [2]National Institute of Health Sciences, Japan; [3]Musashino University, Japan

We have developed a novel technique for quantitative detection of impurity in organic crystal by precise measurements of THz absorption peak frequencies. By using high accurate, high resolution GaP CW THz spectrometer and measuring the sample at low temperature, the highest sensitivity of 4.51 GHz / % and the minimum detection limit of impurity as low as 50 ppm could be obtained.

18:30 **Terahertz Time-Domain Spectroscopy And Low-Frequency Raman Scattering Of Boson Peak Dynamics Of Lithium Borate Glasses** **Tu-POS-22**

Yuta Iijima[1]; Tatsuya Mori[1]; Yasuhiro Fujii[2]; Akitoshi Koreeda[2]; Suguru Kitani[3]; Hitoshi Kawaji[3]; Jae-Hyeon Ko[4]; Seiji Kojima[1]
[1]Division of Materials Science, University of Tsukuba, Japan; [2]Department of Physical Sciences, Ritsumeikan University, Japan; [3]Materials and Structures Laboratory, Tokyo Institute of Technology, Japan; [4]Department of Physics, Hallym University, Korea, Republic of

We performed terahertz time-domain spectroscopy and low-frequency Raman scattering on lithium borate glasses, to detect universal boson peak behavior in glassy materials. In addition, the vibrational density of states spectrum was extracted from the data of low-temperature specific heat measurement. The light-vibration coupling coefficients of infrared and Raman were determined and quantitative analysis has been performed.

18:30 **Intrinsic Losses In Dielectrics Investigated By Terahertz Spectroscopy** **Tu-POS-23**

Liviu Nedelcu[1]; Cezar Dragos Geambasu[1]; Marian Gabriel Banciu[1]; George Mogîldea[2]; Marian Mogîldea[2]
[1]National Institute of Materials Physics, Romania; [2]Istitute of Space Science, Romania

Low-loss dielectrics with various microstructure and, consequently, different extrinsic losses were investigated by using terahertz time-domain spectroscopy. The losses have been extrapolated and compared with those measured at microwave

frequencies. The results showed that extrinsic factors have a considerably contribution in microwave domain. The intrinsic limit of dielectric loss of low absorption polycrystalline materials have been estimated by terahertz spectroscopy.

18:30 **Boson Peak Detection Of Colored Craft Glass By Terahertz Time-Domain Spectroscopy** **Tu-POS-24**

Wataru Yajima[1]; Tatsuya Mori[1]; Yuta Iijima[1]; Yeonkyung Jeong[1]; Seiji Nijima[2]; Yasuhiro Fujii[3]; Akitoshi Koreeda[3]; Seiji Kojima[1]
[1]University of Tsukuba, Japan; [2]Mie Prefecture Industrial Research Institute, Japan; [3]Ritsumeikan University, Japan

We performed terahertz time-domain spectroscopy (THz-TDS) on two color soda lime glass samples. One sample is transparent and the other sample is black. In addition, terahertz imaging was performed on the two-color integrated glass. It was found that the metallic element added to the black glass did not affect the terahertz light absorption. From the spectrum of the glass obtained by THz-TDS, a peak called boson peak appears in a/v^2 spectrum, where a is absorption coefficient. This result shows that THz-TDS is suitable for observing the boson peak of colored glasses.

18:30 **Generation Of Terahertz Vortex Waves In Resonant-Tunneling-Diode Oscillators By Integrated Radial Line Slot Antenna** **Tu-POS-25**

Yunchao Chen; Safumi Suzuki; Masahiro Asada
Tokyo Institute of Technology, Japan

We have proposed and fabricated a resonant- tunneling-diode (RTD) THz oscillator that generates a vortex wave. The RTD is integrated in the cross slot on the substrate, and a radial line slot antenna (RLSA) is spirally placed around the RTD. The output of RTD is incident from the cross slot into the substrate, and emitted from the RLSA as a vortex wave. In the measured radiation pattern of the fabricated oscillator, a dip of the output intensity was observed on the central axis, which is a feature of the vortex wave.

18:30 **A Multi-Carrier Signals Generation Based On DPMZM In Parallel For THz Communication System** **Tu-POS-26**

Wei Jiang[1]; Shanghong Zhao[2]; Qinggui Tan[1]; XiaoJun Li[1]; Dong Liang[1]; Wenrui Zhang[3]
[1]National Key Laboratory of Science and Technology on Space Microwave, China; [2]Air Force Engineering University, China; [3]School of Physics and Optoelectronic Engineering, Xidian University, China

In this paper, a multi-carrier THz signals generation scheme is proposed and demonstrated. The scheme is based on DPMZM (dual-parallel Mach-Zehnder modulator) in parallel and recirculating frequency shifter (RFS). By optimizing all the sub-modulators embedded in the RFS, the multi-carrier signals with double frequency interval are generated. A theoretical analysis and simulation experiment is developed, the scheme can generate 20 carriers with 0.1THz frequency interval, and the side-mode suppression ratio (SMSR) is over 25dB.

18:30 **THz Generation Of DSTMS-DASC Mixed Crystals** **Tu-POS-27**

Koichiro Akiyama; Yoichi Kawada; Takashi Yasuda; Atsushi Nakanishi; Hiroshi Satozono; Hironori Takahashi
Hamamatsu Photonics K.K., Japan

We report novel organic mixed crystals composed of DSTMS and DASC. The THz spectra generated from the mixed crystals showed that absorption around 1 THz was very low compared to that of DAST derivatives. Moreover, the THz spectrum range and the intensity were as well as that of DAST. Thus, the mixed crystals could be better suited as a source of broadband and high power THz generation.

18:30 **Periodic Terahertz-Wave Generation Using A Photoconductive Antenna Array In A Rectangular Metal Waveguide** **Tu-POS-28**

Motoki Bssho; Ryosuke Ito; Jongsuck Bae
Department of Physical Science and Engineering, Nagoya Institute of Technology, Japan

Periodic terahertz waves have been successfully generated using a photoconductive dipole-antenna array with a pitch of 0.16 mm in a rectangular metal waveguide at frequencies between 0.24THz and 0.68THz.

18:30 **High-Power MM-Wave Sources Based On Schottky Diodes** **Tu-POS-29**

Oleg Cojocari; Diego Moro-Melgar; Ion Oprea; Matthias Hoefle; Martin Rickes
ACST GmbH, Germany

A novel approach has been developed at ACST for monolithic integration of Diamond heatspreader with Schottky diodes. This approach allows a very efficient heat dissipation from hot area of the diode structure and allows to increase power-handling capability by several times in comparison to traditional diodes on GaAs-substrate. Experimental results demonstrate feasibility of state-of-the-art conversion efficiency of ACST varactor diodes in combination with high power-handling capability. As a result, up to 180mW and up to 40mW peak output power has been demonstrated at 150GHz and at 300GHz, respectively, from a single-chip multiplier (not power combined). Further characterization is on-going

18:30 **Coherent, Focused, And Threshold-less Cherenkov Radiation From Two-dimensional Sub-wavelength Hole Arrays** **Tu-POS-30**

Yucheng Liu; Weihao Liu; Linbo Liang; Qika Jia; Lin Wang; Yalin Lu
National Synchrotron Radiation Laboratory, China

The threshold-less Cherenkov radiation (CR) is quite attractive due to its low-cost and compactibility. Here we proposed a new way to generate the coherent and threshold-less CR by using a sheet free-electron beam (FEB) to drive an oblique-lined sub-wavelength hole array (SHA). By periodically repeating the oblique-lined SHAs in the beam-moving direction, we could get a unique two-dimensional SHA, from which the Smith-Purcell radiation (SPR) can also be generated. The CR, combined with SPR, will become a focused directional coherent radiation with highly enhanced intensity.

18:30 **On-Chip Terahertz Near-Field Generation/Detection Scheme** **Tu-POS-31**

Dmitry S. Bulgarevich[1]; Yusuke Akamine[1]; Hideaki Kitahara[1]; Valynn Katrine Magusara[1]; Hiroyuki Kato[1]; Masahiro Kusano[2]; Dongfeng He[2]; Masahiko Tani[1]; Makoto Watanabe[2]
[1]Research Center for Development of Far-Infrared Region, University of Fukui (FIR-UF), Japan; [2]National Institute for Materials Science (NIMS), Japan

The semiconductors are commonly used in various emitter and detector modules for terahertz time-domain spectroscopy (THz-TDS) by excitation of their surfaces with sub-picosecond optical pump/probe pulses and consequent generation of transient photocurrents due to optical transitions or/and optical rectification. In studies of corresponding carrier dynamics for semiconductor optimizations, the typical experimental THz-TDS setups employ the far-field THz propagation/detection schemes with bulky THz optics. For example, the Optical Pump THz Probe, Optical Pump Rectification Emission, and Double Optical Pump THz Emission are among such techniques. Here, we demonstrate that THz generation and detection could be also done without any THz optics by using just a sandwiched semiconductor chip, which consists of THz emitter/detector layers. The THz waves are generated and detected in near-field at the emitter/detector interface with pump/probe fs-laser beams. This simple optical setup could find application in some of the above-mentioned schemes and as a magneto-optical sensor with spatial resolution limited by focusing optics.

18:30 **Enhanced Terahertz Radiation From GaSb/InAs Heterostructures** **Tu-POS-32**

Shigehiko Sasa[1]; Masashi Tatsumi[1]; Yohei Kinoshita[1]; Masatoshi Koyama[1]; Toshihiko Maemoto[1]; Iwao Kawayama[2]; Masayoshi Tonouchi[2]
[1]Osaka Institute of Technology, Japan; [2]Osaka University, Japan

Hot electron injection utilizing a GaSb/InAs heterostructure was studied for enhancing terahertz radiation from a semiconductor surface. A 1-nm-thick InAs surface layer was introduced to alleviate the surface band bending due to the Fermi level pinning at the surface. As a result, a stronger THz emission compared to an InAs thin film was obtained. The result indicates that the use of InAs/GaSb/InAs heterostructures is effective for the enhanced electron diffusion, thus the enhanced THz radiation.

18:30 **Optimization Of OH1 Single-Crystalline Thin Film For Effective THz Source By Physical Vapor Deposition** **Tu-POS-33**

Peibin Wang[1]; Hirohisa Uchida[2]; Kei Takeya[3]; Kodo Kawase[3]
[1]Nagoya University, China; [2]ARKRAY Inc, Japan; [3]Nagoya University, Japan

The most important condition for crystal growth is to keep the temperature inside the furnace in the range of 130 ℃ to 135 ℃, which is the best temperature range for encouraging crystal growth. The configuration investigated in this study yields clear thin-film OH1 crystals with long c-axial extensions.

18:30 **Intense THz Source Of Sub-cycle Pulses With Tunable Elliptical Polarization** **Tu-POS-34**

Xavier Ropagnol[1]; Xin Chai[1]; Mohsen Raeiszadeh[2]; Safiedin Safavi-Naeini[2]; matt reid[3]; Tsuneyuki Ozaki[1]
[1]INRS-EMT, Canada; [2]university of Waterloo, Canada; [3]UNBC, Canada
We propose a new THz source based on a large aperture photoconductive antenna for the generation of intense THz waves with tunable elliptical polarization. We designed an interdigitated structure with vertical and horizontal electrodes to produce half-cycle THz pulses with horizontal and vertical polarizations, respectively. A time delay between the two polarizations is introduced using a quartz window deposited onto the parts of the antenna with horizontal electrodes forming a phase mask. We demonstrate the generation of sub-cycle THz pulses with tunable elliptical polarization and a 70 kV/cm electric field. We show that the polarization state can be varied from linear to quasi-circular.

18:30 **Image Enhancement Algorithm Of Terahertz Images Based On Quantum Probability Statistics** **Tu-POS-35**

Zhongbo Zhu; XiaoJun Li; Qinggui Tan; Wei Jiang; Dong Liang
National Key Laboratory of Science and Technology on Space Microwave, China
THz imaging has been progressed significantly and has huge potential applications in many research fields. In this paper, an image enhancement algorithm which based on quantum probability theory is employed to enhance the contrast and get the better profile of THz image. The experimental results are analyzed and discussed. The results show that the proposed method integrate both global and local features and improve images quality effectively. The method can effectively suppress the image noise while preserved the object structures well.

18:30 **An Improved Post-Processing Method For Three-Dimensional Visualization In Terahertz Pulse-Echo Imaging** **Tu-POS-36**

Hiroshi Hanaizumi
Hosei University, Japan
Based on the fact that polarity of the echo depended on types of dielectric discontinuity, we proposed an improved method of the previous post-processing method for 3-D visualization for terahertz pulse-echo imaging (3D TPEI). The proposed method enabled us to recognize the dielectric property of boundaries inside an object via detecting polarity of the echo.

18:30 **Total Internal Reflection THz Devices For High Speed Imaging** **Tu-POS-37**

Rayko Stantchev; Thierry Blue; Emma Pickwell-Macpherson
Chinese Univerisity of Hong Kong, Hong Kong
Electron-hole pair photoexcitation switches a semiconductor's response from dielectric to conducting. We show that this process is most efficient in a total internal reflection (TIR) geometry allowing the use of cheaper, less powerful light sources. Further, by employing a digital micromirror device to spatially pattern the photoexcitation area, we perform imaging with single-element detector and present solutions to the optical problems of imaging in this geometry. We finally show that by taking into account the carrier lifetimes in the signal processing one can improve the acquisition rate by a factor 5.

18:30 **A Novel THz Azimuth Imaging Algorithm Based On MIMO Arc Array** **Tu-POS-38**

Shiyou Wu; Chao Li; Guangyou Fang
Institute of Electronics,Chinese Academy of Sciences, China
A novel azimuth imaging algorithm based on the terahertz single frequency MIMO arc array is proposed. The MIMO arc array is transformed to the MIMO linear array equivalently, based on which the arc array azimuth image reconstruction is designed and realized by using the proposed terahertz single frequency azimuth imaging algorithm based on the RMA algorithm.

18:30 **Terahertz Coded-Aperture Imaging Based On Clustered Sparsity Bayesian Learning** **Tu-POS-39**

Shuo Chen; Chenggao Luo; Hongqiang Wang; Bin Deng; Yuliang Qin; Qi Yang
National University of Defense Technology, China
Terahertz coded-aperture imaging (TCAI) can achieve high-resolution, forward-looking and staring imaging by producing spatiotemporal independent signals in the imaging area. Common Compressive Sensing (CS) algorithms are efficient in the sparsity-driven target imaging, whereas it becomes invalid for clustered sparsity target. Thus, we deduce a clustered sparsity Bayesian learning (CluSBL) method for

this kind of TCAI. In this paper, we build the Bayesian structure and deduce the basic imaging process. Moreover, the advantages of CluSBL are verified by numerical simulations. This technology can be applied in areas such as terminal guidance, security check, etc.

18:30 **A High Sensitivity Terahertz Imaging System Based On Compressed Sensing** **Tu-POS-40**

Yilong Zhang; Wei Miao; Gao Hao; Jie Hu; Shengcai Shi
Purple Mountain Observatory, Chinese Academy of Sciences, China
Terahertz superconducting detector has high sensitivity but it's difficult to achieve high-efficiency for large-scale observation with a single detector. To fully improve efficiency and resolution, a high sensitivity terahertz imaging system designed using compressive sensing (CS) principles was proposed in this paper, which uses a single superconducting detector replacing complex and high-cost array detector. With a random selection from linear encoded masks, the proposed imaging system acquired incoherent measurements using a 0.85THz superconducting detector. A regularized â""1-norm reconstruction method was employed to reconstruct the imaged scene with fewer measurements compared to the size of the image. Experimental results demonstrated that the proposed imaging system could achieve the improvement of imaging efficiency and resolution.

18:30 **Parameter Estimation Of The Precessing Targets With A Wideband Terahertz Radar** **Tu-POS-41**

Qi Yang; Bin Deng; Hongqiang Wang; Yuliang Qin; Chenggao Luo
College of Electronic Science and Engineering, National University of Defense Technology, China
Aiming at the high precision parameter estimation of precessing target in military applications, a method based on geometric solution of the high resolution ISAR image sequence was proposed in this paper. The main concept of the method is searching for the underlying geometric relations during precession and taking full advantages high resolution ISAR image sequence. The feasibility and precision of the method was verified by the experiment with a 0.32 THz wideband radar system, and the estimation error was within 5% in our experiments. The method laid the foundations for the military applications of terahertz radar systems.

18:30 **Passive Terahertz Light Field Imaging With Microbolometer-based Camera System** **Tu-POS-42**

Nanfang Lyu; Cunlin Zhang
Capital Normal University, China
Light field imaging is a novel computational imaging method which is widely used in visible band. In this article, we introduce the light field imaging method into terahertz waveband. We analyzed the factors of noise for an microbolometer-based terahertz array detectors, and established an passive terahertz light field imaging system based on single-camera raster-scan configuration. By reconstruction of acquired 4D light field information from the sample, and the pre-processing of the original images based on fixed-pattern noise extraction, we significantly increased the SNR of the passive terahertz images.

18:30 **Lightening Strategies For Large-Field 2D And 3D Terahertz Imaging** **Tu-POS-43**

Jean Baptiste Perraud[1]; Maher Hamdi[2]; Olivier Redon[2]; Jérémy Lalanne-Dera[2]; Jean-Paul Guillet[1]; Jérôme Meilhan[3]; François Simoens[3]; Patrick Mounaix[1]
[1]IMS - Université de Bordeaux, France; [2]CEATech Nouvelle Aquitaine, France; [3]CEA LETI, France
Large field THz imaging requires an appropriate treatment of the coherent radiation to exploit its unique properties. This study proposes two strategies to eliminate classical ring interferences polluting the images. The first relies on mechanically breaking the spatial coherence of the radiation waves using a low-cost and compact system, while the second uses a commercial galvanometer. The two systems allow both high quality and fast imaging compatible with industrial use and 3D terahertz tomographic reconstruction.

18:30 **Application Of Cepstrum Filtering In THz Imaging Through Scattering Media** **Tu-POS-44**

Omar Osman; Arjun Virk; Hassan Arbab
Stony Brook University, United States
In this study, we discuss the application of a cepstrum-based signal processing technique to reduce the effect of volume and rough surface scattering. The filter is

applied to images of pellets of large and small polyethylene particles. Results show improved signal-to-noise in higher frequencies after applying the filter.

18:30 **Study Of The Point Spread Function Of Multi-Circular Synthetic Aperture Imaging At Terahertz Frequencies** **Tu-POS-45**

Yanwen Jiang; Hongqiang Wang; Bin Deng; Yuliang Qin; Chenggao Luo; Zhaowen Zhuang
National University of Defense Technology, China

A novel terahertz (THz) three-dimensional (3D) imaging scheme based on the multi-circular synthetic aperture is studied in this paper. The integral sidelobe ratio and the imaging resolution is discussed as a function of the signal bandwidth, the number of circular path. The simulated point spread function demonstrates the 3D imaging capability of the novel imaging scheme. The multi-circular synthetic aperture based on array technique can significantly improve the imaging performance.

18:30 **Transmission-type Dual-band Terahertz-waves Coder** **Tu-POS-46**

Shan Yin
Guilin University of Electronic Technology, China

We design a transmission-type dual-band terahertz-waves coder based on a plasmonic device. Utilizing the anisotropy of the plasmonic device and the modulation of the lattice mode, we demonstrate the dual-band binary coding at terahertz frequencies via changing the angle of the coder. without affecting the path of the terahertz beam or altering the structures of the devices, the transmission-type dual-band terahertz-waves coder is practical in terahertz time domain spectroscopy, which is meaningful to promote the application of terahertz communications.

18:30 **Characterize Epoxy-Silver Nanoparticles Composite In Microwave And Millimeter-wave Regime** **Tu-POS-47**

SHIH-CHIEH SU
National Tsing Hua University, Taiwan

We characterize the permittivity and permeability of Epoxy-Silver nanoparticle composites with board frequency band from microwave to millimeter-wave regime. Measured permittivity and permeability have different trend along the volume fraction, and also strong diamagnetism. The effective permittivity of Silver nanoparticles is extracted using the effective medium theory, while the effective permeability of silver nanoparticles is obtained by the scattering method.

18:30 **Terahertz Multispectral Imaging By Thermo-conversion Using MIM Antenna** **Tu-POS-48**

Arthur Salmon[1]; Patrick Bouchon[1]; Sylvain Rommeluère[1]; Pierre Fauché[2]; Jean-Pascal Caumes[2]; Riad Haidar[1]
[1]ONERA, France; [2]Nethis, France

Conversion of terahertz radiation into thermal radiation is a promising approach for terahertz detection by standard IR cameras. However optimizing the efficiency of conversion is still a major issue. In this work, a conversion membrane composed of printed MIM antenna is designed to fully absorb the terahertz radiation at a resonance wavelength. This feature is advantageous for multispectral imaging in the terahertz range.

18:30 **Linear To Circular Polarization Conversion Of Terahertzwave Using Metallic Helix Array** **Tu-POS-49**

Kento Kinumura[1]; Shun Takagi[1]; Norihisa Hiromoto[1]; Kodo Kawase[2]; Saroj Tripathi[1]
[1]Shizuoka University, Japan; [2]Nagoya University, Japan

We developed a 2D array of 3D metallic helix whichconverts linearly polarized THz wave into circularly polarizedTHz wave and acts as a broadband THz wave polarizer. It coversthe frequency range from 140 GHz to 250 GHz, close to one octave.We made two different arrays which consist of left-handed andright-handed metallic helices and we confirmed that these arrayschange the linearly polarized THz wave into right-hand and lefthandcircularly polarized THz wave respectively.

18:30 **THz Gas Detection Using Cellulose Nanoporous Foam Enhanced Meta Structure** **Tu-POS-50**

Wei-Chih Wang[1]; Yen-Tse cheng[2]
[1]University of Washington, United States; [2]National Tsinghua University, Taiwan

We present the design and fabrication of a novel resonator-type gas sensor. The implantation of cellulose nanoporous foam on a meta structure to further improve its sensitivity is the key to the design. The sensor is based on resonance shift and

attenuation due to the adsorption of gas in the cellulose matrix. Utilizing rapid freeze drying, the high porosity of nanoporse cellulose foam can be fabricated.

18:30 **Efficient Waveguide Mode Conversions Based On Phase-Gradient Metasurfaces** **Tu-POS-51**

Tie-Jun Huang; Jiang-Yu Liu; Li-Zheng Yin; Feng-Yuan Han; Pu-Kun Liu
Peking University, China

Based on phased-gradient metasurfaces, an efficient method is developed to convert waveguide modes in a parallel-plate waveguide. An effective wavevector is imparted to the incident mode at each interaction with matesurfaces, resulting in the mode conversion. The numerical simulation indicates that the efficiency and purity of TE1-to-TE2 conversion can significantly reach up to 99.98% and 99.99% at 9GHz. The conversion between TM3 and TM4 is also achieved, which gives a fair verification of the polarization insensitivity. This work can provide technical guidance for compact modes control.

18:30 **Terahertz Modulation Through Thermal Expansion Of Nanogaps** **Tu-POS-52**

Hyeong Seok Yun; Jeeyoon Jeong; Dasom Kim; Dai-Sik Kim
Seoul National University, Korea, Republic of

We present a new way for the thermal modulation of terahertz wave through 5nm wide nanogaps by means of the thermal expansion. Resonance amplitude is decreased by 20% and the resonance frequency is red-shifted from 0.45THz to 0.35THz, which is similar to the resonance features of terahertz wave through nanogaps with smaller gap width. The modulation under temperature changes results from the thermal expansion and the extreme width-to-length ratio of the nanogaps resonant at terahertz frequency can compensate the small thermal expansion coefficient, enabling the width of the nanogap to be changed. COMSOL simulation and coupled-mode method calculation confirm the effect of the thermal expansion on the nanostructures.

18:30 **Terahertz Asymmetric Coplanar Waveguide Filter** **Tu-POS-53**

Han Sun; Han Sun
Terahertz Science Cooperative Innovation Center, China

Abstract--A coplanar waveguide (CPW) filter with asymmetric SRR(split ring resonator) is designed to reduce the loss of terahertz wave in space and solve the alignment problem. This device realized a terahertz band stop filter of 280GHz - 310GHz. This structure has a well on-off characteristics in a wide frequency band can completely block the transmission of terahertz wave, and the insertion loss is relatively small. This device has potential in terahertz communication, imaging and sensing

18:30 **An On-chip Integrated Structure For Terahertz Band Stop Filter/absorber Based On Reflection Wave Cancellation** **Tu-POS-54**

ting zhang[1]; Ziqiang Yang[1]; Yaxin Zhang[1]; Shixiong Liang[2]; Zongjun Shi[1]
[1]University of Electronic Science and Technology of China, China; [2]Hebei Semiconductor Research Institute, China

in this paper, the structure combining complementary split ring resonator (CSRR) and split ring resonator (SRR) with fin line is proposed for band stop filter or waveguide absorber. The results indicated that the proposed structure would reduce the reflection and enhance the absorption by the reflection wave cancellation, which allows filtering and absorbing application in terahertz. The bandwidth can be expanded by increasing the number of resonance cells and the whole structure is very convenient to connect with standard rectangular waveguides.

18:30 **THz Josephson Spectroscopy Of Mode Coupling In Split-ring Resonators** **Tu-POS-55**

Alexander Snezhko[1]; Irina Gundareva[2]; Yuri Divin[2]; Valeriy Pavlovskiy[1]; Vadim Pokalyakin[1]
[1]Kotelnikov Institute of Radio Engineering and Electronics of RAS, Russian Federation; [2]Peter Grünberg Institute, Forschungszentrum Jülich, Germany

Resonance modes in a planar square split-ring resonator (SRR) have been studied by Josephson spectroscopy at frequencies from 150 GHz to 800 GHz and excitation of fundamental modes in internal and external resonators have been observed. In addition, a square open-loop resonator (OLR) of the same dimension as the external resonator of the SRR has been analyzed, and red shift of the low-frequency resonance mode in SRR has been demonstrated.

18:30 **Optically Controlled THz Metamaterial Modulators** **Tu-POS-**

Polina Stefanova; Andreas Klein; Rhiannon Lees; Andrew Gallant; Claudio Balocco
Durham University, United Kingdom
Optically controlled amplitude and phase modulators based on different split ring resonators (SRR) at THz frequencies are compared. The structures are fabricated on High-Resistivity Float-Zone (HR-FZ) Silicon and characterised with a THz network analyzer in reflection and transmission configuration under various polarisation.

18:30 **Modulation Of Polarization Control In Ultrathin Terahertz Metasurfaces** **Tu-POS-57**

Thomas A. Searles
Howard University, United States
We demonstrate a broadband and strong cross-polarized transmission in ultrathin terahertz (THz) metamaterials (MMs). Further, these MMs also exhibit additional high-Q factor modes in co-polarization transmission through the translation of the capacitive gaps. Moreover, by altering the topology of the MMs we have shown a modulation of both amplitude and bandwidth with a full suppression of cross-polarized transmission for a selective window.

18:30 **THz Spectroscopy Inside A Climate Chamber** **Tu-POS-58**

Jan Ornik[1]; Stefan Sommer[1]; Eva-Maria Stübling[1]; Ralf Gente[1]; Jan C. Balzer[2]; Klaus Fey[3]; Thomas Pillich[3]; Martin Koch[1]
[1]Faculty of Physics, Philipps-Universität Marburg, Germany; [2]Universität Duisburg-Essen, Germany; [3]biomedis Laborservice GmbH, Germany
We equip a commercial climate chamber with a terahertz time-domain spectrometer. This allows us to expose the investigated samples to a controlled atmosphere. The temperature in the climate chamber can be varied between -40 and 80 °C. The humidity can be changed between 15 and 98 %. This allows us to monitor drying processes and aging effects due to controlledweathering on various samples.

18:30 **Development Of Efficient Contact Grating Device For Terahertz Wave Generation** **Tu-POS-59**

keisuke nagashima; Masaaki Tsubouchi; Yoshihiro Ochi; Maruyama Momoko
National Institutes for Quantum and Radiological Science and Technology, Japan
We have developed an efficient contact grating device for generating terahertz waves. This device has a very high diffraction efficiency and a wide spectral width. The device has a bi-angular filter and a Fabry-Perot-type structure, which are composed of dielectric multilayers. The bi-angular filter is designed to reflect the 0th-order wave and transmit the -1st-order diffraction wave. Numerical calculations indicate that the new device has a maximum diffraction efficiency over 99% and a spectral width of approximately 20 nm. We measured a high efficiency of 90% over a broad spectral range using a fabricated device.

18:30 **3D-Printed Tunable THz Prism** **Tu-POS-60**

Stefan F. Busch[1]; Enrique Castro-Camus[2]; Felipe Beltran-Mejia[3]; Jan C. Balzer[4]; Martin Koch[5]
[1]Philipps University of Marburg, Brazil; [2]Centro de Investigaciones en Optica A.C., Mexico; [3]National Institute of Telecommunications - Inatel, Brazil; [4]University of Duisburg-Essen, Germany; [5]Philipps University of Marburg, Germany
A mechanically tunable prism is constructed using a conventional 3D printer. First, by printing periodical layers of polystyrene, a dispersive element is obtained. Later, a tunable dispersive element is obtained by linking these layers with 3D printed bow springs. We show how this tunable dispersive element spatially resolves the different frequency components for terahertz radiation.

18:30 **Anti-reflection Characteristics Of Laser Drilling Subwavelength Tapered Structures At Terahertz Frequencies** **Tu-POS-61**

Naoki Horita; Xi Yu; Mahiro Takeuchi; Shingo Ono; Jongsuck Bae
Department of Physical Science and Engineering, Nagoya Institute of Technology, Japan
Anti-reflection characteristics in one dimensional tapered (grating) structures with different pitches which have been fabricated by femtosecond laser processing, have been evaluated experimentally and theoretically at terahertz frequencies. The measured frequency dependence of reflection in the grating structures have been good agreement with theoretical ones. The results have shown that the laser

processing is very useful to fabricate anti-reflection structures with precise dimensions.

18:30 **Studying Of Thermal Influence For Improving Anti-Reflective Characteristics Of Moth-Eye Structures Fabricated By Femtosecond Laser Processing** **Tu-POS-62**

Xi Yu[1]; Naoki Horita[1]; Mahiro Takeuchi[1]; Sudo Masaaki[2]; Shingo Ono[1]; Jongsuck Bae[1]
[1]Nagoya Institute of Technology, Japan; [2]IMRA AMERICA, INC., Japan

Anti-reflective structures formed by periodic grooves, have been fabricated by femtosecond laser processing. Molten materials due to thermal influence during the processing hindered the obtaining of high aspect ratio (=depth/pitch in tapers) and shape control of the taper. These are important to improve the anti-reflective characteristics of these structures. By increasing the scan speed of laser beam, we decreased the effective pulse number to reduce the thermal influence. By controlling the pitch of these tapers, we fabricated tapered structures with different anti-reflection band.

18:30 **High-directivity Terahertz Silicon-lens TEM Horn Antenna** **Tu-POS-63**

Kevin Froberger; Guillaume Ducournau; Jean-François Lampin
Institute of Electronics, Microelectronics and Nanotechnology, France

We present a new design of a TEM horn antenna (TEM-HA), which is a combination of a silicon lens and a normal TEM-HA, for the emission of terahertz radiations up to several hundreds of GHz. Electromagnetic simulations are presented towards fabrication and measure radiation pattern of such kind of antenna.

18:30 **Continuous Wave Multimode Amplitude THz Spectroscopy** **Tu-POS-64**

Alexandra Gerling[1]; Sebastian Dülme[2]; Nils Schrinski[2]; Andreas Stöhr[2]; Martin R Hofmann[1]; Carsten Brenner[1]
[1]Ruhr Universität Bochum, Germany; [2]University of Duisburg-Essen, Germany

We propose a photonic multimode system where direct detection of the amplitudes of individual THz frequencies is possible at high speed.In our setup we use a photomixing process of multiple modulated telecom laser diodes with an unmodulated reference diode. We use a photodiode to generate a THz signal at each difference frequency of the optical modes.By introducing a modulated source into the photomixing process, we introduce the same modulation in the emitted THz frequency. All generated THz frequencies are then modulated by the corresponding frequencies of the original laser sources. This signal is detected by a Schottky Barrier Diode (SBD) whose signal is analyzed with an Electrical Spectrum Analyzer (ESA). Due to the power detection, all difference and sum frequencies will appear in the ESA spectrum. We can thereby directly identify the amplitudes of the individual THz amplitudes by their respective positions on the ESA's frequency spectrum.As the diodes' bandwidth is restricted by a WR2.8 waveguide, we show spectroscopic results of that frequency region.To perform a proof-of-principle, we detect THz absorption of sample materials.By careful selection of the modulation frequencies a multimode photomixing system, covering a wide THz spectrum without frequency tuning or moving mechanical parts, can be built using the same principle.This work was supported by the German Research Foundation within the project C06 of the TRR196 (Marie).

18:30 **CW THz System With 50 DB Dynamic Range At 1 THz Using A N-i-pn-i-p Superlattice Photomixer And An ErAs:InGaAs Photoconductor Operated At 1550nm** **Tu-POS-65**

Mario Méndez Aller[1]; Arthur C. Gossard[2]; Hong Lu[3]; Sascha Preu[1]
[1]TU Darmstadt, Germany; [2]Materials Dept., University of California, Santa Barbara, United States; [3]Nanjing University, China

We report a 1550 nm THz continuous-wave system using a n-i-pn-i-p superlattice photomixer and an ErAs:InGaAs photoconductor with 50 dB dynamic range at 1 THz at 300 ms integration time.

18:30 **Resonant Cavity Enhanced InAlAs / InGaAs-MSM Photodetectors With 3 DB-cut-off Frequency Above 100 GHz** **Tu-POS-66**

Maximilien Billet; Sara Bretin; Yann Desmet; Xavier Wallart; Christophe Coinon; Guillaume Ducournau; Jean-François Lampin; Emilien Peytavit
IEMN CNRS/Lille University, France

We present a resonant cavity enhanced (RCE) InAlAs/InGaAs metal-semiconductor-metal (InAlAs/InGaAs MSM) photodetector driven by a 1550 nm wavelength illumination. The device shows a high dc-photoresponse higher than 0.1 A/W and a

cut-off frequency higher than 100 GHz which are suitable properties for sub-THz and THz optoelectronics applications.

18:30 **Characterization Of Terahertz Wave Propagation Dependent On Metal-rod-array Structures** **Tu-POS-67**

Borwen You[1]; Dejun Liu[1]; Ja-Yu Lu[2]; Toshiaki Hattori[1]
[1]Department of Applied Physics, University of Tsukuba, Japan; [2]Department of Photonics, National Cheng Kung University, Taiwan

Terahertz (THz) wave propagation dependent on the metal-rod-array (MRA) are experimentally demonstrated using the waveguide integrated schemes with and without structural defects on periodic metal rod arrangement. Various MRA defects at different structure periods are prepared to investigate the wave transmission in 0.1--1 THz. Manipulation of THz wave on a chip are thus approached inside the MRA defects based on the interference effect of transverse-magnetic waves. The photonic control of MRA is performed in strong absorption and low-loss waveguiding.

18:30 **Ultra-low-cost THz Wave Plates Based On High-contrast Gratings** **Tu-POS-68**

Andreas Klein; Jonathan Hammler; Claudio Balocco; Andrew Gallant
Durham University, United Kingdom

Dielectric gratings with wavelength-sized features are used as quarter-wave plates operating at THz frequency. An ultra-low-cost variant which is laser-cut from PTFE, with a narrow operational band-width, i.e. single target frequency, is demonstrated and a broadband variant is discussed.

18:30 **Metal-graphene Based Dynamically Tunable Bands Stop Filter** **Tu-POS-69**

Ren Bin Zhong[1]; Yan Liu[2]; Jiebiao Huang[2]; Yilin Lü[2]; Shenggang Liu[2]
[1]Terahertz Research Center, School of Electronics Science and Engineer, University of Electronic Sci, China; [2]School of Electronic Scienc and Engineering University of Electronic Science and Technology of China, China

With hybrid structure, the proposed band stop filter is constructed by unit cells of simple gold strips on the stack of monolayer graphene and substrate. A stable modulation depth up to -23dB can be achieved at mid-infrared frequencies. The amount of the strips in each unit cell determines the number of the stop-bands of the filter. The location of the stop-bands not only can be adjusted by varying the length of gold strips but also can be dynamically controlled by tuning the Fermi energy level of graphene, which providing a simple and flexible approach to develop multispectral devices and can also be used as an index based sensor for its high sensitivity to the surrounding medium.

18:30 **Laser-Ablated Antireflective Structures For Terahertz Radiation Focusing** **Tu-POS-70**

Vincas Tamosiūnas; Simonas Indrisiūnas; Milda Tamosiūnaitė; Linas Minkevičius; Andrzej Urbanowicz; Gediminas Račiukaitis; Irmantas Kasalynas; Gintaras Valusis
Center for Physical Sciences and Technology, Lithuania

Numerical simulations and experimental characterization of laser-ablated anti-reflective, phase shifting and focusing structures for terahertz frequencies are presented. Nearly 90 % transmittance of silicon wafers with anti-reflective structures on both sides was confirmed experimentally within 0.5-0.6 THz frequency range. Focusing binary zone plate for 0.6 THz was produced employing phase shift differences due to the dual function antireflective layer. Close to diffraction--limited focusing performance was demonstrated thus further confirming sufficient uniformity of the structured layer for reliable phase-shifting application.

18:30 **Characterization Of An IR-Blocking, THz Low-Pass Filter For Improved THz Power Metrology** **Tu-POS-71**

Andrea Mingardi[1]; W-D Zhang[2]; Elliott Brown[1]
[1]Wright State University, United States; [2]TeraPico LLC, United States

A new infrared-blocking, black plastic-composite filter was tested and compared with a standard thick black polyethylene filter. The filters were tested for transmission in the infrared region and in the THz region (from 200 to 1400 GHz). The new filter proved to have higher IR attenuation and THz transmission, enabling more accurate THz power metrology for photoconductive devices driven at 1550 nm.

18:30 **High Power Microwave Effects On Critical Chips For Ka-band T/R Module Of Phased Array Radar** **Tu-POS-72**

Guo Guo[1]; Xinjian Niu[1]; Yinghui Liu[2]; Hui Wang[2]; Changyong Guo[2]

[1]Terahertz Research Center, School of Electronics Science and Engineer, University of Electronic Sci, China; [2]School of Electronic Science and Engineering, University of Electronic Science and Technology of Chi, China

Effects of high power millimeter wave on critical chips for the T/R module of phased array radar is experimental studied and analyzed in this paper. A multifunction amplifier chip and an amplitude-phase controller chip are selected for our experiments. A solid continuous wave (CW) source and a high power pulsed magnetron are employed to generate the Ka-band microwave. The input-output characteristics, the degradation and destroy threshold of the chips are obtained through a series of experimental tests. At last, the results are given by figures and analyzed theoretically.

18:30 **Modeling Of THz Pump Induced Plasmonic Oscillations In Silicon Membranes** **Tu-POS-73**

Nan Wang[1]; Emilio Nanni[2]; Xiaozhe Shen[2]; Renkai Li[2]; Matthias Hoffmann[2]; Benjamin Kwasi Ofori-Okai[2]; Qiang Zheng[2]; Jie Yang[2]; Xijie Wang[2]

[1]Stanford University, United States; [2]SLAC, United States

We present a one-dimensional charge density model for an oscillating "plasmon" in a 200 nm thick silicon membrane. The free carriers are generated using photoexcitation, then a single-cycle THz pump induces oscillation of those carriers. We compare the results with measurements of the local field from ultrafast electron diffraction.

18:30 **Dynamics Of The Gas Discharge Sustained By The Powerful Radiation Of Pulsed And CW Terahertz Gyrotrons** **Tu-POS-74**

Alexander Sidorov; Sergey Razin; Alexey Veselov; Alexander Vodopyanov; Alexey Luchinin; Andrey Fokin; Mikhail Morozkin; Alexander Tsvetkov; Mikhail Glyavin

Institute of Applied Physics, Russian Federation

Results of the experimental investigation of the gas discharge dynamics in the beams of the powerful terahertz radiation are presented. Velocity of the discharge front propagation was measured for pulsed (250 kW@250 GHz, 40 kW@670 GHz) and CW (1 kW@263 GHz) terahertz beams in a different gases for a various gas pressures and field intensities. In particular, it was demonstrated that discharge front velocity decreases with gas pressure increase.

18:30 **Parameters Of A CW Plasma Torch Of Atmospheric Pressure Sustained By Focused Sub-terahertz Gyrotron Radiation** **Tu-POS-75**

Alexander Sidorov; Alexander Vodopyanov; Sergey Razin; Igor Dubinov; Sergey Sintsov; Mikhail Proyavin; Mikhail Morozkin; Andrey Fokin; Mikhail Glyavin

Institute of Applied Physics, Russian Federation

The study of the CW discharge of atmospheric pressure, supported by focused sub-terahertz radiation, is performed. The electron density of the plasma torch measured by the Stark broadening of the Balmer series of hydrogen lines. Plasma density was close to $2 \bullet 10^{15}$ cm^{-3}. This exceeds the cut-off value for the frequency of the heating radiation. The electron temperature determined by relative intensities of the argon atomic emission lines. The values of the electron temperature were in the range from 1 to 2 eV.

18:30 **THz Radiation Modulated By Confinement Of Transient Current Based On Patterned CoFeB/Pt Heterostructures** **Tu-POS-76**

Shunnong Zhang[1]; Weihua Zhu[2]; Qin Li[1]; Zongzhi Zhang[2]; Ye Dai[1]; Xian Lin[1]; Jianquan Yao[3]; Guohong Ma[1]; Zuanming Jin[1]

[1]Shanghai University, China; [2]Fudan University, China; [3]Tianjin University, China

We have shown the broadband emission of THz pulse in the metallic patterned ferromagnetic heterostructures CoFeB/Pt based on inverse spin-Hall effect (ISHE), by the irradiation of a femtosecond laser pulse at 800 nm. By changing the size of the subwavelength rectangular metal-blocks in one direction, we can not only effectively control the magnitude of the THz radiation, but also tune the center frequency and bandwidth of the emitted THz pulses subtly. Our current results could contribute to the development of tunable spin-based THz emitter.

18:30 **Tunneling Rectification In Ring Shaped Nanogaps** **Tu-POS-77**

Taehee Kang[1]; R. H. joon-Yeon Kim[1]; Geunchang Choi[1]; Jaiu Lee[1]; Hyunwoo Park[1]; Hyeongtag Jeon[2]; Dai-Sik Kim[1]

[1]Seoul National university, Korea, Republic of; [2]Hanyang University, Korea, Republic of

In this work, we show a ring-shaped metallic nanogap exposed to electromagnetic

fields to manipulate ultrafast tunneling electrons. Eddy currents induced by incoming terahertz pulses project upon the ring, changing the local potentials in vectorial way. Contour-integrated along the perimeter of the ring, the total tunneling currents are critically dependent upon the ring shape. Furthermore, the spatiotemporal dynamics of the fully-rectified terahertz pulses can be visualized by the femtosecond optical pulses.

18:30 **Development Of Metamaterial Structures for THz Frequency Conversion Devices** **Tu-POS-78**

Yusuke Akamine[1]; Dmitry Bulgarevich[1]; Koji Yamamoto[1]; Takashi Furuya[1]; Hideaki Kitahara[1]; Jessica Afalla[1]; Valynn Mag-usara[1]; Keisuke Takano[2]; Khoa Nhat Thanh Phan[3]; Kosaku Kato[3]; Makoto Nakajima[3]; Masahiko Tani[1]; Yusuke Akamine[1]
[1]Reserch Center for Development of Far-Infrared Region, University of Fukui, Fukui, Japan, Japan; [2]Institute of Laser Engineering, Osaka University, Osaka, Japan and Center for Energy and Environment, Japan; [3]Institute of Laser Engineering, Osaka University, Osaka, Japan, Japan

We designed and fabricated a second harmonic generation device in THz frequency region with an array of split-ring resonators (SRR) on GaAs substrate. The properties of the structure were simulated by HFSS calculations and evaluated by THz time-domain spectroscopy (THz-TDS).

18:30 **Long Term Stabilization Of Phase-locking Of A THz-QCL** **Tu-POS-79**

Yoshihisa Irimajiri
National Institute of Information and Communications Technology, Japan

We have successfully demonstrated to extend stabilizing duration of a phase-locking of a THz-QCL to more than few days. In addition to an ordinary phase-locking, a frequency drift of a THz-QCL was compensated by controlling bias voltage of a THz-QCL. A PLL out voltage was used as a trigger control.

18:30 **Imaging Using Terahertz Quantum Cascade Laser Sources Based On Difference Frequency Generation** **Tu-POS-80**

Atsushi Nakanishi; Kazuue Fujita; Kazuki Horita; Hironori Takahashi
Hamamatsu Photonics K. K., Japan

Abstract--Terahertz quantum cascade laser sources based on difference frequency generation (THz DFG-QCLs) are currently the only room temperature monolithic semiconductor laser sources in frequency between 1 and 6 THz, in which broadband emission as well as continuous-wave operation at room temperature has already been achieved. In this paper, we report the first terahertz imaging with a THz DFG-QCL, for which higher quality images are acquired, compared with the results obtained from a THz-QCL with a double metal waveguide. This may be attributed to better far-field emission profiles for the THz DFG-QCL.I. INTRODUCTION Terahertz (THz) quantum cascade laser (QCL) is the most promising light source in THz region. THz imaging technology based on THz-QCL has been investigated widely: real time imaging with THz camera [1] and three-dimensional imaging [2]. However, the maximum operating temperature of THz-QCL is limited to be 200 K so far. Recently, as a room temperature monolithic THz source, THz-QCLs based on intra-cavity DFG have been demonstrated [3]. The performance of THz DFG-QCLs has rapidly improved; as a result, these demonstrated power output of nearly 2 mW in pulsed and 14 μW of continuous-wave operation at room temperature. In our group, we have developed THz DFG-QCLs based on the dual-upper-state active region design, which exhibit broadband emission between 1.6 THz and 3.8 THz with a peak output power of approximately 300 μW [4]. Besides, continuous operation of THz DFG-QCL at room temperature has also been achieved very recently. Although device performances of THz DFG-QCLs have significantly been improved, potential for practical applications with THz DFG-QCL has not been investigated so far. Here, we report the first demonstration of terahertz non-destructive imaging using THz DFG-QCL. Since THz DFG-QCLs reported previously have shown better THz far-field pattern, compared to that of THz-QCLs, these devices could be suitable for non-destructive inspection and quality control. In fact, we acquire high quality images from THz DFG-QCLs, experimentally.

18:30 **High-performance THz Quantum Cascade Lasers In Single-mode** **Tu-POS-81**

Junqi Liu; Yuanyuan Li; Fengqi Liu; Jinchuan Zhang; Shenqiang Zhai; Ning Zhuo; Lijun Wang; Shuman Liu; Zhanguo Wang
Institute of Semiconductors, Chinese Academy of Sciences, China

Single-mode surface-emitting terahertz quantum cascade lasers based on metal-metal waveguides is presented. By inserting a central Ï€-phase shift, single-lobed far-field radiation pattern is obtained with a divergence angle of 4Â° in the direction of the ridge. Single-mode peak power of 12.2 mW is achieved with a side-mode suppression ration above 25 dB.

18:30 **2.08 THz And 4.96 THz Room-temperature Quantum Cascade Lasers Based On Non-polar M-plane ZnMgO/ZnO** **Tu-POS-82**

Vadim Sirkeli[1]; Oktay Yilmazoglu[2]; Franko Küppers[1]; Hans Hartnagel[1]
[1]Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany; [2]Department of High Frequency Electronics, Technische Universität Darmstadt, Germany

We report on numerical study of room-temperature terahertz quantum cascade lasers (THz QCLs) based on a non-polar m-plane ZnMgO/ZnO employing a 2-well design scheme with variable barrier heights and a delta-doped injector well. We show that by varying and optimizing constituent layer widths and doping level of the injector well, high power performance of THz QCLs can be achieved at room temperature: optical gain and radiation frequency is varied from 108 cm^{-1} @ 2.18 THz to 300 cm^{-1} @ 4.96 THz. These results show that among II-VI compounds the ZnMgO/ZnO material system is optimally suited for high-performance room-temperature THz QCLs.

18:30 **Transverse Mode Propagation In Folded Waveguides Of Quantum Cascade Lasers** **Tu-POS-83**

Emilia Pruszynska-Karbownik; Maciej Sakowicz
Institute of Electron Technology, Poland

In this paper we present results of numerical calculations of transverse modes in folded waveguides of mid-infrared quantum cascade lasers. We show that depending on the waveguide geometry the transversal mode distribution along the waveguide is unchanged or there is switching between the fundamental and the first-order transverse mode.

18:30 **Phase Processing In Millimeter Wave Inverse Synthetic Aperture Radar Imaging Of Ship Targets** **Tu-POS-84**

Qi Yang; Bin Deng; Hongqiang Wang; Yuliang Qin
College of Electronic Science and Engineering, National University of Defense Technology, China

Due to the three-dimensional movement of ship targets on the sea, the phase processing during ISAR imaging is complicated. In this paper, experiments on imaging of a boat with a millimeter wave radar were carried out, and phase processing method based on high order PGA was adopted. The performance of the method was verified by the comparison of the imaging results through several traditional phase correction algorithms and the high order PGA algorithm. The algorithm is still suitable for phase processing of other maneuvering targets.

Wednesday, September 12, 2018

08:45 - 09:00 **Announcements** **Shirotori Hall**

Session Type: Others

09:00 - 10:30 **We-A1-S Plenary Session** **Shirotori Hall**

Session Type: Plenary
Chair(s)/Convenor(s)/Facilitator(s): Fritz Keilmann
Discussant(s):

09:00 **Imaging Fluctuations In Matter On Nano-scales -Scanning Noise Microscope (SNoiM)-** **We-A1-S-1**

Susumu Komiyama
The University of Tokyo, Japan

Noise is usually a hindrance to signal detection. This work, however, demonstrates that the noise is an invaluable signal that reveals kinetics of charge particles on nano-scales, which are otherwise inaccessible. MOST matterials, including metals, semiconductors, dielectrics and molecular systems, are composed of positive and negative charge particles, or dipoles. Those charge particles or dipoles are never at rest unless they are at absolute zero temperature, but fluctuate. Resultant local current fluctuation or the current noise brings nanoscopic information of local charge dynamics. If the system is in thermal equilibrium, the fluctuation is

thermally activated Johnson-Nyquist noise [1], and its characteristics can be tested by existing theories [2]. If, on the other hand, the system is out of equilibrium, the local current fluctuation is called excess noise or shot noise, which brings novel and nontrivial information about the local dynamics of non-equilibrium charge particles and/or energy dissipation [3]. We describe a Scanning Noise Microscope (SNoiM, Fig.1), with which ultra-high frequency current noise (15□30 terahertz) is locally detected and its spatial profile is mapped with nanometer scale resolution (20 nm) [4-9]. Two decades ago, it was theoretically suggested to make use of a tip of a scanning tunneling microscope (STM) for locally probing and mapping the current fluctuation (Fig.2 (a)) in conductors [10]. Reported here are imaging of evanescent fields thermally generated on metals and dielectrics [4-7], as well as mapping of current-induced fluctuating evanescent fields on narrow metal wires, nano-constriction devices of GaAs/AlGaAs quasi-two dimensional electron system [8], and constriction devices of graphene [9]: Most remarkably, non-local energy dissipation of hot electrons is visualized in operating micro electronic devices.

09:45 **Terahertz Microscopy Down To The Atomic Scale** **We-A1-S-2**

Tyler Cocker[1]; Dominik Peller[2]; Markus A. Huber[2]; Fabian Mooshammer[2]; Markus Plankl[2]; Fabian Sandner[2]; Jascha Repp[2]; Rupert Huber[2]
[1]Michigan State University, United States; [2]University of Regensburg, Germany
In this talk I will review terahertz scanning probe microscopy with a focus on recent developments that have made experiments with simultaneous ultrafast temporal resolution and atomic spatial resolution possible. Specifically, I will discuss the underlying principle of coupling terahertz radiation to sharp metallic tips, the connection between scattering-type scanning near-field optical microscopy (SNOM) and terahertz lightwave-driven scanning tunneling microscopy (THz-STM), and the key aspects of THz-STM that enable atomic spatial resolution. Finally, as an illustrative example, I will present ultrafast THz-STM snapshots and pump-probe measurements of electron densities in selected molecular orbitals of single molecules with sub-Angstrom spatial resolution.

11:00 - 12:30 **We-A2-R1 Spectroscopy and Material Properties VI** **Shirotori Hall**

Session Type: Oral

11:00 **THz Transient Photoconductivity With Near-field Detection** **We-A2-R1-1**

Niels van Hoof[1]; Stan ter Huurne[1]; Jaime Gomez Rivas[2]; Alexei Halpin[1]
[1]Dutch Institute For Fundamental Energy Research, Netherlands; [2]University of Technology Eindhoven, Netherlands
We demonstrate a novel technique that enables the sub-diffraction near-field study of photo-excited structures probed with broadband THz radiation. As a proof-of-concept this system measures sub-ps temporal dynamics of a thin film of GaAs with a signal to noise of 1000 and a spatial resolution of 60 μm (λ/10 at 0.5 THz peak intensity).

11:15 **Detection Of Boson Peak And Fractal Dynamics Of Protein By Terahertz Time-Domain Spectroscopy** **We-A2-R1-2**

Tatsuya Mori[1]; Yue Jiang[1]; Yasuhiro Fujii[2]; Suguru Kitani[3]; Akitoshi Koreeda[2]; Leona Motoji[1]; Wakana Terao[1]; Kentaro Shiraki[1]; Yohei Yamamoto[1]; Seiji Kojima[1]
[1]University of Tsukuba, Japan; [2]Ritsumeikan University, Japan; [3]Tokyo Institute of Technology, Japan
Glassy materials universally show the boson peak, which is one of the unsolved problems on glass physics, in the terahertz region. On the other hand, in polymer glass and proteins having self-similarity of monomer molecules, it is expected that fractal dynamics appears above boson peak frequency. Until now, the fractal dynamics often has been discussed by using low-frequency Raman scattering, and recent terahertz spectroscopic studies have not mentioned about detection of such excitaion. In this study, we propose how to detect fractal dynamics by terahertz spectroscopy using protein as an example.

11:30 **Synthetic THz Nanoholography For Imaging CVD Graphene** **We-A2-R1-3**

Daena Madhi
Technical University of Denmark, Denmark
We combine THz scattering-type scanning near-field optical microscopy (s-SNOM) and synthetic optical holography (SOH) to enable fast, amplitude and phase

resolved THz nanoimaging using a THz gas laser and Schottky diode detector. We demonstrate our novel tool by imaging graphene grown via chemical vapor deposition (CVD) and other 2D materials.

11:45 **Preprocessing For Robust Estimation Of Material Parameters By Continuous Wave THz Spectroscopy** **We-A2-R1-4**

Benedikt Friederich; Kevin Kolpatzeck; Xuan Liu; Thorsten Schultze; Jan C. Balzer; Andreas Czylwik; Ingolf Willms
University of Duisburg-Essen, Germany

In this paper, a computationally efficient preprocessing approach for continuous wave THz spectroscopy based on Tukey windowing in the time-domain is proposed. Tukey windowing eliminates the effects of standing waves in the measurement setup while preserving the signal-to-noise ratio (SNR) and high frequency resolution of the spectroscopy system.

12:00 **λ-Ti3O5 With Temperature And Laser Induced Phase Transition Characteristics For Active Tuning Of Terahertz Wave Transmission** **We-A2-R1-5**

Qiwu Shi
College of Materials Science and Engineering/ Sichuan University, China

λ-Ti_3O_5 exhibits intriguing phase transition between λ, β and α phase, which has great application potential in tunable optoelectronic devices. However, the fabrication of λ-Ti_3O_5 still presents great challenge and its application in THz range has been rarely reported so far. Our work developed two strategies to fabricate λ-Ti_3O_5 and investigated its phase transition properties in THz range. It indicated that the λ-Ti_3O_5 exhibited temperature induced semimetal-metal phase transition and laser induced semimetal-semiconductor phase transition characteristics, which can be used in dynamic controlling of THz wave transmission.

12:15 **Proton Tunneling Detected In Cesium Silicate Compound LDS-1** **We-A2-R1-6**

Hiroshi Matsui
Tohoku University, Japan

In low dimensional cesium silicate compound LDS-1 with extremely short hydrogen-bonding distance, proton tunneling was successfully detected in the wide-range of absorbance spectra (10-7800 cm-1). The optical transitions and energy level schemes were demonstrated through the analysis of eigenvalue problem for symmetric double-minimum potentials. Moreover we identified two different collective modes of protonic vibrations.

11:00 - 12:30 We-A2-1b Metamaterial Structures and Applications II — Room 131+132

Session Type: Oral

11:00 **[Keynote] Information Metamaterials And Metasurfaces - From Concepts To Systems** **We-A2-1b-1**

Tie Jun Cui
Southeast University, China, China

Metamaterials are traditionally described by effective medium parameters due to subwavelength scales of unit particles. The continuous nature of the medium parameters makes the traditional metamaterials behave as analog metamaterials. Recently, the concept of coding metamaterials or metasurfaces has been proposed, in which metamaterials are characterized by 1-bit digital coding particles of '0' and '1' with 180° phase difference, or 2-bit digital coding particles of '00', '01', '10', and '11' with 90° phase difference, etc. It was demonstrated that the electromagnetic waves can be manipulated by changing the digital coding sequences. The coding particles provide a link between the physical world and digital world, leading to digital metamaterials and even field programmable metamaterials, which can be used to control the electromagnetic waves in real time. The digital coding representation of metamaterials or metasurfaces allows the concepts and signal processing methods in information science to be introduced to the physical metamaterials, realizing extreme controls to the electromagnetic waves, such as Shannon entropy, convolution theorem, and addition theorem. Such studies set up the foundation of information metamaterials and metasurfaces. In this manner, metamaterials are not only the effective materials, but can also be real-time information processing systems (e.g. new-concept radar, programmable imaging and hologram, and new-concept communication systems). In this presentation, the coding, digital, and field programmable metamaterials and metasurfaces are

systematically introduced with particular emphases on recently new developments. The future trend of information metamaterials is also predicted.

11:30 **From Terahertz Surface Waves To Spoof Surface Plasmon Polaritons** **We-A2-1b-2**

Jiaguang Han
Tianjin University, China
Surface plasmon polaritons (SPPs) promise versatile potential applications in many aspects and thus have been a subject of enormous interest. However, in the terahertz regime, due to perfect conductivity of most metals, it is hard to realize a strong confinement of SPPs although a propagation loss could be sufficiently low. Here we introduce the recent work from terahertz surface waves to spoof SPPs based on metasurfaces.

11:45 **Nanoscale Observation Of Real-Space Mid-Infrared Field Distribution In A Stamp-Type Plasmonic Structure** **We-A2-1b-3**

Ryoichi Yuasa; Takuya Okamoto; Akira Sasagawa; Yukio Kawano
Tokyo Institute of Technology, Japan
By utilizing scattering-type scanning near-field optical microscopy (s-SNOM) in mid-infrared (MIR) band, we observed nanoscale real-space optical field distribution in a Bull's eye (BE) plasmonic structure, which was fabricated through a template-assisted stamp method. Nanoscale near-field images were shown to agree with plasmonic features of electromagnetic simulation results, showing that the fabricated BE structure works as a plasmonic device. The s-SNOM thus offers a strong tool for gaining nanoscale real-space optical distribution in plasmonic micro/nanostructures.

12:00 **A High Transmission Terahertz-wave Quarter-wave Plate By Double-layer SRRs With Film Metamaterial** **We-A2-1b-4**

Zhengli Han[1]; Seigo Ohno[2]; Yu Tokizane[1]; Kouji Nawata[1]; Takashi Notake[1]; Yuma Takida[1]; Hiroaki Minamide[1]
[1]Riken, Japan; [2]Tohoku University, Japan
A high transmission terahertz-wave quarter-wave plate (QWP) is demonstrated by double-layer split ring resonators (SRRs) with film metamaterial. The double-layer metallic patterns with rectangular SRR design provide freedom to use different resonant modes regarding to the polarization to introduce birefringence for the QWP. A transmittance of 0.8 is obtained from experiment with ellipticity of 0.99 at 0.98THz.

12:15 **Broadband Terahertz Coding Metasurface Integrated With Bias Circuit** **We-A2-1b-5**

Hongxin Zeng[1]; ziqiang yang[1]; Yaxin Zhang[2]; Feng Lan[2]
[1]Terahertz Science Cooperative Innovation Center, University of Electronic Science and Technology of, China; [2]University of Electronic Science and Technology of China, China
Terahertz dynamic coding metasurface has always aroused extensive attention for many years. However, complicated bias circuit design still is a significant challenge. Here, we design a terahertz metasurface composed of the unit cells with bias circuit integrated. We have experimentally demonstrated the anomalous reflection of the terahertz metasurface in a wide frequency band (0.32 to 0.46 THz) by employing different coding sequences. This work provides potential applications for the development of interesting dynamic terahertz devices.

11:00 - 12:30 **We-A2-1c Imaging and Remote Sensing II** **Room 133+134**

Session Type: Oral

11:00 **Diffuse Beam With Electronic THz Source Array** **We-A2-1c-1**

Daniel Headland; Robin Zatta; Ullrich Pfeiffer
University of Wuppertal, Germany
An array of terahertz sources in 0.13 μm SiGe BiCMOS has previously been developed to mitigate the well-known issue of low available power from compact terahertz sources. However, the device projects beams toward different, non-overlapping directions, rendering it unsuitable for use as a general-purpose illumination source. To address this issue, custom optics are employed for incoherent power combining, and subsequently utilized in a demonstration of terahertz imaging.

11:15 **A Gold Coated Plasmonic Sensor For Biomedical And Biochemical Analyte** **We-A2-**

Detection **1c-2**

Md. Saiful Islam; Jakeya Sultana; Alex Dinovitser; Brian Wai. Him. Ng; Derek Abbott
University of Adelaide, Australia

A photonic crystal fiber based surface plasmon resonance biosensor is designed and characterized in the visible to mid-infrared region. Using gold as a plasmonic material we obtain a highest wavelength sensitivity of 62000 nm/RIU than ever proposed by any plasmonic sensor. Moreover, we obtained a high amplitude sensitivity of 1415 RIU-1. The proposed highly sensitive PCF is feasible to fabricate using the existing fabrication technology and currently the fabrication and experimental characterization is underway.

11:30 **Liquid Crystal Based Terahertz Spatial Light Modulator For Imaging Application** **We-A2-1c-3**

Anup Kumar Sahoo[1]; Chan-Shan Yang[2]; Chun-Ling Yen[1]; Yuan Chun Lu[1]; Hung Chun Lin[3]; Yi-Hsin Lin[3]; Osamu Wada[4]; Ci-Ling Pan[1]
[1]National Tsing Hua University, Taiwan; [2]National Taiwan Normal University, Taiwan; [3]National Chiao Tung University, Taiwan; [4]Kobe University, Japan

We demonstrate a liquid crystal based THz spatial light modulator (SLM). Indium tin oxide finger type patterns were used for transparent (>70 % at 0.08 to 1.2 THz) conductor and self-cross polarizer. The phase shift and amplitude modulation achieved is greater than 90 degree and 30 % in broadband in THz frequency. This SLM could become a promising candidate for high-speed THz imaging application via compress sensing algorithm.

11:45 **Image Reconstruction For Terahertz Holographywith SparseRandom Frequencies** **We-A2-1c-4**

Chao Li
Institute of Electronics, Chinese Academy of Sciences, China

In this paper, THz imaging concept based on sparse information wasintroduced.Holography with sparse random frequencies was proposed for surface layer image reconstruction. Proof-of-state demonstration at 0.2THz band was performed to verify the effectiveness of the proposed method.

12:00 **Dual-Polarization Imaging With Real-Time Capability Using A Terahertz Noise Source For Food Inspection** **We-A2-1c-5**

Daisuke Takehara[1]; Masao Endo[2]; Tadao Ishibashi[3]; Makoto Shimizu[4]; Satomi Kusanagi[4]; Tatsuo Nozokido[5]; Jongsuck Bae[1]
[1]Nagoya Institute of Technology, Japan; [2]the University of Tokyo, Japan; [3]NTT Electronics Techno Corporation, Japan; [4]NTT Electronics Corporation, Japan; [5]University of Toyama, Japan

A dual-polarization terahertz imaging system using a noise source which has frequency components between 0.075 THz and 0.11 THz has been newly developed for food inspection. The imaging system can take horizontal and vertical polarization images independently and simultaneously with a spatial resolution of smaller than 4 mm and a high data acquisition speed of 10 lines data (1,200 pixels)/msec. These characteristics of the imaging system fulfills industrial requirements for inspection of foods conveyed at a velocity of higher than 20 m/min.

12:15 **A High-speed And Stable THz Spectroscopic Imaging System Using Multiwavelength Is-TPG** **We-A2-1c-6**

Kosuke Murate; Kazuki Maeda; Yunzhuo Guo; Kodo Kawase
Nagoya University, Japan

In this study, we demonstrated a high-speed terahertz (THz) spectroscopic imaging system using a multiwavelength injection-seeded THz parametric generator (is-TPG). Multiwavelength is-TPG can identify reagents based on the repetition rate of the pump laser because the spectroscopic measurement is performed in a single pulse. Furthermore, highly stabilized measurements are realized by splitting the THz wave into measurement and reference beams. This system significantly shortens the measurement time for spectroscopic imaging with high stability.

11:00 - 12:30 **We-A2-1a Sources, Detectors, and Receivers IV** **Room 141+142**

Session Type: Oral

11:00 **[Keynote] Metamaterial-enhanced Quantum Infrared Detectors** **We-A2-1a-1**

Yanko Todorov; Daniele Palaferri; Mathieu Jeannin; Alireza Mottaghizadeh; Djamal Gacemi; Angela Vasanelli; Carlo Sirtori

Laboratoire Matériaux et Phénomènes Quantiques, France
Recent advances on infrared detectors that operate in metamaterial arrays of sub-wavelength metallic resonators are reported. The metallic metamaterial resonators have a quantitative impact on the high temperature detector performance, owe to the combination of a strong local field enhancement and an antenna effect. The latter allows collecting photons from an area that is much larger than the electrical area of the device, resulting in a strong reduction of the thermally excited detector dark current.

11:30 **Broadband Terahertz Detection With An Antenna Coupled Zero-Bias Field-Effect Transistor** **We-A2-1a-2**

Stefan Regensburger[1]; Amlan k. Mukherjee[1]; Hong Lu[2]; Arthur C. Gossard[3]; Sascha Preu[1]

[1]Terahertz Systemtechnik - TU Darmstadt, Germany; [2]University of Nanjing, China; [3]University of California, Santa Barbara, United States
We de-embed the measured responsivity of an antenna coupled field-effect transistor and compare it with the ideal responsivity calculated from device parameters. The broadband zero-bias detector is characterized from 0.1 to 1.6 THz, reaching a de-embedded noise equivalent power of 7 pW/√Hz at 0.6 THz. The III-V high electron mobility transistor is processed with UV-contact lithography.

11:45 **Far Infrared And THz Detectors: Principles Of Operation And Figures Of Merit** **We-A2-1a-3**

Marco Zerbini[1]; Adrea Doria[1]; Gian Piero Gallerano[1]; Emilio Giovenale[1]; Giuseppe Galatola-Teka[2]

[1]ENEA Frascati, Italy; [2]Università di Padova, Italy
We will review and discuss characteristics and relevant experimental applications of detectors in the FIR and THz spectral range, from 50 GHz to 1000 GHz (5mm - 300 micron), with special attention to Plasma Diagnostics, THz Time Domain Spectroscopy (THz-TDS) and and Free Electron Laser devices. A classification of detectors and detection systems, optimised for the spectral range of interested, will be discussed, in conjuction with the relevant noise parameters and figures of merit. This framework will be validated and completed with the specific experimental data.

12:00 **Terahertz InP DHBT-based Detectors For Studies Of Water Status Of Sorghum Leaves** **We-A2-1a-4**

Dominique Coquillat[1]; Nina Dyakonova[1]; Christophe Consejo[1]; Yoann Meriguet[2]; Jérémie Torres[2]; Frédéric Teppe[1]; Virginie Nodjiadjim[3]; Konczykowska Agnieszka[3]; Muriel Riet[3]; Jean-Luc Verdeil[4]; Knap Wojciech[1]

[1]Laboratoire Charles Coulomb, University of Montpellier, CNRS, France; [2]Institut d'Electronique et des Systèmes, University of Montpellier, CNRS, France; [3]III-V Lab, France; [4]CIRAD UMR AGAP, France
Currently, high frequency electronics uses two distinct families of semiconductors-based transistors: field effect transistors and heterojunction bipolar transistors (HBTs). They compete reaching impressive cut off frequencies going up to THz range. Except their usual functions related to switching and amplifying of current or voltage both have been demonstrated as efficient direct THz radiation detectors. Both types of the transistors have shown that once equipped with antennas, they can capture THz radiation from the open space and deliver the voltage or current proportional to incoming THz radiation power (THz rectification).Most of the work was dedicated to the field effect transistors that rectify THz radiation by plasma related nonlinearities. After pioneering works of El Hadi et al. and Vassilev et al., only very small attention was devoted to HBTs. In this work, we present experimental studies of THz detection by different HBTs fabricated using InP double HBT (DHBT) technologies. We investigate two different modes of operation. In the first mode (called passive), emitter-base junction of HBT rectifies THz radiation but collector-base junction is unbiased. In the second mode (called active), collector-base junction is biased, and the HBT not only detects but also amplifies the detected signal. We compare the two modes and discuss their potential differences and advantages. We also show that the sensitive HBTs detectors can be used for THz spectroscopy and 2D THz imaging to study how the water content affects the polarization rate and biattenuation in fibrous sorghum leaf.

12:15 **Enhancing Heterodyne System Performances With Millimeter Wave Mixers With 36 GHz Instantaneous IF Bandwidth And 35 % Relative Detection Bandwidth** **We-A2-1a-5**

Jeanne Treuttel[1]; David Gonzalez-Ovejero[2]; Choonsup Lee[3]; Imran Mehdi[3]

[1]LERMA Observatory of Paris, France; [2]Institut d'Électronique et de Télécommunications de Rennes, France; [3]Jet Propulsion Laboratory, United States
Above 400 GHz, heterodyne systems offer the best way to characterize or detect signals with high spectral resolution. The development of low noise and wide instantaneous IF and RF bandwidth fundamental mixers is reported. The proposed architecture offers attractive potential for ultra-large bandwidth and fast data rates wireless links. Moreover, it could be used to either reduce total power radiometer sensitivity or to enhance large scale mapping heterodyne systems for atmospheric science instruments.

11:00 - 12:30 We-A2-R2 Quantum Cascade Lasers I — **Reception Hall**

Session Type: Oral

11:00 **[Keynote] Low-frequency Terahertz Generation Based On High-Power Quantum Cascade Lasers Emitting At λ~14 Mm** — **We-A2-R2-1**

Kazuue Fujita; Akio Ito; Masahiro Hitaka; Tatsuo Dougakiuchi; Tadataka Edamura
Central Research Laboratory, Hamamatsu Photonics K.K., Japan
Authors present low frequency generation from terahertz quantum cascade laser sources based on intra-cavity nonlinear frequency mixing. In order to obtain higher nonlinear susceptibility in low frequency region, we design a long wavelength dual-upper-state active region in which transition dipole moments are increased. A fabricated device with distributed feedback grating demonstrates a THz peak output power of 20 μW at room temperature, with multi-mode THz emission at a frequency of 1.1 THz. Besides, the device produces a THz output power of 267 μW at 110 K, which is comparable to the power of low-frequency (1.2-1.6 THz) THz-QCLs at liquid helium temperature. THz quantum cascade laser (QCL) is a promising candidates to supply intense coherent terahertz light. The operation ranges of THz QCL spans from 5.4 to 1.2 THz. However, population inversion for low-frequency QCL is difficult to achieve due to poor injection efficiency of electrons from the injector in the upper laser state as well as the intersubband absorption in the injector. On the other hand, THz QCL sources based on intra-cavity difference frequency generation [1] are only electrically driven monolithic semiconductor light sources capable of operating at room temperature in the terahertz spectral range. Taking advantage of the high design flexibility of quantum cascade laser structures with giant second-order nonlinear susceptibility, these devices have expanded spectral coverage, extending over nearly the entire 1-6 THz range. Since this approach does not require maintaining population inversion across THz transitions in a QCL, THz DFG-QCL may be suitable for lower frequency operation. In fact, the operation at 1.2 THz of a THz DFG-QCL has been demonstrated using an external cavity setup, though the obtained power was a few microwatt at room temperature [2]. For difference frequency mixing in low-frequency THz range, optical rectification may become significant in addition to double resonance process [3].Here we report a THz DFG-QCL with the dual-upper-state active region [4] designed for λ~14μm that possesses very high nonlinear susceptibility in the low THz frequency range (<2THz). The devices demonstrate a THz peak output power of 20 μW at room temperature, with multi-mode THz emission at a frequency of 1.1 THz.

11:30 **Real-Time Molecular Spectroscopy Through Self-Mixing In A Terahertz Quantum-Cascade Laser** — **We-A2-R2-2**

Till Hagelschuer; Martin Wienold; Heiko Richter; Heinz-Wilhelm Hübers
German Aerospace Center (DLR), Germany
We report on a new detection method for real-timemolecular spectroscopy with a terahertz quantum-cascade laser.The self-mixing effect is exploited to tune the lasing frequencyacross molecular absorption lines of D_2O and CH_3OD and for thedetection of the self-mixing signal. The method allows for real-timemonitoring of gas mixtures in an absorption cell.

11:45 **Towards Room Temperature Operation Of Terahertz Quantum Cascade Lasers: Carrier Leakage Engineering As A Novel Design Concept** — **We-A2-R2-3**

Asaf Albo[1]; Yuri Flores[2]
[1]Bar Ilan University, Israel; [2]MIT, United States
The terahertz spectral region is subject to intensive research in view of its potential in a number of application domains such as medical diagnostics, trace molecule sensing, astronomical detection, non-invasive quality control and more. However, maximum operating temperature achieved with terahertz quantum cascade lasers

(~200 K) imposes cryogenic techniques. In general, the ideal operation mode of a terahertz quantum cascade laser assumes that an electron injected externally into the device will generate multiple photons -- one in each "energy cascade"-- while transporting through the heterostructure. However, alternative scattering leakage paths deviate electron transport from the ideal picture and present a considerable effect on devices' performance. In that context, temperature-driven leakage of charge carriers out of the laser's active region states is considered as an unwanted effect that limit its temperature performance [1-4]. However, as we showed in our latest works [5, 6], contrary to common sense expectations, carrier leakage under some conditions can be beneficial for the device and enhance lasing. Our results highlight the importance of the carrier leakage out of the lower laser level to the laser's performance. This understanding clearly point out to a potential improvement direction in the design of highly temperature-insensitive terahertz quantum cascade lasers, namely to minimize thermally activated leakage from the upper laser level and maximize thermally activated leakage from the lower laser level. In other word, to address a carrier leakage engineering procedure as a new design concept for high performance terahertz quantum cascade lasers. In this talk, I will present the challenge of carrier leakage for the temperature performance of terahertz quantum cascade lasers and the potential of carrier leakage engineering as a design concept for improving their operating temperatures. Additionally, I will present the strength of analyzing the laser's output power versus temperature measurements as an effective strategy to probe microscopic mechanisms that govern the laser temperature sensitivity [5, 6], Figure 1.

12:00 **Wavelength Tunability Of The Transistor-Injected Quantum Cascade Laser** **We-A2-R2-4**

Zhiyuan Lin[1]; Zhuoran Wang[1]; Guohui Yuan[1]; Jean-Pierre Leburton[2]
[1]University of Electronic Science and Technology of China, China; [2]University of Illinois at Urbana Champaign, United States
Wavelength Tunability of the transistor-injected quantum cascade laser (TI-QCL) is analyzed by calculating the spectral gain cross section under different electric fields. Calculated results show that the tunability of the TI-QCL ranges from 10.61 μm to 9.56 μm and from 15.31 μm to 12.34 μm for different optical transitions as the electric field varies from 42 kV/cm to 62 kV/cm, agreeing well with the results by transition dipole moments analysis.

12:15 **Active And Passive Frequency Comb Generation In Terahertz Quantum Cascade Lasers** **We-A2-R2-5**

Hua Li; Juncheng Cao
Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences,, China
Quantum cascade lasers (QCLs) emitting in terahertz frequency range are the ideal candidates for generating high power radiation in the frequency range between 1 and 5 THz. In this work, we report the frequency comb generation based on terahertz QCLs via active and passive methods. Using the active radio frequency modulation, the spectral coverage of the QCL comb can continuously span over 300 GHz. By integrating a passive saturable absorber into the laser cavity, we demonstrate self-reduction in phase noise of up to 20 dB and self-stabilization of inter-mode beat note linewidth of down to 30 kHz.

11:00 - 12:30 **We-A2-4 Gyro-Oscillators and Amplifiers II** **Room 432**
Session Type: Oral

11:00 **[Keynote] Terahertz Gyrotrons With Unique Parameters** **We-A2-4-1**

Mikhail Glyavin; Gregory Denisov
Institute of Applied Physics RAS, Russian Federation
This review aims to bring together information about the development and the most striking examples of high frequency gyrotrons applications. The paper describes the main features of terahertz gyrotrons. Some data about pulsed and CW tubes, working in the specified frequency range, are given. This gyrotrons demonstrate (in some specific combinations) extremely low voltage and beam current, narrow frequency spectrum, wide frequency tuning. Novel schemes of high frequency gyrotrons are analyzed.The CW gyrotrons developed at IAP RAS provides radiation with a power up to 1 kW in the frequency range 0.26-0.52 THz and the pulsed gyrotrons operates with 300 kW power level at 0.25 THz up to 0.5 kW at 1.3 THz frequency. The highest power and frequency has been obtained at the fundamental harmonic and for the high harmonic excitation additional method of

improved mode selection was used. In particular, successful operation in the frequency range 0.8-1 THz was demonstrated at large orbit gyrotron with axis-encircling electron beam at the third harmonic and at the second harmonic double-beam gyrotron with additional generating beam. An electrodynamic method for suppressing low-frequency oscillations at the fundamental cyclotron resonance in a gyrotron at a high cyclotron harmonic is proposed and investigated at complex cavity gyrotron.The stable CW single mode operation with 1 kW power level realized at the 0.26 THz frequency. Low operating current -- only 20 mA -- gives at 14 kV beam voltage the output power about 10W, which enough for spectroscopy application. The same power level was obtained for extremely low operating voltage -- 1.5 kV with an operating current about 0.5A. A possibility of frequency stabilization was tested experimentally at the same tube. The phase lock loop control of anode voltage has been used and the width of the frequency spectrum was decreased to 1 Hz. Obtained spectrum width and frequency stability were previously achieved in backward-wave oscillators, utilized in spectroscopy, but with power levels of tens of mW, while stabilization system with anode voltage control in gyrotrons has no apparent limiting factors in the field of gyrotron output power -- as it was demonstrated with output power of 40 W.The simple method of increasing the bandwidth of smooth frequency tuning in gyrotron by the use of a short cavity driven by an electron beam with high current was proposed. Numerical simulations based on both averaged equations and PIC-code show a feasibility of the gyrotron with the output power higher than 1 kW within a 10-GHz band around a frequency of 0.2 THz. The examples of initiation of gas discharges, high-resolution molecular spectroscopy in a gas mixture, high speed production of pure nanopowders by material evaporation and condensation, information transmitting is presented.

11:30 **Demonstration Of A 593 GHz Gyrotron For DNP** **We-A2-4-2**

Monica Blank
CPI, United States

Dynamic nuclear polarization (DNP) enhanced nuclear magnetic resonance (NMR) spectroscopy is a popular and growing application for high-frequency, continuous wave (cw) gyrotrons that produce powers in the range of tens to hundreds of watts at millimeter-wave and terahertz frequencies. As an original equipment manufacturer of gyrotrons for Bruker Biospin DNP systems, CPI has developed a series of high-frequency gyrotrons, the most recent of which is a 50 W, 593 GHz device for a 900 MHz NMR spectrometer. Design and performance details for the 593 GHz gyrotron will be discussed.

11:45 **Two-beam Self-excited Frequency Gyro-multiplier** **We-A2-4-3**

Andrei Savilov[1]; Ilya Bandurkin[1]; Mikhail Glyavin[1]; Ivan Osharin[1]; Toshitaka Idehara[2]
[1]Institute of Applied Physics of Russian Academy of Sciences, Russian Federation; [2]University of Fukui, Research Center for Development of Far-Infrared Region, Japan

A two-resonator frequency gyro-multiplier based on the use of a two-beam electron gun is proposed. Efficient generation in such a scheme is achieved due to a special choice of the beam radii, when one of the beams provides excitation of the first cavity at the fundamental cyclotron resonance, while the other excites the second cavity at a high cyclotron harmonic. Calculations predict the possibility of terahertz generation at the third cyclotron harmonic with a watt-level power.

12:00 **Development And First Operation Of The 170 GHz, 2 MW Longer-Pulse Coaxial-Cavity Modular Gyrotron Prototype At KIT** **We-A2-4-4**

Tomasz Rzesnicki; Konstantinos Avramidis; Gerd Gantenbein; stefan Illy; Zisis Ioannidis; Jianbo Jin; Ioannis Pagonakis; Sebastian Ruess; Tobias Ruess; Martin Schmid; Manfred Thumm; Joerg Weggen; Andy Zein; John Jelonnek
Karlsruhe Institute of Technology (KIT), Germany

Karlsruhe Institute of Technology (KIT) is progressing in the development of a multi-megawatt class gyrotron for fusion applications. After the successful experimental verification of the operation of the modular KIT 170 GHz, 2 MW short-pulse coaxial-cavity pre-prototype gyrotron with pulse lengths up to a few ms, the key gyrotron components have been upgraded by adding suitable cooling systems, keeping their previously validated scientific design. The new gyrotron construction allows the operation with pulses up to ~100 ms, however further increase of the pulse length is planned, after the installation of the diamond window and improved

collector. The basic upgrade of the individual components, the final assembly and the first experimental results are presented.

12:15 **ECRH At W7-X -- Concurrent Operation Of 10 Gyrotrons** **We-A2-4-5**

Harald Braune; Kai Jakob Brunner; Heinrich Peter Laqua; Stefan Marsen; Dmitry Moseev; Frank Noke; Frank Purps; Niko Schneider; Tino Schulz; Torsten Stange; Peter Uhren; Fabian Wilde
Max-Planck-Inst. f. Plasmaphysik Garching/Greifswald, Germany
At the stellarator Wendelstein 7-X (W7-X) Electron Cyclotron Resonance Heating (ECRH) is the main heating system for steady-state operation and was the only available heating system during the operation phase OP1.2a in 2017. The ECRH, equipped with 10 operational 140 GHz gyrotrons [1], was used for different tasks at W7-X such as wall conditioning, controlled plasma start-up from the neutral gas up to steady state plasma control and different heating scenarios such as X2-mode and O2-mode heating as well as current drive (ECCD). The achieved plasma parameters with respect to the performance of the ECRH plant will be discussed.

14:00 - 15:30 We-P1-R1 Spectroscopy and Material Properties VII — Shirotori Hall

Session Type: Oral

14:00 **[Keynote] All-Electronic THz Nanoscopy** **We-P1-R1-1**

Fritz Keilmann
Ludwig-Maximilians-Universität, Germany
We demonstrate 50-nm resolved near-field imaging at λ=500 μm for the first time, using a high-harmonic microwave circuit for emitting/detecting via free space to a standard s-SNOM, and map conductivity contrasts at near single-charge sensitivity.

14:30 **An Effective Application Of THz Spectroscopy For Identifying Fabric Fibers And Their Quality Evaluation** **We-P1-R1-2**

Toru Kurabayashi; Shunsuke Masuyama; Shinichi Yodokawa
Akita University, Japan
We have been examined about the homogeneous process of the fibers with no defects generation relevant to the destruction of inter-molecular linkages and higher-order structure of cellulosic fibers, silk fibers, etc. The discriminative absorption peaks observed in THz region enabled to determine the mixing rate of blended fibers. In addition, the amplitude of the differential spectra showed a defect intensity of inter-molecular linkages in the fibers.One of the key of this research is the sample preparation by the cut which maintained the cross-sectional form of the fiber at a suitable length. The process using a hand-operated microtome takes much time. Although this method may not be applied to the industrial analysis immediately from its complexity, we assume that the method has an essential role as a new quantitative analytical method among the similar related fibers, and their quality evaluation.

14:45 **Material Characterization With Frequency Domain THz Ellipsometry** **We-P1-R1-3**

Andreas Klein[1]; Polina Stefanova[1]; Andrew Gallant[2]; Claudio Balocco[1]
[1]Durham University, United Kingdom; [2]Durh, United Kingdom
A rotating-analyzer ellipsometer operating at THz frequencies is demonstrated. The instrument is based on a Network Analyzer operating at 0.75-1.1 THz and is used to characterize various materials for different parameters, e.g. permittivity and thickness measurements.

15:00 **The Atomic Dynamics Of Disordered Crystals Elucidated With Terahertz Time-Domain Spectroscopy And Ab Initio Simulations** **We-P1-R1-4**

Michael Ruggiero[1]; Johanna Kolbel[1]; Wei Zhang[2]; Daniel Mittleman[2]; J. Axel Zeitler[1]
[1]University of Cambridge, United Kingdom; [2]Brown University, United States
The nature of the low-frequency vibrational motions occurring within disordered solids has been a topic of great debate of the last several decades. Using a combination of experimental terahertz time-domain spectroscopy and state-of-the-art quantum mechanical simulations, the dynamics of disordered solids are obtained with atomic-level detail. Such understanding has wide-reaching implications, as these motions are responsible for many physical phenomena including spontaneous crystallisation, charge transfer, and pharmaceutical stability.

15:15 **Photo-carrier Dynamics Of MBE-grown GaAs On Silicon Studied By Optical-** **We-P1-**

pump Terahertz-probe **R1-5**

Jessica Afalla[1]; Karl Cedric Gonzales[2]; Joselito Muldera[1]; Elizabeth Ann Prieto[3]; Gerald Catindig[3]; John Daniel Vasquez[3]; Horace Husay[3]; Takeshi Moriyasu[4]; Hideaki Kitahara[1]; Dmitry Bulgarevich[1]; Valynn Mag-usara[1]; Takashi Furuya[1]; Armando Somintac[3]; Arnel Salvador[3]; Elmer Estacio[3]; Masahiko Tani[1]
[1]Research Center for Development of Far-Infrared Region, University of Fukui, Japan; [2]University of the Philippines Diliman, Philippines; [3]National Institute of Physics, University of the Philippines Diliman, Philippines; [4]Deparment of Applied Physics, School of Engineering, University of Fukui, Japan

GaAs films were grown on Si (100) substrates with a "two-step buffer" growth technique using molecular beam epitaxy, wherein a low temperature GaAs buffer is grown at two substrate temperatures prior to the GaAs layer. Results of GaAs layer growth at two different substrate temperatures are compared using photoluminescence, Raman, and optical-pump terahertz-probe spectroscopy.

14:00 - 15:30 We-P1-1b Metamaterial Structures and Applications III — Room 131+132

Session Type: Oral

14:00 **Sensitivity Enhancement For Asymmetric Split Ring Resonators In A Vertical Coupling Geometry** **We-P1-1b-1**

Tuan Anh Pham Tran; Peter Haring Bolívar
Institute for High Frequency and Quantum Electronics, University of Siegen, Germany

We present a new concept to enhance the sensitivity of asymmetric split ring resonators towards micro-mechanical modulation or sensing related tuning of the resonance. By changing the gap geometry to a vertical configuration, field concentration can be better localized at the gap between the split resonator structures gaps. Resonances can be shift to lower frequencies and attain a significantly enhanced tunability range while retaining good Q-factor.

14:15 **Diffraction Enhanced Transparency In A Hybrid Gold-Graphene THz Metasurface** **We-P1-1b-2**

Stan ter Huurne[1]; Niels van Hoof[1]; René Vervuurt[2]; Ageeth Bol[2]; Alexei Halpin[1]; Jaime Gómez Rivas[2]
[1]Dutch Institute for Fundamental Energy Research - DIFFER, Netherlands; [2]Eindhoven University of Technology, Netherlands

Diffraction enhanced transparency (DET) is a phenomenon based on interference in periodic lattices of resonators, leading to sharp transmission peaks where the associated anomalous dispersion can be used to delay THz radiation traversing the lattice. In this contribution we use an atomically thin graphene layer to strongly suppress DET altering the THz propagation. The response of this system is investigated both in the far- and near-field, where the suppression of DET can be measured both in the spectral response of the sample and in the changing near-field distributions surrounding the resonators. Changing the properties of the graphene layer allows for control over the transparency window, which is relevant for active THz devices.

14:30 **Bi-layer Metamaterial Based Broadband Linear Polarization Converter Under Two Coherent Beam Illumination** **We-P1-1b-3**

Wei Tan[1]; Caihong Zhang[2]; Hua Li[2]; Dacheng Wang[1]; Zheng Feng[1]; Biaobing Jin[2]
[1]Microsystem and Terahertz Research Center, CAEP, China; [2]Research Institute of Superconductor Electronics, Nanjing University, China

We demonstrate a bi-layer metamaterial structure with mirror symmetry that acts as a linear polarization converter under two antisymmetric beam illumination. Its high performance, including broad bandwidth, high transmittance and high efficiency, originates from the combination of two interference processes: the Fabry-PÃ©rot-like cavity effect between two metallic patterned layers and coherent excitations of spatially separated subwavelength resonators. Terahertz (THz) experiments show good agreement with numerical simulations.

14:45 **Anisotropic Dielectric Metamaterials With Multipolar Mie Resonances For High Efficiency Terahertz Polarization Control** **We-P1-1b-4**

Da-Cheng Wang; Wei Tan; Song Sun; Zheng Feng
Microsystem and Terahertz Research Center, China

Anisotropic terahertz dielectric metamaterials with multipolar Mie resonances are proposed and experimentally demonstrated in this work. The multiple interference

effects among different Mie resonances can suppress the reflection and enhance the transmission intensity. Different combinations of multipolar Mie resonance modes provide an alternative approach to alter the phase dispersion. By engineering the multiple interference effects, the anisotropic design can control the phase delay between two orthogonal directions to reach ½π and π with high transmission. Such anisotropic dielectric metamaterials can become a new paradigm for terahertz meta-devices.

15:00 **[Keynote] Broadband Terahertz Linear-to-Circular Polarization Conversion** **We-P1-1b-5**

Chun-Chieh Chang; Hou-Tong Chen
Los Alamos National Laboratory, United States
We use a bilayer anisotropic terahertz metasurface to demonstrate broadband linear-to-circular polarization conversion in reflection. In experiments the metasurface structure enables ~90% conversion efficiency, 55% fractional bandwidth, and nearly 100% degree of circular polarization. By simply rotating the metasurface by 90° it allows the conversion to the other circular polarization. Such a metasurface device can open a host of applications where circular polarization and modulation are desirable.

14:00 - 15:30 **We-P1-1c Imaging and Remote Sensing III** **Room 133+134**

Session Type: Oral

14:00 **A THz Imaging System Using Sparse Antenna Array For Security Screening** **We-P1-1c-1**

SHAOQING HU; Xiaodong Chen; Yasir Alfadhl
Queen Mary University of London, United Kingdom
We have simulated a realistic THz imaging scenario by using a MOM and RL-GO combined approach in FEKOTM. The simulation has shown that a 3.5 mm resolution at 4 m can be achieved by using the proposed sparse antenna array with a large element spacing of 5.13 wavelengths;. The result looks encouraging in view of the cost saving while retaining a good imaging performance. We are in the process of setting-up a verifying experiment in the Lab and hope to present some preliminary results in the time of conference.

14:15 **CMOS Terahertz Imaging Pixel With A Wideband On-chip Antenna** **We-P1-1c-2**

Yuri Kanazawa[1]; Shota Hiramatsu[2]; Eiichi Sano[1]; Sayuri Yokoyama[1]; Prasoon Ambalathankandy[1]; Masayuki Ikebe[1]
[1]Hokkaido University, Japan; [2]Sony, Japan
We propose a Si-CMOS terahertz image sensor to solve the paucity of low-cost detectors. The imager chip consists of imaging pixel array and column ADCs. The imaging pixel consists of an on-chip antenna and an amplifier acting as envelope detector. We fabricated the pixel array with two-types antennas which are microstrip-patch and folded-slot types, respectively by using 0.18 -μm CMOS process. Measurement results shows that the folded-slot antenna has about over 0 dBi gain at 900 GHz, and broader bandwidth from about 850 GHz to about 1.05 THz.

14:30 **0.35 THz Dynamic Aperture Far-field Imaging Using A Several 10k Pixel THz-SLM** **We-P1-1c-3**

Sven Augustin[1]; Peter Jung[2]; Sven Frohmann[3]; Tom Szollmann[2]; Heinz-Wilhelm Hübers[4]
[1]Humboldt Universität zu Berlin, Germany; [2]Technische Universität Berlin, Germany; [3]German Aerospace Center, Germany; [4]Humboldt-Universität zu Berlin, Germany
Here, we present imaging results of a 0.35 terahertz (THz) dynamic aperture imaging approach that uses (dithering), pseudo-random Bernoulli masks with an optically controllable THz spatial light modulator (SLM). It is shown that with this approach sub-wavelength resolution imaging can be achieved even in the far-field. The limits of this approach are discussed and it is proposed that with a dithering/convolution extension this approach can be improved further in terms of spatial resolution and reconstruction speed.

14:45 **Far-Infrared Remote-Sensing Enabled By Room-Temperature Thermopile Imagers** **We-P1-1c-4**

GIACOMO MARIANI; Matthew Kenyon; Sabah Bux; Zachary Small
NASA JET PROPULSION LABORATORY, United States

Thermal imaging is a remote-sensing technique capable of providing surface and atmospheric maps with high radiometric and spectral accuracy. Thermal imagers (TIs) based on thermopile technology are broadband, exhibiting a flat response over a wide spectral range (0.2-200μm), lightweight because no cryogenic cooler is required, and versatile as the detectors are insensitive to substrate temperature variations. This class of instruments has successfully flown on many missions such as Pioneer 10 & 11 (Infrared Radiometer), Voyager (IRIS instrument), Viking Orbiter (IRTM), Cassini (CIRS), Mars Reconnaissance Orbiter (MCS), and Lunar Reconnaissance Orbiter (Diviner). Thermopile pixels are inherently insensitive to instrument temperature drifts, and highly linear to incident radiation with overall detector sensitivity D*>10^9 cmHz^1/2/W @ 300K. The effort at JPL is to provide kilo-pixel arrays fully integrated with read-out integrated circuits (ROICs). Rigid-flex hybrid configurations are explored for plug-and-play focal plane module assemblies. Thermopiles are broadband, making them especially suitable for Earth and planetary missions. The objective of this work is to realize high-detectivity focal plane systems for far infrared detection at room temperature.

15:00 **[Keynote] Detection Of Terahertz Time-domain Signals With KIDs** **We-P1-1c-5**

Jean-Louis Coutaz[1]; Federico Sanjuan[1]; Gizem Soylu[1]; Emilie Herault[1]; Jean-Francois Roux[1]; Alessandro Monfardini[2]; Florence Levy-Bertrand[2]
[1]IMEP-LAHC, France; [2]Institut Neel, France
Kinetic induced detectors are used for the first time to measure time-domain THz signals generated by optical rectification or by photo-conducting antenna. We measured signals of average power as low as ~ 0.1 fW.

14:00 - 15:30 **We-P1-1a Sources, Detectors, and Receivers V** **Room 141+142**

Session Type: Oral

14:00 **Terahertz (THz) Direct Detectors Based On Superconducting HEBs With Thermal, Microwave And THz Biasing** **We-P1-1a-1**

Jian Chen
Nanjing Univ., China
Terahertz (THz) direct detectors based on superconducting niobium nitride (NbN) hot electron bolometers (HEBs) with thermal, microwave (MW) and THz biasing have been studied at 0.65 THz and 4.2 K systematically. The current responsivity and noise equivalent power (NEP) have been measured and compared respectively. The detectors with the MW and THz biasing have about one order higher current responsivity than that of the thermal one. With the MW biasing, an NEP at the order of pW/√Hz is obtained by choosing the MW frequency and power appropriately.

14:15 **Ultrabroadband Terahertz Detectors Based On CMOS Field-Effect Transistors With Integrated Antennas** **We-P1-1a-2**

Kęstutis Ikamas[1]; Dovilė Čibiraitė[2]; Maris Bauer[2]; Alvydas Lisauskas[1]; Viktor Krozer[2]; Hartmut Roskos[2]
[1]Vilnius University, Lithuania; [2]Johann Wolfgang Goethe-Universität, Germany
We report on the modeling, implementation and characterization of optimized, ultrabroadband antenna-coupled field-effect transistors for the detection of terahertz (THz) radiation. The detectors were fabricated in 90-nm silicon CMOS technology with integrated bow-tie and log-spiral antennas. We also investigated a third design with a narrowband dipole antenna. In the frequency range from 0.5 to 1.5 THz, the detector with the bow-tie antenna design exhibited a nearly flat frequency response at an optical responsivity of ~100 V/W. We found minimum optical noise equivalent powers (NEPs) as low as 48 pW/√Hz at 0.6 THz and 70 pW/√Hz at 1.5 THz. The dipole-design detector achieved an optical NEP of 17 pW/√Hz at resonance frequency of 490 GHz. Our detectors were optimized with the help of a self-developed circuit model based on device parameters such as transistor geometry, antenna impedance matching and the peculiarities of the employed fabrication technology.

14:30 **Terahertz Photon Counters For HBT Intensity Interferometry** **We-P1-1a-3**

Hiroshi Matsuo[1]; Hajime Ezawa[1]; Masahiro Ukibe[2]; Go Fujii[2]; Shigetomo Shiki[2]
[1]National Astronomical Observatory of Japan, Japan; [2]National Institute of Advanced Industrial Science and Technology, Japan
Photon counting detectors in terahertz frequencies are developed for future astronomical intensity interferometry. Superconducting tunnel junction detectors

with extremely low leakage current can be used for fast photon counting, more than a GHz bandwidth, in terahertz frequencies. We plan to demonstrate intensity correlation using antenna coupled SIS terahertz photon counters to measure the statistical behavior of thermal photons. This could bring a new measurement opportunity in the field of terahertz quantum optics.

14:45 **Investigating The Potential Of SiGe Diode In BiCMOS 55nm For Power Detection Or Datacom Applications At 300 GHz** **We-P1-1a-4**

Joao Carlos Azevedo Goncalves[1]; Issa Alaji[2]; Daniel Gloria[1]; Sylvie Lepilliet[2]; François Danneville[2]; Christophe Gaquière[2]; Guillaume Ducournau[2]
[1]STMicroelectronics, France; [2]IEMN, France

This paper describes millimeter wave (mmW) on-wafer power detection using dedicated high frequency diode junction with a cut-off frequency (fc) up to 2 THz, integrated in SiGe BiCMOS 55 nm technology from STMicroelectronics. This extraction was performed in order to evaluate the potential of this diode junction for power detection as well as sub-Terahertz Transmission Link on 220 to 320 GHz Frequency Range. The power detection is performed by biasing the diode on its forward regime. That, allows to obtain a voltage responsivity (γ) stands roughly around 2000 V/W within the whole frequency band.

15:00 **[Keynote] THz Detection With Field-effect Transistors: The Role Of Plasma Waves And Of Thermoelectric Contributions** **We-P1-1a-5**

Hartmut Roskos[1]; Maris Bauer[1]; Kestutis Ikamas[2]; Florian Ludwig[1]; Alvydas Lisauskas[2]
[1]Goethe-University Frankfurt, Germany; [2]Vilnius University, Lithuania

Field-effect transistors owe their usefulness as detectors of THz radiation (TeraFETs) to their rectification capability. At low frequencies, the dominant mechanism is resistive mixing, supported at THz frequencies by the Dyakonov-Shur mechanism involving charge density waves in the transistor's channel. Additionally, a hot-carrier photo-thermoelectric effect can significantly contribute. We have developed a hydrodynamic transport model and implemented it in a commercial device simulator which handles these contributions on an equal footing. We show that thermoelectrics can significantly contribute not only in graphene TeraFETs but also in devices made from conventional semiconductors such as AlGaN/GaN TeraFETs. The simulations also allow us to address the question of why it has proven to be difficult to experimentally verify the signal enhancement by Fabry-Perot-like plasmon resonances in the channel predicted by Dyakonov and Shur to occur at high frequencies.

14:00 - 15:30 We-P1-R2 Quantum Cascade Lasers II — Reception Hall

Session Type: Oral

14:00 **Ultra-stable Heterodyne Detection In The Mid-IR** **We-P1-R2-1**

Djamal Gacemi; Yanko Todorov; Azzurra Bigioli; Daniele Palaferri; Carlo Sirtori
MPQ Lab University Paris 7, France

In this work we demonstrate the use of a stabilized Mid-infrared quantum cascade laser as a local oscillator for ultra-sensitive Mid-IR heterodyne detection. We show a measurement of 80dB signal to noise ratio GHz heterodyne signal measured with a resolution bandwidth of 1 Hz using ultrafast quantum well infrared photodetector.

14:15 **Continuous-wave Highly Efficient Low-divergence Terahertz Wire Lasers** **We-P1-R2-2**

Simone Biasco[1]; Katia Garrasi[1]; Fabrizio Castellano[1]; Lianhe Li[2]; Harvey Beere[3]; David Ritchie[3]; Edmund Linfield[2]; Giles Davies[2]; Miriam Vitiello[1]
[1]NEST, CNR-Istituto Nanoscienze and Scuola Normale Superiore, Italy; [2]School of Electronic and Electrical Engineering, University of Leeds, United Kingdom; [3]Cavendish Laboratory, University of Cambridge, United Kingdom

In recent years Terahertz (THz) quantum cascade lasers (QCLs) have undergone a fast development, showing high power, ultra-broadband gain and quantum-limited linewidth. For many applications, THz QCLs need to provide continuous-wave (CW) operation, tight control of the emission spectrum and highly collimated beam profiles. These requirements have been addressed exploiting distributed feedback (DFB), photonic crystals or micro-cavities, tailoring either the laser beam divergence or emission frequency, or both of them simultaneously in the case of third-order DFBs. Here we report a novel architecture consisting in a wire DFB THz QCL, which is based on a lateral sinusoidal corrugation for the feedback and

frequency control, while an array of surface hole provides light outcoupling. This new photonic structure has led to the achievement of low-divergent beams (10°), single-mode emission, high slope efficiencies (250 mW/A), and stable CW operation.

14:30 **Epitaxial Growth Of InGaSb Layers On GaAs Substrates For Fabrication Of InGaSb-based THz-QCLs** **We-P1-R2-3**

Hiroaki Yasuda
National Institute of Information and Communications Technology, Japan

We propose InGaSb-well-based THz-QCLs for higher temperature operation. For the preparation of the MBE growth of the InGaSb-well-based QCLs, we optimize growth conditions of InGaSb layers on a GaAs substrate with introducing an $In_xGa_{1-x}Sb$ graded buffer layer.

14:45 **High-speed Pure Frequency Modulation And Pulse Optimization Based On A Quantum Cascade Laser By All-optical Modulation** **We-P1-R2-4**

Ze-Ren Li; Tao Chen; Liguo Zhu; Chen Peng
Institute of Fluid Physics, China Academy of Engineering Physics, China

Purified frequency modulation is demonstrated in a middle-infrared quantum cascade laser by illuminating its front facet with two optimized near infrared lasers. Pulse control and optimization are demonstrated in a standard middle-infrared quantum cascade laser via an all optical approach. It has the potential for application in free space optical communication and high speed frequency modulation spectroscopy.In conclusion, a purified FM of QCL with all optical approach has been presented for the first time, based on positive and negative AM of QCL with different NIR exciting wavelengths. Compared with the electric drive, the QCL pulse rise and fall times are shortened by 3/4 and 2/5, respectively. Simultaneously, we can precisely adjust the QCL pulse width, amplitude, and repetition rate. The optical approach can be used in MIR FSOC and high speed frequency modulation spectroscopy application.

15:00 **[Keynote] Broadband On-chip THz Frequency Combs** **We-P1-R2-5**

Giacomo Scalari; Andres Forrer; Tudor Olariu; David Stark; Mattias Beck; Jerome Faist; Giacomo Giacomo Scalari
ETH Zürich, Switzerland

Recently, on-chip quantum-cascade-laser-based frequency combs are gaining increasing attention both in the Mid-IR and in the THz spectral regions. THz devices offer the possibility of filling the gap of comb sources in a spectral region were no table top comb is available. We will report on recent progresses including broadband (>1 THz) comb generation, dual color comb source operating as combs and spaced by exactly one octave in frequency and new homogenous laser design with ultra broad bandwidth.

14:00 - 15:30 **We-P1-4 Gyro-Oscillators and Amplifiers III** **Room 432**
Session Type: Oral

14:00 **Theoretical Analysis Of Gyrotron Self-Injection Locking By Delayed Reflection** **We-P1-4-1**

Maria Melnikova[1]; Alexandra Tyshkun[1]; Andrey Rozhnev[2]; Nikita Ryskin[2]
[1]Saratov State University, Russian Federation; [2]Saratov Branch, Institute of Radio Engineering and Electronics RAS, Russian Federation

Self-injection locking by delayed reflection becomes a popular method for improving frequency stability and enhance of the frequency tunability of a gyrotron oscillator. In this paper, we develop a theoretical model of a self-injection-locked gyrotron and analyze the influence of reflections on frequency tuning by magnetic field. The results of theoretical analysis are verified by numerical simulation of time-dependent fixed-field and self-consistent models of a gyrotron.

14:15 **Pulse Test Of A W-band Second Harmonic Gyrotron Based On A 1.8 T Continuous Operation Solenoid** **We-P1-4-2**

Dimin Sun; Tingting Zhuo; Guowu Ma; Linlin Hu
Institute of Applied Electronics, China Academy of Engineering Physics, China

The pulse test results of a W-band second harmonic gyrotron based on a 1.8 T continuous operation solenoid is presented. When the solenoid is driven by a DC current of 500 A, magnetic field of 1.8 T in the gyrotron cavity region is generated. The power consumption of the solenoid is 21.5 kW. A W-band second harmonic gyrotron was built based on this solenoid. In the pulse test, the operating mode TE02 frequency of 94.22 GHz was observed. The output power is 11.4 kW when driven by an electron beam of 44 kV, 1.6 A, corresponding to an efficiency of

16.2%. These results indicated that a medium power W-band, CW gyrotron without superconducting magnet could be realized.

14:30 **Study On Approach Of Ultra-wide Band Step Tuning Across Multiband In A Gyrotron** **We-P1-4-3**

Guowu Ma; Linlin Hu; Dimin Sun; Tingting Zhuo; Yinhu Huang; Hongbin Chen; Fanbao Meng
Institute of Applied Electronics, China Academy of Engineering Physics, China

An approach of ultra-wide band step tunable gyrotron across multiband is proposed in the paper. A series of modes are selected according to the transmission conditions of the quasi-optical system which is consisted of a Vlasov launcher, a quasi-parabolic mirror and other reflectors. The use of a cavity with small tapered inner wall makes the modes have similar currents and quality factors, which is beneficial to the output power homogenization of each mode in the tuning bandwidth. The time-dependent multimode calculation results show that the gyrotron cavity can be tuned from 33.3 GHz to 170.56 GHz by changing the magnetic field with a fixed orbital-to-axial velocity ratio of 1.5 and a step interval of 27.5 GHz. An output power of about 100 kW level at each frequency is achieved.

14:45 **Two-Stage Energy Recovery System For THz Band Double-Beam Gyrotron** **We-P1-4-4**

Vladimir Manuilov[1]; Vladislav Zaslavsky[2]; Irina Zotova[2]; Toshitaka Idehara[3]; Mikhail Glyavin[2]
[1]Insitute of Applied Physics RAS, Russian Federation; [2]Institute of Applied Physics RAS, Russian Federation; [3]FIR UF, Japan

The development of the sub-terahertz radiation sources with output power about tens watt opens the way to create the new generation of high-field DNP-NMR spectroscopy. From this point, one of the most promising tubes in the THz band are CW gyrotrons, operating on the second or even third cyclotron harmonic, which combines rather small size, weight and cost. High-harmonic operation needs improved methods of mode selection. It can be successfully solved in double-beam gyrotrons [2]. The typical feature of sub-millimeter gyrotrons is rather low efficiency, which usually does not exceed some percent at least. The energy recovery system (CPD-collector) successfully used to increase the total efficiency. For conventional gyrotrons the one-stage CPD makes possible to increase the efficiency in 1.5 times. More effective is two-stage energy recovery systems, allowing increase the gain more than 2 times, but two-stage collector needs the special complicated system for the separation of the energy fractions. . Fortunately,, the double-beam gyrotrons no need additional system for space separation of two beams. So, it is quite natural check the possibility to use the two-stage energy recovery system at double-beam gyrotrons. Below analysis of two stage CPD system for the double-beam CW 0.79 THz gyrotron with two generating beams is performed.It is shown that it is possible to increase the total efficiency of gyrotron more than 4 times and correspondingly to decrease the power load of the collector. It allows utilize the small and simple adiabatic cylindrical collector with diameter 20 mm only and at the same time to provide the power density not more than 0.4 kW/cm2, that is quite suitable for CW regime.

15:00 **High-power Ultra-wideband Operation Of The JINR-IAP FEM-amplifier** **We-P1-4-5**

Nikolai Peskov[1]; Alim Kaminsky[2]; Sergey Sedykh[2]; Ilya Bandurkin[1]; Andrey Savilov[1]; Vladislav Zaslavsky[1]
[1]Institute of Applied Physics RAS, Russian Federation; [2]Joint Institute for Nuclear Research, Russian Federation

Powerful high-efficiency FEM-amplifiers operating over Ka frequency range have been developed in collaboration between IAP RAS and JINR. Potential to reach a broad amplification band in different regimes of e-beam/RF-wave interaction was investigated theoretically and examined in the series of experiments. In the FEM with a regular wiggler operating in the so-called grazing incident regime, output power of 20 MW was simulated in the frequency range of 30 Ã‚Â± 2 GHz. In the experiments, the designed power level and the instantaneous band of about 1 GHz (restricted by the tuning band of the driving magnetron) were achieved. According to the simulations, the use of original regime of non-resonant trapping in tapered wiggler allows enhance in the output power up to 35 - 40 MW with simultaneous widening of the amplification band. In the experimental realization of this novel FEM scheme, an output power on the level of 25 MW was measured when various

magnetrons with the frequencies in the range from 29 GHz to 35 GHz were utilized to drive the amplifier.

15:15 **Generation Of Train Of Ultrashort Ka-band Pulses By Helical Gyro-TWTs With Nonlinear Cyclotron Resonance Absorber In The Feedback Loop** **We-P1-4-6**

Naum Ginzburg; Grigory Denisov; Mikhail Vilkov; Alexander Sergeev; Sergey Samsonov; Irina Zotova
Institute of Applied Physics, Russian Federation

Based on a time-domain model we demonstrate that a periodic train of powerful ultrashort microwave pulses can be generated in an electron oscillator consisting of helically corrugated gyrotron travelling wave tube (gyro-TWT) and saturable absorber based on cyclotron resonance interaction of radiation with initially rectilinear electron beam. The gyro-TWT operates at the second cyclotron harmonic while in the absorber interaction at the fundamental harmonic should be realized. According to simulations with the parameters of an experimentally realized Ka-band gyro-TWT, the peak power of generated pulses with duration of 200 ps is about 400 kW.

15:30 - 17:00 **We-POS Poster Session** **Event Hall**

Session Type: Poster

15:30 **Infrared Spectroscopic Tracing Of Hydration/dehydration Processes Of Dry Yeast Cells** **We-POS-01**

Natsuki Matsuoka; Satoru Nakashima
Osaka University, Japan

Hydration/dehydration processes of dry yeast cells have been monitored by infrared micro-spectroscopy under controlled relative humidity and temperature. Changes in IR absorption bands of water together with those of amides (proteins) and lipids were analyzed during transitions among dormancy, live and dead states.

15:30 **Developments To Enhance The Feasibility Of SMILES-2 Mission** **We-POS-02**

Satoshi Ochiai[1]; Philippe Baron[2]; Yoshihisa Irimajiri[2]; Yoshinori Uzawa[2]; Toshiyuki Nishibori[3]; Yutaka Hasegawa[3]; Akinori Saito[4]; Masato Shiotani[4]
[1]National Institute of Information and Communications Technology (NICT), Japan; [2]National Institute of Information and Communications Technology, Japan; [3]Japan Aerospace Exploration Agency, Japan; [4]Kyoto University, Japan

SMILES-2 is a spaceborne mission using THz superconducting receiver for measurement of the atmospheric thermal limb emission. The mission concept is prepared for a proposal to JAXA/ISAS M-class scientific satellite mission. SMILES-2 will measure wind, temperature, atmospheric compositions, and their diurnal cycles. Three-band receiver at 638 GHz, 763 GHz, and 2 THz can cover the unprecedented wide altitude range of wind and temperature observation. A technical concern of the mission is a large power consumption comparing to the resource on an M-class satellite on a non-sun-synchronous orbit. Large power is necessary to operate cryocooler for cooling superconducting devices that work at temperature of around 4 K. We are studying measures to reduce the power consumption of the mission payload.

15:30 **Enhanced Transmission Of THz Radiation Through Fe2+: ZnSe Crystals** **We-POS-04**

Maria Zhukova[1]; Yaroslav Grachev[1]; Anton Tcypkin[1]; Sergey Putilin[1]; Vladimir Chegnov[2]; Olga Chegnova[2]; Victor Bespalov[1]
[1]ITMO University, Russian Federation; [2]Research Institute of Materials Science and Technology, Russian Federation

By doping ZnSe crystals with Fe^{2+} ions at a level of 0.23 wt. %, the transmission of broadband terahertz (THz) radiation from 0.4 to 0.5 THz range have been enhanced for up to 20%. The sample transmission was carried out using a terahertz time-domain spectroscopy setup. To explain the arising effect and changes in band structure, non-linear absorption of undoped and Fe-doped ZnSe samples was studying using femtosecond pump - supercontinuum probe spectroscopy in visible and NIR spectral ranges. Such enhanced transmission of Fe^{2+}: ZnSe can be applied for creating terahertz radiation control devices.

15:30 **Broadband Electron Paramagnetic Resonance Using A Tunable Continuous-Wave Terahertz Photomixer Source** **We-POS-05**

Eiji Ohmichi; Tatsuya Fujimoto; Keisuke Minato; Hideyuki Takahashi; Hitoshi Ohta
Kobe University, Japan

We developed a novel broadband electron paramagnetic resonance (EPR) technique

using a tunable continuous-wave (CW) terahertz(THz) source. A photoconductive antenna (PCA) generates frequency-tunable THz waves in a wide frequency region of 0.05-1.1 THz as a beat frequency of two laser beams with different wavelengths. We successfully observed EPR signals of some samples at room temperature in a transmission setup. Advantages of this technique are its high dynamic range of homodyne detection and continuously tunable THz generation/detection. Thus, high-resolution EPR spectroscopy as well as frequency-swept EPR experiment will become possible using this technique.

15:30 **Terahertz Optical Characteristics Of Organometallic Lead-iodide (Bromide) Perovskites And Cesium Lead Halide Nanocrystals** **We-POS-06**

Alexander Andrianov; Andrey Aleshin
Ioffe Institute, Russian Federation

Optical properties of organometallic lead-iodide (bromide) perovskites CH3NH3PbI3 (CH3NH3PbBr3) and cesium lead halide nanocrystals CsPbI3 have been studied in the 0.2-2.9 THz spectral range. THz spectra of CH3NH3PbI3 perovskite demonstrate several resonant features, which were previously attributed to low-frequency phonon modes associated with vibrations of Pb-I bonds. However, observed changes in THz spectra of studied perovskites under substitution of I by Br or methyl-ammonium group (CH3NH3) by Cs make the previous interpretation of main low-frequency phonon modes in CH3NH3PbI3 perovskite questionable. It is conceivable that vibrations of cation (CH3NH3+, Cs+) strongly contribute to the formation of main THz phonon modes of the perovskite.

15:30 **THz- And Mid IR Fourier Transform Spectroscopy On Physical Aged Polyethylene** **We-POS-07**

Joerg Beckmann[1]; Ulrich Schade[2]; Matthias Jaunich[1]; Dietmar Wolff[1]
[1]Federal Institute for Materials Reseach and Testing (BAM), Germany; [2]Helmholtz Zentrum Berlin für Materialien und Energie, Germany

THz and mid IR spectroscopy of high-molecular PE (HMW) and ultra high-molecular PE (UHMW) reveals modifications of the molecular structure. Characteristic absorption bands are changed if the two materials are exposed by γ-Co60 radiation up to 600 kGy and subsequently stored at an annealing temperature of 398 K until for 729 days. UHMW-PE and HMW-PE behave differently during the ageing process because of their molecular weight and inherent structure distinctions. The spectroscopic data offer characteristic absorption bands, which have been used to describe the complete ageing process in more detail. For instance, the integral absorption in the B_{1u} THz-region can be used to describe quantitatively the reduction of crystallinity. The formation of trans vinylene unsaturation and the decay of vinyl during ageing can be observed in detail in the mid IR range.

15:30 **PHASE-MATCHING FOR THz-WAVE GENERATION AND MIXING IN KTP CRYSTAL** **We-POS-08**

ZHIMING HUANG[1]; JINGGUO HUANG[1]; YANQING GAO[1]; GAOFANG LI[1]; YURY ANDREEV[2]; Grygory Lanskii[2]; NAZAR NIKOLAEV[3]; ALEXANDR MAMRASHEV[3]; DMITRII EZHOV[4]; VALERII SVETLICHNY[4]
[1]Shanghai Institute of Technical Physics CAS, China; [2]Institute of Monitoring of Climatic and Ecological Systems SB RAS, Russian Federation; [3]Institute of Automation & Electrometry SB RAS, Russian Federation; [4]Siberian Physical-Technical Institute of Tomsk State University, Russian Federation

Several THz applications, such as stand-off THz imaging and remote environmental studies, require mobile sources of high-power THz radiation with a central frequency of 0.1- 0.5 THz. This spectral region is particularly attractive because of the low absorption by water vapor in ambient air, which allows propagation of the THz waves for up to several km under typical atmospheres. Pure and MgO-doped LiNbO3 crystals demonstrated top efficiency and output powers in generation of ultrashort THz pulses in this spectral range under TW laser pumping. To overcome strong (10 -100 cm-1) absorption and group velocity mismatch, near surface geometry of the tilted-pulse-front pumping was used with aside output of THz waves. A three- to fivefold increase of the terahertz energy was demonstrated and theoretically confirmed by cooling the LN, which significantly reduced the terahertz absorption that allowed to increase generation efficiency. Further increase of the efficiency is problematic owing to the strong temperature dispersion of optical properties of LiNbO3 crystals. On the other hand, it is well known that oxide Potassium Titanyl Phosphate (KTiOPO4 or KTP) crystal can generate very high average output power of SHG (up to 300 W at 532 nm) and its properties are

insensitive to temperature variations. However, its optical properties and potential in THz wave generation is not studied yet. In this study, for the first-time, optical properties of high resistivity KTP crystal were studied by THz TDS among 5 - 300 K temperature range. It showed a smaller absorption coefficient than that of LiNbO3 crystal. Dispersion equations of KTP were formulated. Phase-matching for down-conversion of near IR radiation into and frequency conversion within the THz range were found feasibly. These properties render KTP crystal as very prospective for high power THz generation.

15:30 **Simple THz Faraday Spectroscopic System Using A Phase Shifter** **We-POS-09**

Atsushi Nakane; Tomohide Morimoto; Masaya Nagai; Masaaki Ashida
Osaka University, Japan

We demonstrate the terahertz Faraday spectroscopy using a low-cost phase shifter to detect the phase difference of circularly polarized THz pulse. This technique opens new and sensitive magneto-THz spectroscopy.

15:30 **Temporal Frequency Distribution Of THz Pulses By Changing Pump Pulse Conditions** **We-POS-10**

Junichi Hamazaki[1]; Norihiko Sekine[2]; Akifumi Kasamatsu[2]; Iwao Hosako[2]
[1]National Institute of Information and Communications Technology, Japan; [2]NICT, Japan

We have addressed temporal frequency chirped terahertz pulses to open possibilities of THz technologies. For this purpose, we investigate temporal frequency distributions of THz pulses generated from GaP crystal via optical rectification effect by using Hilbert transform analysis. It is observed that the distributions are changed drastically with respect to the chirp of the pump pulse. At certain chirp, non-trivial temporal frequency distribution, i.e., Λ- and/or V-shaped frequency shifts are observed. Using a simple model, origin of various temporal frequency distributions is discussed.

15:30 **Development Of Millimeter-Wave Fabry-Pérot Resonator For Simultaneous Electron-Spin And Nuclear-Magnetic Resonance Measurement At Low Temperatures** **We-POS-11**

Yutaka Fujii[1]; Yuya Ishikawa[1]; Yuta Koizumi[1]; Tsunehiro Omija[1]; Kenta Ohya[1]; Shunsuke Miura[2]; Akira Fukuda[3]; Seitaro Mitsudo[1]; Hidetomo Yamamori[2]; Hikomitsu Kikuchi[2]
[1]Research Center for Development of Far-Infrared Region, University of Fukui, Japan; [2]Graduate School of Engineering, University of Fukui, Japan; [3]Department of Physics, Hyogo College of Medicine, Japan

We have developed millimeter-wave Fabry-PÃ©rot type resonator (FPR) aiming for simultaneous electron-spin and nuclear-spin resonance (ESR/NMR) measurements at very low temperatures below 1 K. The flat mirror of FPR is fabricated using a gold thin layer in order to minimize disturbance to radio frequency wave for NMR. An optimum thickness of the gold layer by measuring Q value is found. We actually succeeded to detect both ESR and NMR at very low temperatures.

15:30 **Measurement Of Coupling Properties Of Free Space Terahertz-wave To Surface Plasmon Resonator** **We-POS-12**

Yu Tokizane[1]; Jun-ichi Shikata[2]; Yuma Takida[1]; Hiroaki Minamide[1]
[1]RIKEN, Japan; [2]Nihon University, Japan

Angle dependence of the coupling properties between surface plasmon and free-space THz-wave was studied using a bull's eye structure. The split of coupling wavelength was the first ever measured in the THz frequency region.

15:30 **Measurement Of The Dielectric Constant Of Optically Dense Materials By Polarization-sensitive Terahertz Ellipsometry** **We-POS-13**

Quan Guo; Dongwen Zhang; Yindong Huang; Jianmin Yuan
National University of Defense Technology, China

We constructed a terahertz ellipsometry that can measure both transversal electric field components simultaneously. To illustrate the reliability of this system, we measured a Si wafer with a resistivity of 0.05Ω·cm which is an optically dense material in THz band. The simultaneous detection of the orthogonal components shows a well precision of the dielectric constant. The difference between the experimental data and the Drude model means imperfect qualities of the optical elements and the accuracy of the system should be improved by some calibration ways.

15:30 **High-Index, Low-Loss Nd3+:Oxyfluorosilicate Glasses For THz Applications** **We-POS-14**

Ramachari Doddoji[1]; Chan-Shan Yang[2]; Chun-Ling Yen[1]; Chao-Kai Wang[1]; Osamu Wada[3]; Ci-Ling Pan[1]
[1]Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan, Taiwan; [2]Institute of Electro-optical Science and Technology, National Taiwan Normal University, Taipei 11677, Taiwan; [3]Office for Academic and Industrial Innovation (Oacis), Kobe University, Kobe 657-8501, Japan, Japan
The refractive index and absorption loss of Nd3+:OFS glasses were found to be 3.7 and below 10 cm-1 at 0.5 THz, respectively. Based on the present results, ZNbKLSNd glasses are expected to be useful for low-loss, high refractive index, and even highly nonlinear materials in THz applications.

15:30 **Enhanced Terahertz Emission Of GaAs Microstructures** **We-POS-15**

Inhee Maeng[1]; Gyu-Seok Lee[1]; Chul Kang[1]; Gun-Wu Ju[1]; Kwang Wook Park[2]; Seoung-Bum Son[3]; Yong-Tak Lee[1]; Chul-Sik Kee[1]
[1]Gwangju Institute of Science and Technology, Korea, Republic of; [2]Korea Advanced NanoFab Center, Korea, Republic of; [3]National Renewable Energy Laboratory, United States
We observed the enhancement of terahertz radiation emitted from GaAs microstructures under wavelength tuned optical excitation. GaAs microstructure thin films were prepared by molecular beam epitaxy method. The peak amplitude of terahertz radiation from GaAs microstructure is more than eight times that from semi-insulating GaAs.

15:30 **Development Of Millimeter-Wave Electron-Spin-Resonance Measurement Apparatus For Ultralow Temperatures And Its Application To Measurement Of CuPzN** **We-POS-16**

Yuya Ishikawa[1]; Yutaka Fujii[1]; Kenta Ohya[1]; Yuta Koizumi[1]; Shunsuke Miura[2]; Seitaro Mitsudo[1]; Akira Fukuda[3]; Takayuki Asano[2]; Takao Mizusaki[1]; Akira Matsubara[4]; Hikomitsu Kikuchi[2]; Hidetomo Yamamori[5]
[1]Research Center for Development of Far-Infrared Region, University of Fukui (FIR-UF), Japan; [2]Department of Applied Physics, University of Fukui, Japan; [3]Department of Physics, Hyogo College of Medicine, Japan; [4]Department of Physics, Graduate School of Science, Kyoto University, Japan; [5]Technical division, Graduate School of Engineering, University of Fukui, Japan
1.Introduction

Electron spin resonance can help us directly observe the interactions between electrons and between electrons and nuclei, and ESR is an effective method for investigating the static and dynamical behaviors of spin systems [1-3]. Very low temperatures are often required to study the quantum nature of, or ground states in, quantum materials, such as quantum-spin systems, in order to suppress thermal fluctuations [4]. At ultralow temperatures, one encounters the problem of heating of the sample by the power of the electromagnetic waves used for the measurements. In order to overcome this technical difficulty, it is necessary to know the sensitivity of the measurement system and the relation between the sample temperature and the electromagnetic-wave power. In this paper, we show our developed measurement apparatus and describe one possibility for such a temperature sensor that we have found in a spin-1/2 quasi one dimensional antiferromagnet compound [5], copper pyrazine dinitrate Cu(C4H4N2)(NO3)2, or CuPzN for short.

2.Developments and Experimental Result

We have developed a high-frequency ESR measurement system that can perform over the frequency range of 125--130 GHz at temperatures below 1 K. The lowest temperature at which we have performed ESR measurements in the present work is 0.25 K. We have also developed a tunable FPR with a piezo actuator that enables us to change the frequency. We have demonstrated the tunability of the FPR by moving the piezo actuator at 2.6 K and have shown that one can select a frequency with a better S/N ratio. Moreover, we performed ESR measurements on single-crystal CuPzN, a Heisenberg antiferromagnetic quantum-spin chain, and we observed the two predicted ESR lines corresponding to the two different copper sites. From ESR measurements on CuPzN at 128.9 and 129.6 GHz in the temperature range from 6.5 to 0.25 K and with magnetic fields applied close to the

l direction (which is intermediate between the b-axis and the c-axis), we have found that the split width between the two ESR lines increases continuously with decreasing temperature down to the lowest temperature reached in this investigation [6]. The rate of increase of the split width due to the temperature change is nearly the same for the two experiments. We thus point out that CuPzN is useful as a temperature sensor for the ultralow-temperature region down to 0.25 K.

15:30 **Significant Electric Near-field Enhancement In Ringlike Structures** **We-POS-17**

Valerii Trukhin[1]; Miron Kagan[2]; Stanislav Paprotskiy[2]
[1]ITMO University, Ioffe Institute, Russian Federation; [2]Kotelnikov Institute of Radio Engineering and Electronics, Russian Federation
We report on the experimental study of the signal of near-field contribution to scattering of THz electromagnetic waves in ringlike microstructures using terahertz near-field microscope. It was established that terahertz near-field signal is strongly enhancement inside the ring.

15:30 **About Effect Of The Temperature Operating Conditions On The Noise Temperature And Noise Bandwidth Of The Terahertz Range NbN Hot-Electron Bolometers** **We-POS-18**

Ivan Tretyakov; Natalya Kaurova; B. M. Voronov; Gregory Goltsman
MSPU, Russian Federation
Results of an experimental study of the noise temperature (Tn) and noise bandwidth (NBW) of the superconductor NbN hot-electron bolometer (HEB) mixer as a function of its temperature (Tb) and NbN bridge length are presented. It was determined that the NBW of the mixer is significantly wider at temperatures close to the critical ones (Tc) than are values measured at 4.2 K. The NBW of the mixer measured at the LO frequency of 2.5 THz at temperature Tb close to Tc was ~13 GHz, as compared with 6 GHz at Tb = 4.2 K. This experiment clearly demonstrates the limitation of the thermal flow from the NbN bridge at Tb ~ Tc for mixers fabricated on the in situ technique. This limitation is close in its nature to the Andreev reflection on the superconductor/metal boundary. In this case, the noise temperature of the studied mixer increased from 1000K to 3500 K.

15:30 **0.34-THz High-Temperature Superconducting Josephson-Junction Mixer With Superior Noise And Conversion Performance** **We-POS-19**

Xiang Gao[1]; Ting Zhang[2]; Jia Du[1]; Yingjie Guo[2]
[1]Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia; [2]University of Technology Sydney, Australia
We present, in this work, a new thin-film antenna-coupled high-temperature superconducting (HTS) Josephson-junction terahertz (THz) mixer that demonstrates superior performance at frequencies around 0.34 THz. A novel dual-meander-slot thin-film antenna is designed to significantly improve the antenna-junction impedance matching and thus more efficient coupling of the THz signal power. Theoretical and experimental investigations are carried out to evaluate the mixer performance. This mixer can be applied to the sensitive THz wireless receivers.

15:30 **Characteristics Of VOx Microbolometer On Si3N4/SiO2 Membrane Fabricated By Deep-RIE And XeF2 Vapor Etching For THz-detectors** **We-POS-20**

Kohei Maeda[1]; Van Nhu Hai[1]; Kunio Nishioka[2]; Akihiro Matsutani[2]; Takashi Tachiki[1]; Takashi Uchida[1]
[1]National Defense Academy, Japan; [2]Tokyo Institute of Technology, Japan
VOx thin films were fabricated on Si3N4/SiO2/Si substrates by metal-organic decomposition (MOD). Then, a VOx microbolometer was fabricated on a Si3N4/SiO2 membrane. A membrane was realized by dry etching of the backside of the Si substrate using a Deep-RIE and XeF2 vapor etching with a good reproducibility. The DC sensitivity of the bolometer on membrane was 2310 W-1. This value was about 15 times higher than that of the VOx microbolometer on the Si3N4/SiO2/Si substrate and about two orders of magnitude higher than that of the Bi microbolometer on a dielectric substrate.

15:30 **Antenna-Coupled Terahertz Microbolometers With Meander Structures: The Comparison Of Titanium And Platinum Thermistors** **We-POS-21**

NORIHISA HIROMOTO[1]; AMIT BANERJEE[2]; DURGA ELAMARAN[1]; HIROAKI SATOH[1]; CATUR APRIONO[3]; DAI ITOH[1]; ERIK BRUENDERMANN[4]; EKO TJIPTO RAHARDJO[3]; HIROSHI INOKAWA[1]

[1]Shizuoka University, Japan; [2]National University of Singapore, Singapore; [3]Universitas Indonesia, Indonesia; [4]Karlsruhe Institute of Technology, Germany
Uncooled terahertz (THz) detectors with low noise-equivalent power (NEP) are especially important for the application of non-destructive sensing in many fields. Antenna-coupled THz microbolometers with meander thermistors of titanium (Ti) and Platinum (Pt) are studied to develop room-temperature THz detectors. The responsivity and NEP of the microbolometer with a meander Ti thermistor are much improved for 1 THz irradiation in comparison with those of the previous one with a straight Ti thermistor. The THz performance of the meander Ti bolometer is much better than the one with a meander Pt thermistor. Those results can be explained by the increase of the thermistor resistance and temperature coefficient of resistance (TCR) through innovating the meander line and also improving the fabrication process based on the electron beam (EB) lithography. The widths and lengths of the meander line of the titanium (Ti) or platinum (Pt) thermistors are 0.1 μm and 90 μm and 0.2 μm and 49 μm. A Ti heater is used because Ti has relatively large resistivity in all metals and the bulk resistivity of Ti is 4-time larger than that of Pt. The heater of Ti is directly connected to the antennas made of gold (Au). The length of the dipole antenna including a Ti heater is 52 μm which fits to resonance length of a half wavelength of 1 THz wave on the Si surface. The resistances of Ti and Pt thermistors of 0.1 μm wide lines in the THz antenna-coupled microbolometers are 16 kΩ and 4 kΩ respectively. The THz responsivity of Ti's is 36 time higher than that of Pt's. The noise of the Ti's was 4 time larger than the Pt's. If the THz radiation power within the area equal to square of the wavelength on the Si surface (119 μm for 1 THz) is absorbed, the NEP of the antenna-coupled microbolometers with Ti and Pt meander thermistors are 1.8×10^{-10} W/Hz$^{1/2}$ and 1.5×10^{-9} W/Hz$^{1/2}$ respectively, which shows the Ti's is 12 time better than the Pt's. It is improved by 2.5 times compared with the previous study. These results can be explained by the increase in the resistance and TCR of Ti lines of 100 nm order . The THz responsivity of the antenna-coupled microbolometer with Ti thermistor is consistent with the electrical measurement. It is also consistent with the theoretical analysis using the effective area of antenna deduced by the electromagnetic simulation and the area in which the antenna absorbs the THz irradiation.

15:30 **Cavity Mode Evaluation Of THz-wave Oscillators Using Superconducting Bi-2212 Intrinsic Josephson Junctions For High Power Generation** **We-POS-22**

Takashi Tachiki; Takashi Uchida
National Defense Academy, Japan
Three radiation power peaks of terahertz-waves were observed at different bias voltages applied to a rectangular $Bi_2Sr_2CaCu_2O_{8+\delta}$ mesa-type oscillator. The radiation frequencies at these peaks were estimated to be 0.302, 0.499 and 0.649 THz, and the cavity modes producing the radiation were evaluated as the 112, 111 and 121 modes, respectively. The maximum power was obtained at the peak for the 121 mode. The numerical simulations using a 3D cavity model indicated that the radiation power of an oscillator array was proportional to the square of the number of the oscillators by selecting the 121 mode resonance.

15:30 **The Impact Of Flip-chip Process On Nb5N6 Microbolometer Arrays For Terahertz Detection** **We-POS-23**

Xinle Guo; Chengtao Jiang; Peng Xiao; Shimin Zhai; Xuecou Tu; Xiaoqing Jia; Lin Kang; Jian Chen; Peiheng Wu
Nanjing University, China
Flip-chip technology is a common way of connecting Terahertz (THz) array detectors with readout circuits. However, for our Nb5N6 microbolometer THz array detectors, temperature and stress introduced from flip-chip process may adversely affect the performance of detectors. To evaluate this influence, firstly, we simulate the impact of solder bumps in a detector unit. Secondly, through flip-chip experiments between detectors and re-wiring test chips, we have characterized the performance of detectors before and after the process, which provide the technical support for optimizing this process and the interconnection between array detectors and readout circuits.

15:30 **The Effect Of Metal Reflector On Responsivity Of Nb5N6 THz Detector** **We-POS-24**

Peng Xiao; Xuecou Tu; chengtao Jiang; shiming zhai; xinle guo; xiaoqing jia; lin kang; jian chen; peiheng wu
Nanjing University, China
We investigate the effect of metal reflector on responsivity of Nb5N6 detector in the

frequency range from 0.6 THz to 0.7 THz. The measured results show that the designed response spectrum of the detector is consistent with the signal intensity on the substrate surface whether it contains a metal reflector or not. Compared to the detector on the Si substrate with resonant frequency at 0.648 THz, the resonant frequency of the detector on the Si substrate with a metal reflector shifts to 0.683 THz, meanwhile, appearing multiple peaks in the response spectrum. It distinctly reveals the effect of metal reflector on responsivity of Nb5N6 THz detector.

15:30 **Superconducting Nanowire Single-photon Detectors At A Wavelength Of 2000nm** **We-POS-25**

ruiying xu; guanghao zhu; lin kang; Xuecou Tu; xiaoqing jia; labao zhang; Biaobing jin; jian chen; weiwei xu; peiheng wu
Nanjing University, China

In this article, we demonstrate a superconducting nanowire single photon detector (SNSPD) at a wavelength of 2000 nm. We use numerical simulations to optimize the parameters of the device structure. Guided by the obtained numerical results, we fabricated and measured the device that operates at 2000 nm at 2.3K. The results indicate that our device responses well in 2000 nm with a dark count rate of 10Hz. The recovering time is 120 ns.

15:30 **Development Of A Quick-response Microwave Bolometer For The Stray Radiation Measurement In LHD** **We-POS-26**

Hiroe Igami
National Institute for Fusion Science, Japan

A quick-response microwave bolometer has been developed to detect the stray radiation during ECRH in LHD. A prototype installed in the ECRH antenna port can response within 20 ms after starting power input. This performance is sufficient for using the output as a trigger to stop the ECRH power input when the stray radiation increases above the acceptable level.

15:30 **Terahertz Antenna Characterized By High Temperature Superconducting YBCO Grain Boundary Josephson Junction** **We-POS-27**

Haifeng Geng; Mei Yu; Tao Hua; Weiwei Xu; Peiheng Wu
Nanjing University, China

We apply a YBa2Cu2Ox (YBCO) grain boundary (GB) Josephson junction to characterize a meander antenna loaded with a bowtie. The first-order Shapiro step height and the voltage responsivity of the detector are measured to seek the resonance frequency of the antenna. This research indicates that the bowtie loaded meander antenna is matched to the impedance of a 4-μm-wide junction at 219 GHz in a quasi-optical system within a quartz hyperhemishere lens.

15:30 **The Design Of A Bowtie Antenna For 0.65 THz Detection** **We-POS-28**

Chengtao Jiang; xuecou tu; peng xiao; shimin Zhai; xinle guo; xiaoqing jia; lin kang; jian chen; peiheng wu
Nanjing University, China

We designed a planar bow-tie antenna structure on the high-resistivity silicon substrate for the Nb5N6 micro-bolometer at the frequency range from 0.55 THz to 0.75 THz. To effectively couple the high frequency signal, the Nb5N6 microbolometer is placed in the antenna gap. CST software was used to carry out numerical simulations for this antenna structure. The E-field and radio frequency (RF) current distribution show conspicuous resonance at about 0. 65 THz. Finally, the delicate design was verified by the experimental results.

15:30 **Dual Band Kinetic Inductance Bolometers For Submillimeter-wave Imaging: Experimental And Theoretical Optical Response** **We-POS-29**

Shahab Oddin Dabironezare[1]; Juha Hassel[2]; Erio Gandini[1]; Leif Grönberg[2]; Hannu Sipola[2]; Visa Vesterinen[2]; Nuria Llombart[1]
[1]Delft University of Technology, Netherlands; [2]VTT Technical Research Center of Finland, Finland

In this contribution, a focal plane array (FPA) at sub-millimeter wavelengths is presented for security applications. The detectors are based on kinetic inductance bolometers. Two frequency selective absorber (FSA) sets were designed to implement a security imager. The effective pattern of the imager coupled to a black body point source over a wide frequency band (1:6) was demonstrated experimentally with excellent agreement to the one estimated by using a Fourier optics based technique.

15:30 **Blind Restoration Method For Near-field Millimeter-wave SAIR** **We-POS-**

Jianfei Chen[1]; Jian Guo[1]; Sheng Zhang[1]; Xiaowei Zhu[2]
[1]Nanjing University of Posts and Telecommunications, China; [2]Southeast University, China

Due to the fact that real millimeter-wave (MMW) images are difficult to be measured, a novel blind restoration method (BRM) is proposed for synthetic aperture imaging radiometer (SAIR) to find the real MMW images in this paper. According to different parameter sensitivity of SAIR's imaging models, BRM first to find the matching parameters by comparing the error between different imaging methods. Then, real MMW images will be reconstructed by the improved imaging model with matching parameters. The simulation results demonstrate that the proposed method can find the real images for SAIR effectively

15:30 **Three-dimensional Millimeter Wave Imaging Of Borehole Wall Cracks** **We-POS-31**

Qijia Guo; Tianying Chang; Hong-Liang Cui
College of Instrumentation and Electrical Engineering, Jilin University, China

Millimeter wave features penetrating capability for many materials and millimeter resolution to detect inclusions and cracks. It is widely used in non-destructive testing, security screening and medical imaging. In this work, a millimeter wave imaging radar is proposed to detect borehole wall defects. Benefiting from the favorable combination between resolution and penetration, defects both on the wall surface and buried beneath it can be imaged.In order to construct three-dimensional images of a cylindrical borehole, a specific scenario is adopted: a cylindrical conformal, monostatic antenna is supposed to sample in two directions, rotating angularly in the azimuth dimension and, moving along the longitudinal dimension. The reflection wave model of ideal points is reformulated in the cylindrical coordinate system, and the source is supposed to conform to spherical wave. In order to apply fast Fourier transform to accelerate the computation, the target must be scanned uniformly. However, it is difficult to decouple the azimuth and the range components in the wavenumber domain. An alternative is to treat the azimuth pulse compression as an inverse scattering problem, the most efficient solution of which is to apply the adjoint operator of the Green's function in free space that is equivalent to the step of scene center compensation in range migration algorithm (RMA), termed phase-shift migration algorithm (PMA). It is more precise than RMA, as it is free of interpolation; and much faster than back projection algorithm (BPA), with high image quality retained. The sampling criteria and resolution in the angular dimension are derived according to the Nyquist sampling theory other than the procedure of PMA. As expected, shorter center wavelength acquires higher resolution but needs much higher sampling rate. Two simulations are performed to validate the proposed algorithm, and the reflecting wave are calculated by the method of moments (MoM). Numerical simulation of extremely small metal spheres is undertaken to test the performance of the point spread function. Furthermore, a more complex target -- an extremely thin metal ring with 2 pairs of crossed slots symmetrically distributed -- is used to verify the imaging performance of the algorithm in a general case. Both simulations demonstrate the effectiveness of the proposed approach in detecting borehole wall cracks.

15:30 **Optical Performance Of A Wideband 28nm CMOS Double Bow-Tie Slot Antenna For Imaging Applications** **We-POS-32**

Sven van Berkel; Satoshi Malotaux; Daniele Cavallo; Marco Spirito; Andrea Neto; Nuria LLombart
Delft University of Technology, Netherlands

The optical performance of a wideband double bow-tie slot antenna, implemented in 28nm CMOS technology, is evaluated. The antenna serves as a verification antenna for an uncooled single-pixel radiometer operating from 200 GHz to 600 GHz. The performance is evaluated in terms of radiometric pattern that is derived from the measured radiation patterns and simulated optical efficiency.

15:30 **Shadow Effect Analysis For Diffractive Axicon Like Element** **We-POS-33**

Martyna Rachon; Karolina Liebert; Jaroslaw Suszek; Maciej Sypek; Agnieszka Siemion
Faculty of Physics Warsaw University of Technology, Poland

Typical THz and sub-THz systems require high performance optical components to increase their efficiency. It is worth to notice that classical refractive lenses can be

replaced by compact, lightweight diffractive optics, especially for narrowband applications.

A typical kinoform (introducing phase retardation range 0-2π) can theoretically reach even 100 % of the diffraction efficiency. However, for high aperture kinoform lenses (having diameter bigger than focal length) diffraction efficiency may decrease due to shadow effect[1].

Authors discuss the shadow effect for blazed diffraction grating depending on the illumination system geometry. Additionally, a high performance axicon diffractive lens with "reversed teeth" is designed and discussed.

15:30 **On The Contribution Of Thermally Generated Surface Plasmon Polaritons To Heat Radiation Of Metal Objects** **We-POS-34**

Vasily Gerasimov[1]; Ildus Khasanov[2]; Alexey Nikitin[2]; Ta Thu Trang[2]
[1]Budker Institute of nuclear physics SB RAS, Russian Federation; [2]Scientific and Technological Center for Unique Instrumentation of RAS, Russian Federation
We present theoretical and experimental evaluations of the thermally generated surface plasmon polaritons (TSPPs) contribution to heat radiation of metal objects. It is found that this contribution is significant only for the edges of such objects flat facets observed at sliding angles to the facets planes and it is p-polarized. The analytical model for calculation the spectrum and the integral intensity of the entire set of TSPPs arriving to the edge of their sources line has been developed. In contrast to thermal radiation, intensity of TSPPs is proportional to the third rather than fourth degree of temperature, while the TSPP spectrum is shifted towards low frequencies relative to the thermal radiation spectrum.

15:30 **Active THz Imaging Using MEMS Resonator-Based Bolometer And Quantum Cascade Laser** **We-POS-35**

Isao Morohashi[1]; Ya Zhang[2]; Boqi Qiu[2]; Yoshihisa Irimajiri[1]; Norihiko Sekine[1]; Kazuhiko Hirakawa[2]; Iwao Hosako[1]
[1]National Institute of Information and Communications Technology, Japan; [2]The University of Tokyo, Japan
In this paper, we report on THz imaging using a microelectromechanical system (MEMS) resonator-based bolometer and a quantum cascade laser (QCL) operating at 3 THz. The MEMS bolometer has high sensitivity and high-speed response, and detects THz waves as the change in the resonant frequency, so that THz imaging systems with short acquisition time can be constructed. As a preliminary experiment, THz imaging of an etched metal bookmark fabricated with very small holes has been demonstrated. An estimated spatial resolution was less than 200 μm.

15:30 **Phase Self-Calibration For Millimeter Wave MIMO Imaging** **We-POS-36**

Xianzhong Tian; Qijia Guo; Tianying Chang; Hong-Liang Cui
College of Instrumentation & Electrical Engineering, Jilin University, China
A simple approach of phase self-calibration for millimeter wave imaging is proposed. By exploiting features of direct coupling between pairs of transmitting and receiving antennas, the channel group delay caused by the hardware can be calculated. Then the data after pulse compressionis phase-shifted before imagingto remove the phase error.This phase calibration procedure requires no additional reference target.Experimental results verify the validity and effectiveness of the proposed self-calibrationapproach, which can serve as a benchmark or basis for more sophisticated phase calibration approaches.

15:30 **Optimal 1D MIMO Array Topology For Millimeter-wave Short-range Imaging** **We-POS-37**

Yan You[1]; Lingbo Qiao[1]; Ziran Zhao[2]
[1]Nuctech Company Limited, China; [2]Department of Engineering Physics, Tsinghua University, China
In multistatic radar imaging systems, the topology of the antenna array is one of the key techniques having great impacts on the image quality. In this paper, we investigated the imaging performance of four different topologies of 1D MIMO linear arrays. PSFs of the four topologies with different number of transmitter number and receiver antenna combination at different imaging distance, and different frequency bandwidth are detailed. The optimal topology is depending on both imaging

distance and frequency bandwidth. By combining with SAR or quasi-optical technique, high-performance 3-D imaging can be obtained.

15:30 **THz Magnifying Near-field Image Structure Based On Monolayer Graphene** **We-POS-38**

Shengyu Shan; Cunjun Ruan; Yufei Wang
SCHOOL OF ELECTRONICS INFORMATION ENGINEERING, China
The characteristics of a Terahertz magnifying near-field image structure are investigated in this paper. With the Fabry-Perot resonance built on monolayer graphene ribbons, the steady surface plasmon resonance of electric field can help complement near-field image with high resolution. The propagation of terahertz wave on fan-shaped structure keeps the advantage of resonance field with image magnification of target by the special shape. The result shows that the minimum distance of terahertz targets can be differentiated with 223nm, and the bandwidth of the structure can reach 5.2THz at central frequency of 5THz.

15:30 **Sensitivity Of SOI Lateral Diodes For Bolometric Sensing** **We-POS-39**

Dan Corcos[1]; Thomas Morf[2]; Danny Elad[1]
[1]ON Semiconductor, Israel; [2]IBM Research - Zurich, Switzerland
In this study we characterize the thermal sensitivity of lateral diodes fabricated in a commercial 180 nm SOI-CMOS process. The current responsivity to temperature and the low-frequency noise were measured and correlated to the device dimensions. We also report on a FPA microbolometer sensor for THz imaging (0.6--1.2 THz) implemented with lateral diode detectors coupled to on-chip antennas.

15:30 **Quantitative Characterization Of Some Bisphenol Environmental Hormones By Terahertz Spectroscopy And Machine Learning Methods** **We-POS-40**

Pengju Du; Xingxing Lu; Pengfei Xie; Yiwen SUN
Shenzhen University, China
The development of new spectral analysis methods has generated intense interest in terahertz (THz) spectroscopy and its application in a wide range of fields. In this paper, a machine learning methods are applied to the quantitative characterization of some bisphenol environmental hormones detected by terahertz time-domain spectroscopy. The absorption spectra data are analyzed using the support vector regression method to learn the underlying model of the frequency against the target concentration. The learned mode successfully predicts the concentrations of the unseen test samples with coefficient of determination R2=0.97985.

15:30 **Diffractive Focusing Structures For Broadband Application In THz Range** **We-POS-41**

Karolina Liebert; Martyna Rachon; Jaroslaw Bomba; Artur Sobczyk; Agnieszka Siemion; Jaroslaw Suszek; Maciej Sypek
Warsaw University of Technology, Poland
Because of small thickness resulting in low absorption, the diffractive structures are ideal for THz beam shaping. Diffraction structures, however, are characterized by high chromatic aberrations. There are several methods that can be applied to suppress them, such as usage of high order kinoform. In this paper high order kinoforms and structures with increased depth of focus are used for chromatic aberration reduction.

15:30 **The Analysis Of FSS For Dual-band Reflectarray Using Conformal Mapping Technique** **We-POS-42**

Qianzhong Xue; Baokun Xi; Lan Bi; Yong Wang
Institute Of Electronics Chinese Academy Of Sciences, China
Using a conformal mapping method approximation was developed for estimating the effective permittivity (εr,eff) of an FSS. This method could be appliedto FSS by modeling relevant sections of the FSS as coplanar strip or coplanar waveguide transmission lines. To test this method, a conformal mapping approximation was developed for the square loop FSS used to reduce the coupling in dual-band reflect array antenna. By using this conformal mapping model to approximate εr,eff , a Matlab model was developed to calculate the frequency response from an FSS embedded within a dielectric structure. The results agree with that of CST simulation. This model can be extended to calculate other FSS elements, once conformal maps and LC approximations for these elements are determined.

15:30 **An Improved Double-PI Model For Millimeter Wave CMOS On-ChipInductor** **We-POS-43**

Jiayu Dong; Yunqiu Wu; Chenxi Zhao; Huihua Liu; Yiming Yu; Hongyan Tang; Kai Kang
University of Electronic Science and Technology of China, China

An improved double pi model for CMOS on-chipinductor is presented in this paper. The series resistor- inductor(R-L) network is used to characterize the loss and phase-shiftthrough the transmission line. And the second order cascadedparallel R-L network is induced to model the skin and proximityeffects. Besides, the resistor-capacitor networks are used tocharacterize the loss and coupling in the substrate. To validate themodel, the model calculation results are compared with the EMsimulation and measurement results, and good agreements areachieved.

15:30 **Noise And Echo Simulation And Removal Of Terahertz Time-domain Spectroscopy** **We-POS-44**

Hua Geng[1]; Wen LYU[1]; Yingxin Wang[1]; Xiaoping Zheng[2]
[1]Tsinghua University, China; [2]T, China

Terahertz (THz) time-domain spectroscopy usually contains unwanted Fabry-Perót (FP) echo signals, environmental, mechanical and other noises due to changes in the experimental environment and devices, etc. This paper simulates THz time-domain signal with echo signal and additive noise like white gaussian noise and proposes a removal method based on the local mean decomposition (LMD). The proposed scheme replaces the echo and noise with one low-frequency Production Functions (PF) after LMD decomposition. The proposed method is evaluated with the qualitative and quantificational analysis on simulated and experimental spectra. Results show that the proposed algorithm can eliminate echo signal and white gaussian noise effectively. Furthermore, this paper compares the performance and application scenario of the proposed method and the EMD based method with qualitative and quantificational analysis based on the simulation and experimental results. The objective quantitative comparison of advantages and disadvantages of different methods is based on simulation results. First simulate terahertz time domain signal and add echo signal and white gaussian noise regarding as model data. Then illustrate the proposed algorithm and EMD by applying them to the model data and experimental data. The evaluation criterion of performance of two methods is the root-mean-square error (RMSE) between repaired THz model signals and real model ones. Quantitative evaluation shows that the proposed scheme outperforms the EMD based scheme.

15:30 **The Optimization And Design Of Extended Interaction Oscillators** **We-POS-45**

jian Cui; aidi Li; guangfei Lu
NORTH CHINA UNIVERSITY OF TECHNOLOGY, China

In terms of time and accuracy, this program is feasible, it can be used to analyze the impact of various parameters of EIOs on output power to obtain the optimized structure.

15:30 **Enhanced Terahertz Electromagnetically Induced Transparency Metamaterials Via Inconsistent Thickness Of The Resonators** **We-POS-46**

Lan Wang[1]; Yaxin Zhang[1]; Shixiong Liang[2]; Zongjun Shi[1]; Ziqiang Yang[1]
[1]University of Electronic Science and Technology of China, China; [2]Hebei Semiconductor Research Institute, China

We demonstrate a classical analogue of electromagnetically induced transparency (EIT) in a planar terahertz metamaterial comprised of uneven ring resonators. Here we present control of EIT through tuning of thickness difference between inner ring and outer ring, and finally achieved the EIT with greatly improved transmittance.

15:30 **THz Microcavity Made Of Wire Grid Structures Containing Electrical Split Ring Resonator Metamaterials** **We-POS-47**

Dieu Thanh Nguyen Thi; Kyosuke Okabe; Shota Inoue; Fusao Shimokawa; Shunsuke Nakanishi; Noriaki Tsurumachi
Kagawa university, Japan

We proposed a THz microcavity structure containing metamaterial as a candidate for a new THz active device. According to the FDTD simulation, splitting of the transmission peak due to the mode coupling was observed when the electric split ring resonator (eSRR) having the same resonance frequency was placed at the center of the microcavity made of the wire grid structure as the mirror.

15:30 **Enhanced Terahertz Smith-Purcell Radiation By Combining Meta-film Arrays With Gratings** **We-POS-48**

Weihao Liu; Yucheng Liu; Linbo Liang; Qika Jia; Lin Wang; Yalin Lu
University of Science and Technology of China, China

We proposed an enhanced Smith-Purcell radiation scheme by using a free-electron beam to excite a pre-designedgrating loaded by an array of meta-material films. By coupling the enhanced surface plasmons on meta-films with the resonator modes of

a grating, it combines both advantages of material and of structure profiles, and generates a remarkably high efficiency coherent SPR in the terahertz region, which will pave a way for developing high power and efficiency terahertz sources.

15:30 **Electron Beam-Induced Airy Beam-Like THz Radiation From Graded Metallic Grating** **We-POS-49**

Tatsunosuke Matsui; Ryosuke Yoshida; Kazuki Omura
Mie University, Japan

We have numerically analyzed an electron beam -induced Airy beam-like terahertz (THz) radiation from graded metallic grating structures with graded groove spacing (GGS) based on a simplified particle-in-cell finite-difference time-domain method. Airy beam-like directional THz beams are obtained from GGSs designed to give appropriate phase delay in each scattered radiation from each grooves. Our findings may open the way for a development of novel THz radiation source based on the wide variety of metallic grating structures.

15:30 **Active Tuning Of Effective Refractive Index Based On Double-Layered Closed-Ring Resonator Array Terahertz Metamaterials** **We-POS-50**

Yuki Watanabe; Tatsunosuke Matsui
Mie-University, Japan

We numerically demonstrate index-tuning capability of terahertz (THz) metamaterials made of double-layered closed-ring resonator (CRR) arrays. The double-layered CRR arrays show narrow-band transmission peak in a relatively wide stop band and that peak show spectral shift by slightly shifting relative position of the CRR arrays or changing dielectric constant of the dielectric media inserted between CRR arrays. We also show that effective refractive index can be widely tuned by the same working principle from unnaturally high positive to near-zero and negative values. Our approach may open the way for the development of novel type of THz active devices.

15:30 **Infrared Localized Surface Plasmon Resonances On Subwavelength Corrugated Metal Disks** **We-POS-51**

Vladislava Bulgakova[1]; Alexey Lemzyakov[1]; Vasily Gerasimov[1]; Ilya Melekhin[2]
[1]Budker Institute of Nuclear Physics SB RAS, Russian Federation; [2]Novosibirsk State University, Russian Federation

A numerical simulation of multipole localized surface plasmon resonances on subwavelength corrugated metal disks with a C-resonator has been made. It has been found that the resonance frequencies depend on the geometrical parameters of the disk (the inner radius, the gap between the disk and the C-resonator, and the angle of the C-resonator). The real dielectric permittivity of the metal surface must be taken into account when analysing such structures.

15:30 **Terahertz Surface Plasmon Sensing Based On Rectangular Metal Gratings** **We-POS-52**

Vladislava Bulgakova[1]; Vasily Gerasimov[1]; Alexey Lemzyakov[1]; Ilya Melekhin[2]; Boris Goldenberg[1]
[1]Budker Institute of Nuclear Physics SB RAS, Russian Federation; [2]Novosibirsk State University, Russian Federation

The method of surface plasmon resonance (SPR) excitation on subwavelength rectangular gratings using broadband IR radiation is promising for sensing of dielectric media. In this paper, numerical simulations of the reflectance spectra of electromagnetic radiation incident on a subwavelength one-dimension rectangular grating have been made. The optimal grating parameters to excite surface plasmon resonances (SPRs) in the THz range were found. The real value of the dielectric permittivity of the metalized surface of the grating should be taken into account in analyzing the resonances. The wavelengths, depths, and width of the resonances depend on the dielectric medium filling the grating.

15:30 **Inverse Smith-Purcell Effect In Photonic Crystals** **We-POS-53**

Xiaoqiuyan Zhang; Min Hu; Sen Gong; Yueheng Cao; Pengfei Hu; Shenggang Liu; Zhenhua Wu
University of Electronic Science and Technology of China, China

Free electrons passing along the surface of the grating produce a stimulated emission, referred to as the Smith-Purcell (SP) effect. Here we firstly report theoretically evidence of the inverse Smith-Purcell effect at about 300GHz (ISP) by loading the specially designed photonic crystals (PCs) with negative refractive on a slits structure, which could provide a new idea for coherent Smith-Purcell. The inverse Smith-Purcell effect reflect that with the observation moving from the front

to the rear, the observation frequency change first from the intermediate frequency to the high frequency, and then from the low frequency to the intermediate frequency, which is different from the normal SP. The proposed ISP is of great significance for obtaining power enhanced, coherent and tunable terahertz radiation.

15:30 **Negative Refractive Index Fishnet Enhancement By Wire Shift** **We-POS-54**

Wei-Chih Wang; Antoine Wegrowski
University of Washington, United States
We report a modification of the negative refractive index fishnet design introduced by Ding et al., where the gold wires connecting two adjacent slabs of the fishnet are shifted from the central axis. This new design, referred to as the bd design, displays a negative refractive index twice as low as the original, while drastically reducing its loss. We use simulations of the inner electromagnetic fields to explain its superior performances

15:30 **Terahertz Prism Analogue Based On Meta-surface** **We-POS-55**

Guangyou Fang; Chao Li
Institute of Electronics, Chinese Academy of Sciences, China
A THz prism analogue based on metasurface working in transmission diffraction mechanism is proposed to generate THz rainbow spectrum. The experimental results show that, the prism analogue can spread the incident spectrum from 0.15-0.22THz in an angular scope about 30.8Ã‚Â°.

15:30 **Microfluidic Terahertz Dual-band Sensor With Hybrid Fano Meta-atoms For Stronginteraction Expansion** **We-POS-56**

Luo Feng; Lan Feng
Terahertz Research Center, School of Electronics Science and Engineer, University of Electronic Sci, China
A metamaterial perfect absorber (MPA) based terahertz dual-band ultrasensitive sensor is theoretically and experimentally demonstrated here. The transverse resonances induced by the absorptive channel with hybrid Fano meta-atoms beget the higher dual-band normalized sensitivities of 0.53/RIU and 0.59/RIU at 0.92 THz and 0.69 THz, respectively. The experimental result of Bovine Serum Albumin (BSA) sample exhibit promising applications for microfluidic biosensing.

15:30 **Exciting Fano Resonance In Symmetric Terahertz Metamaterials For Thin-film Sensing Applications** **We-POS-57**

Ibraheem Al-Naib
Imam Abdulrahman Bin Faisal University, Saudi Arabia
A novel biosensing procedure by applying thin-film analyte to half of a metamaterial unit cell is presented. We observe a remarkable excitation of Fano resonance eigenmode due to the analyte coating. In future, this procedure could be utilized for highly efficient label-free biosensing.

15:30 **The Rosette Petal Width Influence On Ellipticity Angle Of Chiral Metasurface For Sub-terahertz Frequency Range** **We-POS-58**

Maxim Masyukov; Anna Vozianova; Alexander Grebenchukov; Mikhail Khodzitsky
ITMO University, Russian Federation
In this paper geometry dependent chiral metasurface as polarization converter in terahertz frequency range was proposed. The chiral metasurface consisted of a conductive rosette and dielectric substrate. It was shown that the resonant frequencies and ellipticity angle strongly depend on the rosette petal width. Besides the switching between right-handed and left-handed polarization rotation at the changing of petals width was observed. Such metasurface may be used in biomedical applications, for instance cancer diagnostics.

15:30 **High-power Long-pulsed Operation Of Nanosecond Switches For 260 GHz** **We-POS-59**

Maxim Kulygin
Institute of Applied Physics RAS, Russian Federation
260 GHz waveguide semiconductor switches driven by laser emission are used to cut a continuous-working (CW) microwave emission to series of wave packets. The main advantage of the switches is low distortion to the phases of the packets' high frequency fillings at the output. The phases are linked to each other since the microwave input emission is coherent, e.g. a gyrotron in a phase stabilization regime. Recent studies achieved nanosecond level of switching performance for 260 GHz frequency band and 532 nm laser emission using a semiconductor plate of plain gallium arsenide.

15:30 **Investigations On 0.2-THz Traveling-Wave Tubes With Staggered Grating Slow-Wave Structure** **We-POS-60**

Nikita Ryskin[1]; Andrey Rozhnev[1]; Andrey Ploskih[2]; Anton Burtsev[3]; Igor Navrotsky[3]; Aleksei Danilushkin[3]
[1]Saratov Branch, Institute of Radio Engineering and Electronics RAS, Russian Federation; [2]Saratov State University, Russian Federation; [3]RPE "Almaz", Russian Federation

0.2-THz traveling-wave tubes (TWT) with a grating slow-wave structure (SWS) are studied. The results of design and simulation of sheet-beam and multiple-beam electron-optical systems are reported. Electromagnetic parameters of SWSs are calculated. The results of small-signal and large-signal gain analysis are presented. According the simulations, for 0.1-A 20-kV sheet beam, peak small-signal gain and saturated power are about 39 dB and 80 W, respectively.

15:30 **Development Of Planar Slow-Wave Structures For Low-Voltage Millimeter-Band Vacuum Tubes** **We-POS-61**

Nikita Ryskin[1]; Andrey Rozhnev[1]; Andrey Starodubov[2]; Alexey Serdobintsev[2]; Roman Torgashov[1]; Viktor Galushka[2]; Anton Pavlov[2]
[1]Saratov Branch, Institute of Radio Engineering and Electronics RAS, Russian Federation; [2]Saratov State University, Russian Federation

A novel technology for microfabrication of millimeter-band planar microstrip slow-wave structures (SWS) is proposed. The technology is based on magnetron sputtering and laser ablation methods. V-band (50-70 GHz) and W-band (75-110 GHz) meander-line SWSs are fabricated and characterized by scanning electron and optical microscopy. Electromagnetic parameters of the developed SWSs are studied by numerical simulation and cold-test measurement. Small-signal and large-signal gain is calculated.

15:30 **Polyimide Splitters For Terahertz Surface Plasmons** **We-POS-62**

Vasily Gerasimov[1]; Alexey Nikitin[2]; Alexey Lemzyakov[1]; Ivan Azarov[3]; Boris Knyazev[1]; Evgeni Bezus[4]; Elena Kadomina[4]; Leonid Doskolovich[5]
[1]Budker Institute of nuclear physics SB RAS, Russian Federation; [2]Scientific and Technological Center for Unique Instrumentation of RAS, Russian Federation; [3]Rjanov Institute of Semiconductor Physics of the Siberian Branch of the RAS, Russian Federation; [4]Image Processing Systems Institute of RAS, Russian Federation; [5]Samara National Research University, Russian Federation

This work is the first experimental demonstration of the fact that a polyimide kapton film of submillimetre thickness can effectively split THz SPs. Measurements of the transmission and reflection coefficients of SPs on gold-ZnS layer plane structures using monochromatic terahertz (λ=130 μm) radiation of the Novosibirsk free-electron laser have shown good accordance with theoretical and numerical calculations.

15:30 **(Withdrawn)** **We-POS-63**

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15:30 **Evolutionary Optimization Of THz Components** **We-POS-64**

Vanessa Fenlon; Rhiannon Lees; Polina Stefanova; Andreas Klein; Andrew Gallant; Claudio Balocco
Durham University, United Kingdom

The use of a genetic algorithm combined to a finite-difference time-domain (FDTD) simulator is presented for the optimization of the shape of THz patch antennas on SU8 substrate. In this work the optimization aimed at maximizing the collected power, but any other behavior can easily be considered by using the appropriate fitness function.

15:30 **Pre-Launch Radiometric Calibration Systems For The MetOp-SG MWS Instrument** **We-POS-65**

Fiachra Cahill[1]; Peter Huggard[2]; Manju Henry[2]; Roseanna Green[2]; Brian Ellison[2]
[1]STFC RAL Space, United Kingdom; [2]STFC, United Kingdom

We present results on the design and test of pre-launch radiometric calibration systems for the Microwave Sounder (MWS) remote-sounding payload of the MetOp-SG mission. MetOp-SG is the second generation of European polar orbiting

meteorological satellites and will provide weather forecast and climate monitoring data for decades to come. Accurate calibration prior to launch is required in order to achieve a measured radiometric temperature sensitivity of ±0.1 K. The requirements for the calibration targets are <-45 dB with a temperature stability of 0.05 K over 5 minutes and 0.5 K over 1 hour. The calibration method is based on the principal of introducing blackbody targets of know radiometric brightness temperature. Each MWS instrument will be tested, prior to integration with the satellite, in a thermal vacuum chamber simulating the environment of space. Two calibration targets will be used to represent the measurement view of Earth and the cold calibration view of space. There will also be a warm on-board calibration target on each instrument.

This work includes design, analysis and optimisation of the calibration targets geometry, consisting of a 2D array of metallic pyramidal tines coated in absorbing epoxy material. The ratio of pyramid height to base width is optimized along with the absorber thickness, to work in the frequency range 23 GHz to 230 GHz. Return-loss measurements have been performed on a purpose-built quasi-optical reflectivity measurement system for prototype 150 mm diameter MWS targets, and have been shown to meet the <-45 dB requirement across the full bandwidth. We are currently manufacturing a full-size MWS target, which needs to be 480 mm in diameter in order to capture the -35 dB contour of the MWS beam at the lowest relevant frequency. This presents a significant manufacturing challenge, results from return loss measurements will be presented. Another consideration in the design is that thermal radiation incident on the targets can create a bias offset between a target's physical temperature, as measured by standard platinum resistance thermometers located in the metallic core of the target, and it's brightness temperature as measured by a radiometer. To reduce this effect a thermally controlled shroud is used to reduce the target's solid angle view of the thermal scene. We have also characterised the effect by convolving results from thermal and electromagnetic simulation software and generating a brightness temperature model. Results from this model and our modelling method will also be presented.

15:30 **Broadband Output Windows For THz Gyro-TWAs** **We-POS-66**

Craig Donaldson; Liang Zhang; Alan Phelps; Wenlong He
University of Strathclyde, United Kingdom
This paper presents the design, simulation and technical considerations of terahertz output windows, based on the multilayer type, for THz gyro-TWAs. Such windows can achieve very low reflection levels over a frequency broadband when the thickness of the dielectric layers are properly matched. The optimized window, in this design, was numerically calculated to achieve a passband of over greater than 7% bandwidth with a reflection of less than -30 dB.

15:30 **SISMA: A Numerical Simulation Software For SIS Mixer Design** **We-POS-67**

Wenlei Shan[1]; Wentao Wu[2]; Shengcai Shi[3]
[1]National Astronomical Observatory of Japan, Japan; [2]Shanghai Institute of Microsystem and Information Technology, China; [3]Purple Mountain Observatory, China
SISMA is a numerical simulation software programmed for the design of SIS mixer with single junction or junction arrays. It is based on quantum mixing theory with involving the 2nd harmonic. The temperature and frequency dependent complex surface impedance is calculated in the simulation of thin-film superconducting passive components. The graphic interface of this software is a benefit to fast optimization of the circuit design.

15:30 **Opportunities And Challenges For EIK's In DNP NMR Applications** **We-POS-68**

Melanie Rosay[1]; Ivan Sergeyev[1]; Leo Tometich[1]; Christopher Hickey[1]; Albert Roitman[2]; Doug Yake[2]; Dave Berry[2]
[1]Bruker BioSpin, United States; [2]Communications & Power Industries, Canada
Dynamic Nuclear Polarization (DNP) experiments have been demonstrated as a vital technique to enhance the sensitivity of solids state nuclear magnetic resonance (NMR) experiments and enable a range of applications spanning from small molecules to large biological complexes and materials. Millimeter-wave irradiation of

electron spins drives polarization transfer from the electron spins to the nuclear spin for this enhanced sensitivity. DNP experiments at modern 1H NMR frequency, 400-900 MHz, require millimeter-wave sources operating in the range of 263-593 GHz with continuous-wave (CW) operation, high output power, spectral purity, and frequency and power stability. The scarcity of suitable microwaves sources at this high frequency range had traditionally limited DNP to select academic research groups. In the past decade, DNP methods have made great strides to move from basic research and development to more widespread NMR applications. In that timeframe, Bruker has developed both instrumentation and methods to assist progress in the field and reach new application areas.

G-band (110-300 GHz) Extended Interaction Klystrons have been designed and manufactured by CPI Canada since the 1980s. These devices are compact and operate in CW or pulsed mode. The EIK focusing system uses permanent magnets and has low sensitivity to the external magnetic field. This permits operation in direct proximity of superconducting NMR magnets and makes EIK a good candidate for DNP experiments [2]. To produce 5 W of CW output power at 263 GHz, the EIK thermionic cathode operates with average loading of 9 A/cm2. The CPI "triple alloy" coating is used to reduce cathode operating temperature with expected lifetime of 20,000 hours without the life extender technology. The power supply is developed by CPI SATCOM division and provides option for automated adjustment of cathode heater voltage (life extender technology), which can double the cathode lifetime to 40,000 hours. CPI has recently completed the development of a G-band diamond window and made improvements to power supply which enhances overall system reliability and fault protection. The klystron is mounted close to the NMR magnet and an overmoded corrugated waveguide is used to transmit the 263 GHz beam from the EIK to the NMR probe.

Comparison of NMR spectra acquired with the EIK on and EIK off demonstrate a gain in sensitivity of 180. The transmission line and position of EIK was optimized for maximum DNP efficiency and the system stability was tracked for extended period of time.

15:30 **Development Of A High-Power Gyrotron For Beamed Energy Propulsion Applications** **We-POS-69**

Masafumi Fukunari[1]; Yasuhisa Oda[2]; Tsuyoshi Kariya[3]; Ryutaro Minami[3]; Yuusuke Yamaguchi[1]; Yoshinori Tatematsu[1]; Teruo Saito[1]; Keishi Sakamoto[2]; Tsuyoshi Imai[3]; Kimiya Komurasaki[4]
[1]Research Center for Development of Far-Infrared Region, University of Fukui, Japan; [2]National Institutes for Quantum and Radiological Science and Technology, Japan; [3]Plasma Research Center, University of Tsukuba, Japan; [4]School of Engineering, The University of Tokyo, Japan

A high-power gyrotron is under development to investigate the thrust generation by the incident microwave beam for the beamed energy propulsion rocket. The beam frequency is set at 94 GHz which is the window frequency of air. The target output power is 600 kW at maximum. A mode converter is installed to deliver a Gaussian beam. The electron gun of the gyrotron is a diode type. The electrodes were designed by using the EGUN code. The power supply is composed of a capacitor bank and a high voltage switching devise. This power supply can charge the capacitor bank at 80 kV at maximum. This study is the first gyrotron development in the field of the aerospace.

15:30 **Theoretical And Experimental Studies Of Oversized Ka-band Surface-wave Oscillators Based On 2D Periodical Corrugated Structures** **We-POS-70**

Vladislav Zaslavsky; Naum Ginzburg; Evgeny Ilyakov; Igor Kulagin; Andrey Malkin; Nikolai Peskov; Alexander Sergeev
IAP RAS, Russian Federation

Based on the quasi-optical approach and direct PIC simulations, we study dynamics of oversized relativistic surface-wave oscillators (SWO) of the Cherenkov type with 2D periodical corrugated structures of cylindrical geometry. Such corrugation allows significant rarefication of the spectrum of modes with different azimuthal indices. As a result, selective excitation of a mode with a given azimuthal index is possible. Azimuthal index of the generated mode depends on the voltage rise time. For short (nanosecond scale) rise time, generation at the azimuthally symmetric mode can be realized. For longer (hundreds nanoseconds to microseconds) rise time, the modes with high azimuthal indexes would be excited. These conclusions are supported by

the experiments where Ka-band SWO with 2D corrugated structure was realized based on the thermionic-emission accelerator SATURN 300 keV / 100 A / 4 μs. In this SWO-oscillator having the oversize factor (perimeter to wavelength) of about 16, stable narrow-band generation with output power of 2 - 2.5 MW was obtained at the frequency of 32.5 GHz corresponding to the mode with azimuthal index of m = 3. The project of Ka-band sub-gigawatt power SWO operating at the azimuthally symmetric mode based on the high current explosive-emission accelerator SINUS-6 500 keV / 4 kA / 20 ns is under development at IAP RAS currently.

15:30 **Vector Method For High Power Microwave Phase Retrieval Using IR Images** **We-POS-71**

Jianwei Liu; xinjian niu; yinghui liu; hui wang; guo guo; xu sun
School of Electronic Science and Engineering, University of Electronic Science and Technology of Chi, China

Vector method for high power microwave phase retrieval has been proposed. Based on Stratton-Chu formula and the measured data of infrared images on several position of the high power microwave, phase distribution of the major electric field component Ey has been reconstructed through iteration method. Simulation results show the vector correlation coefficient at the position X1 is 99.59%.

15:30 **Perspective Field Emitters For Electron-Beam Microwave Devices Of Short-Wave Millimeter And Submillimeter Range** **We-POS-72**

Gennadii Sominskii; Vyacheslav Sezonov; Tatiana Tumareva; Evgenii Taradaev
Peter the Great Saint Petersburg Polytechnic University, Russian Federation

In this report, distributed field emitters are considered, which are perspective for use in miniature but high-voltage electronic devices operating in a technical vacuum. The main attention is paid to the latest developments of the authors on the creation of a new type cathodes: multitip silicon cathodes with protective metal-fullerene coating and multilayer cathodes prepared from the brought into contact materials with different work function. The possibility of obtaining with the help of these cathodes field emission currents and current densities sufficient for maintenance of operation of microwave devices of millimeter and submillimeter range is demonstrated.

15:30 **Study Of Mode Competition In The Third Harmonic Gyrotron With Inclusion Of The Electron Velocity Spread And The Beam Width** **We-POS-73**

Olgerts Dumbrajs
Institute of Solid State Physics, University of Latvia, Latvia

Influence of the electron velocity spread and the beam width on the mode competition and efficiency is investigated in the 1.185-THz third harmonic gyrotron to be used in dynamical nuclear polarization -- nuclear magnetic resonance (DNP-NMR) spectrometer.

15:30 **Simulations Of Nonuniform Electron Beams In A Gyrotron Electron-Optical System** **We-POS-74**

Oleg Louksha; Pavel Trofimov
Peter the Great St. Petersburg Polytechnic University, Russian Federation

New results on influence of emission inhomogeneity on quality of the electron beam formed in a gyrotron electron-optical system were obtained using the emission current distributions measured for different cathodes in the 74.2 GHz, 100 kW gyrotron. The maximum level of emission inhomogeneity acceptable for effective operation of gyrotrons is discussed.

15:30 **Observation Of Increased Number Of Frequency Steps In Multi-Frequency Oscillations With A Two-Cavity Gyrotron** **We-POS-75**

Yuusuke Yamaguchi; Masafumi Fukunari; Taisei Ogura; Tatsuya Ueyama; Yuto Maeda; Kyoya Takayama; Yoshinori Tatematsu; Teruo Saito
Research Center for Development of Far-Infrared Region, University of Fukui, Japan

A two-cavity configuration was introduced to increase the number of operating frequencies of a gyrotron. Each cavity has a series of oscillation modes which can be selected with the cyclotron frequencies of injected electron beams. The experimental observations showed that the different oscillation modes for each cavity can be selectively excited according to the changes in the magnetic field strength in the cavity. The obtained results predict a further multiple-frequency operation is possible with multiply connected cavities.

15:30 **Frequency-Stabilized Terahertz Gyrotron Backward-Wave Oscillator During Electronic Tuning Process** **We-POS-76**

Shi Pan[1]; Chao-Hai Du[1]; Zi-Chao Gao[1]; Lu-Yao Bao[1]; Juan-Feng Zhu[1]; Claudio Paoloni[2]; Pu-Kun Liu[1]

[1]Peking University, China; [2]Lancaster University, United Kingdom
This paper proposes an electronic-tuning frequency stabilization scheme with power tuning for a Watt-level terahertz gyrotron oscillator in gyro-BWO state. The intrinsic positive relationship between electron-beam pitch factor α and accelerating voltage V in electron gun contributes to Doppler shift compensation during electronic tuning. When the pitch factor α varies from 1.1 to 1.9, the prototype three-sectioned gyrotron oscillator can be fixed at 253.98 GHz with 10 MHz level error. The output power is tuned by 40% from maximum. This approach is of importance for heat-effect-oriented applications in biomedicines and material processing.

15:30 **Two-stage Energy Recovery System For DEMO Gyrotron** **We-POS-77**

Mikhail Glyavin[1]; Vladimir Manuilov[2]; Mikhail Morozkin[1]
[1]Institute of Applied Physics RAS, Russian Federation; [2]Insitute of Applied Physics RAS, Lobachevsky State University, Russian Federation
The results of optimization of the two-stage energy recovery system for the gyrotron planned for use in the DEMO project are presented. The main attention is paid to the problem of spatial separation of electrons having different residual energy after interaction with the RF field. A separation mechanism with electron drift in weakly nonuniform electric and magnetic fields is chosen. To create such fields, a scheme with an azimuthal electric field between the first and second stages of the collector was used. It is shown that such a scheme makes it possible to achieve a sufficiently good spatial separation of energy fractions and thus obtain a full gyrotron efficiency of more than 70%.

15:30 **Quasi-Optical Mode Converter For A 0.42 THz TE17,4 Gyrotron** **We-POS-78**

Wei Wang; Ning Zhang; Tao Song; Chenghai Wang; Diwei Liu; Shenggang Liu
University of Electronic Science and Technology of China, China
A quasi-optical mode converter (QOMC) for a 0.42 THz, TE17,4 mode pulsed gyrotron oscillator is designed, fabricated and tested. Based on the coupled-wave theory, geometric optics theory and vector diffraction theory, a computer code is developed to design and optimize the QOMC which converts the high order TE17,4 mode into a fundamental Gaussian distribution. The numerical results show that the scalar fundamental Gaussian mode content of the wave beam at the output window is about 98.1%. The experiment result shows that a well-focused Gaussian-like beam with 95.2% scalar Gaussian mode content has been obtained by using an infrared video camera. The measured results agree well with the theoretical predictions.

15:30 **A Quasi-Optical Mode Converter For 220 GHz Confocal Gyro-TWTs** **We-POS-79**

Xiaotong Guan; Wenjie Fu; Dun Lu; Tongbin Yang; Yang Yan
University of Electronic Science and Technology of China, China
Motivated by transforming the high output power of confocal gyrotron traveling wave tubes (gyro-TWTs) into Gaussian beam, a quasi-optical mode converter (QOMC) for 220GHz confocal TE06 mode gyro-TWTs is designed and experimental tested. Based on the technique of Gaussian beam transformation, the proposed QOMC, consists of a dimpled Vlasov launcher and two reflection mirrors, is investigated and optimized by a 3D simulation software, FEKO. Simulation results predict that the proposed QOMC could successfully transform confocal TE06 mode into Gaussian-like beam at 220GHz, corresponding to an energy conversion efficiency of 90.3% and a conversion loss of 0.4 dB. Initial cold-test results demonstrate that the output field of this QOMC is a well-focused Gaussian-like beam with a scalar Gaussian mode content up to 98.5%.

15:30 **Enhanced THz Absorption Of Polar Molecule-formed Plasma** **We-POS-80**

Yindong Huang[1]; Quan Guo[2]; Ziyi Zhang[1]; Biyi Yi[1]; Jing Zhao[2]; Jianmin Yuan[2]; Zengxiu Zhao[2]
[1]National Institute of Defense Technology Innovation, China; [2]National University of Defense Technology, China
In this work, two kinds of THz absorption are identified from the polar molecule-formed plasma, namely, the broad band resonant absorption induced by the separation of electrons and ions within plasma, and the rotational transitions between different rotational states. Interestingly, we observe the enhanced THz absorption of the rotational transition lines within the resonant absorption frequency range. Gas pressure is varied to show that the enhanced THz absorption lines are

related to the plasma frequencies. This work is not only a new observation on the THz absorption within plasma, but also a glimpse of the coherent nature of laser-prepared plasma.

15:30 **Ultrafast Magnon Dynamics In Antiferromagnetic Nickel Oxide Observed By Optical Pump-Probe And Terahertz Time-Domain Spectroscopies** **We-POS-81**

Toshiro Kohmoto[1]; Takeshi Moriyasu[2]
[1]Kobe University, Graduate School of Science, Japan; [2]University of Fukui, Japan

We have studied the ultrafast magnon dynamics in an antiferromagnetic 3d-transition-metal monoxide, nickel oxide (NiO), using optical pump-probe spectroscopy and terahertz time-domain spectroscopy (THz-TDS). Terahertz damped magnon oscillations were observed in the Faraday rotation signal and in the transmitted THz electric field via optical pump-probe spectroscopy and THz-TDS, respectively. Three magnon modes were observed via optical pump-probe spectroscopy, and two magnon modes were observed via THz-TDS. The observed temperature dependence of the magnon frequencies is discussed using three different molecular field theories.

15:30 **Double-pump-pulse Terahertz Emission Method As A Novel Tool To Investigate Ultrafast Processes In Semiconductors** **We-POS-82**

Ieva Beleckaite; Lukas Burakauskas; Ramunas Adomavicius
Center for Physical Sciences and Technology, Lithuania

Terahertz (THz) pulse generation dynamics in InAs was investi-gated using double-pump-pulse terahertz emission method. The dynamics highly depends on the polarization of the excitation light. By changing the polarization of the first optical pulse, it is possible to select the direction of the emerging electric fields, and the second optical pulse can control the orientation of the THz pulse emitting electric dipole relative to the semiconductor sur-face. Our suggested method is shown to be a precise and sensitive way to study electric fields and photocarrier dynamics in semi-conductors after photoexcitation.

15:30 **Efficient Continuously Tunable Narrowband Spintronic THz Emission From Mn3-xGa Nanofilms** **We-POS-83**

Nilesh Awari[1]; S. Kovalev[1]; C. Fowley[1]; K. Rode[2]; Y-C Lau[2]; D. Betto[2]; N. Thiyagarajah[2]; B. Green[1]; O. Yildrim[1]; J. Lindner[1]; J. Fassbender[1]; M. Coey[3]; A. Deac[1]; M. Gensch[1]
[1]Helmholtz Zentrum Dresden Rossendorf, Germany; [2]Trinity College, Dublin, Ireland; [3]Trinity college, Dublin, Ireland

We report on the observation of narrow band THz emission from ferrimagnetic Mn3-xGa nanofilms. The emission originates from coherently excited spin precession. The central frequency of the emitted radiation is determined by the anisotropy field, while the bandwidth relates to Gilbert damping. It is shown how THz emission can be used for the characterization dynamical properties of ultra-thin magnetic films. We furthermore discuss the potential of these types of films as an efficient on-chip spintronic THz emitter.

15:30 **High-order Sideband Generation Under Circularly Polarized Light Excitation In Monolayer Transition Metal Dichalcogenides** **We-POS-84**

Kohei Nagai[1]; Naotaka Yoshikawa[1]; Koichiro Tanaka[2]
[1]Department of Physics/Kyoto University, Japan; [2]Department of Physics/Kyoto University, Institute for Integrated Cell-Material Sciences (iCeMS)/Kyot, Japan

We observed high-order sideband generation in monolayer transition metal dichalcogenides. Polarization selection rule of the sideband emission under circularly polarized light excitaion is determined experimentally.

18:45 - 20:45 **Banquet**
Session Type: Others

Thursday, September 13, 2018

08:45 - 09:00 **Announcements** **Shirotori Hall**

Session Type: Others

09:00 - 10:30 **Th-A1-S Plenary Session** **Shirotori Hall**

Session Type: Plenary
Chair(s)/Convenor(s)/Facilitator(s): Martina Havenith-Newen
Discussant(s):

09:00 **Two Decades Of Terahertz Transient Photoconductivity Spectroscopy: Where Do We Stand And Where Are We Going?** **Th-A1-S-1**

Charles A. Schmuttenmaer
Yale University, United States

Developments in transient photoconductivity in semiconductors as probed by terahertz (THz) spectroscopy are described. First, previous work is discussed, which is then followed by a few thoughts regarding future directions.

09:45 **Toward Cancer Treatment Using Terahertz Radiation: Demethylation Of Cancer DNA** **Th-A1-S-2**

Joo-Hiuk Son; Hwayeong Cheon
University of Seoul, Korea, Republic of

Carcinogenesis involves DNA methylation which is a primary alteration in DNA in the development of cancer occurring before genetic mutation. Because the abnormal DNA methylation is found in most of cancer cells, the detection and manipulation of DNA methylation using terahertz radiation can be a novel pioneering method in cancer study. The DNA methylation has been directly observed by terahertz spectroscopy at around 1.65 THz and this epigenetic chemical change could be manipulated to the state of demethylation using a high-power terahertz radiation. Demethylation of cancer DNA is a key problem in epigenetic cancer therapy and our results may lead to the treatment of cancer in early stage.

11:00 - 12:30 **Th-A2-R1 Spectroscopy of Gases, Liquids, and Solids I** **Shirotori Hall**

Session Type: Oral

11:00 **[Keynote] Catching A Glimpse Of Ultrafast Solvent Rearrangement By Non Linear THz Spectroscopy** **Th-A2-R1-1**

Martina Havenith
Ruhr University Bochum, Germany

Hydrogen bond rearrangements via librational or diffusional motions constitute the heart of network dynamics in liquid water. Reorientation of water molecules on the ps and sub-ps time scale is a decisive step in the formation and breaking of hydrogen bonds. Here we report the results of ultrafast nonlinear THz experiments carried out at the free electron laser FELIX and with an amplified THz laser source probing the ultrafast response of the solvent in the diffusional and the librational band of water.

11:30 **Structure Analysis Of Disorder In A Molecular Crystal With Terahertz Spectroscopy And Solid-state Density Functional Theory** **Th-A2-R1-2**

Feng Zhang[1]; Houng-Wei Wang[2]; Keisuke Tominaga[1]; Michitoshi Hayashi[2]; Tetsuo Sasaki[3]
[1]Molecular Photoscience Research Center, Kobe University, Japan; [2]Center for Condensed Matter Sciences, National Taiwan University, Taiwan; [3]Research Institute of Electronics, Shizuoka University, Japan

This work presents a methodology of applying THz spectroscopy to solve one outstanding problem in crystallography--the structure analysis of disorder. Form I of diflunisal, which shows atomic occupational disorder, is used for the illustration. Through analyzing the roles played by disordered atoms to THz vibrations, we have retrieved concrete information about the symmetric restrictions on the spatial correlations of disordered atoms and revealed indiscriminate experimental evidence of the existence of explicit correlation patterns.

11:45 **Molecular Spectroscopy With A Terahertz Quantum-cascade Laser By Illumination-induced Frequency Tuning** **Th-A2-R1-3**

Tasmim Alam[1]; Martin Wienold[2]; Heinz-Wilhelm Huebers[2]
[1]German Aerospace Center, Germany; [2]German Aerospace Center (DLR), Germany

We report on molecular spectroscopy with a terahertz quantum-cascade laser (QCL). The frequency of the QCL is tuned by illuminating one of its facets using a near-infrared laser. A tuning range of 17 GHz is achieved for continuous-wave operation.

12:00 **DIfferential Frequency-domain Absorption Spectrometer In The TErahertz Region (DI-FASTER) For Fast Gas Sensing** **Th-A2-R1-4**

Yuma Takida[1]; Toshiyuki Ikeo[2]; Kouji Nawata[1]; Yasuhiro Higashi[2]; Hiroaki Minamide[1]
[1]RIKEN, Japan; [2]RICOH COMPANY, LTD., Japan

We present a differential frequency-domain absorption spectrometer in the

terahertz region (DI-FASTER) for fast gas sensing applications. The system is based on an injection-seeded terahertz (THz)-wave parametric generator (is-TPG) driven by a dual-pulse self-frequency-switched microchip laser. Within a single excitation cycle of the laser, the is-TPG generates two THz-wave pulses with 11-GHz center frequency separation and 200-μs time interval. These pulses can be directly used to measure differential absorption signals and first-derivative spectra of gas molecules with 50-Hz data acquisition rate.

12:15 **Coherent THz Light Source For High Precision Spectroscopic Measurement** **Th-A2-R1-5**

Daisuke Fukuoka[1]; Kiyofumi Muro[1]; Kazufusa Noda[2]
[1]Spectra Quest Lab, Inc., Japan; [2]Oshima Prototype Engineering Co., Japan
The photomixing based on ASE-Free, narrow line width tunable diode lasers with a uni-traveling-carrier photodiode (UTC-PD) provides high-resolution (3 MHz), narrow band (> 1 MHz), high-power (1 μW at 400 GHz), wide dynamic range (at least 40dB of SNR in power ratio) coherent terahertz waves. Combined with a calibration system of different frequency of mixing sources by using thermally stable etalon with invar rods, it assures the THz waves frequency accuracy of 10-6/K, this system is suitable for the high precision measurement of THz frequency domain spectroscopy in wide frequency range over 4 THz.

11:00 - 12:30 **Th-A2-1b Metamaterial Structures and Applications IV** **Room 131+132**

Session Type: Oral

11:00 **[Keynote] 3 GHz Electrically Controlled Terahertz Spatial Modulator Based On A Stagger-Netlike GaN HEMT Metasurface** **Th-A2-1b-1**

Yuncheng Zhao[1]; Yaxin Zhang[1]; Shixiong Liang[2]; Zhihong Feng[2]; Ziqiang Yang[1]
[1]School of Electronic Science and Engineering, University of Electronic Science and Technology of Chi, China; [2]National Key Laboratory of Application Specific Integrated Circuit, Hebei Semiconductor Research Ins, China
In this paper, we present a composite stagger-netlike metamaterial THz modulator(SMMTM) that combines optimized metallic metasurface with AlGaN/GaN heterostructure array to improve modulation speed and depth. In the SMMTM, feeder circuits are simplified as far as possible and ingeniously integrated into metamaterial structure, which significantly reduced parasitic factors of the modulator. By electrically controlling the carrier concentration of 2DEG, resonant mode conversions between two different analogous dipolar resonances have been realized. In real-time dynamic tests, this THz spatial modulator achieves 93% modulation depth and 3 GHz modulation speed.

11:30 **Terahertz Quadruple-Band Switching Polarization Converter Based On HEMT-Embedded Net-Grid Metasurface** **Th-A2-1b-2**

Luyang Wang[1]; Feng Lan[1]; Hongxin Zeng[1]; Ziqiang Yang[1]; Pinaki Mazumder[2]; Feng Luo[1]; Abdur Rauf Khan[1]; Zongjun Shi[1]
[1]School of Electronic Science and Engineering, University of Electronic Science and Technology of Chi, China; [2]Department of Electrical Engineering and Computer Science, University of Michigan, United States
A reflective polarization converter with HEMT-embedded net-grid metasurface is demonstrated here. The polarizer can convert a linearly polarized (LP) wave to its cross-polarized wave at four resonant frequencies with a high polarization conversion ratio, and it can convert the LP wave to a circularly polarized (CP) wave at the other eight resonant frequencies. The novel polarization converter may greatly benefit potential applications in terahertz ultrafast polarization manipulation.

11:45 **"Reverse Fabrication" Technique To Develop Mechanically Tunable THz Metasurfaces Using A Flexible Polydimethylsiloxane Substrate** **Th-A2-1b-3**

S.C. Ambhire[1]; S. Palkhivala[1]; A. Agrawal[1]; A. Gupta[1]; G. Rana[2]; R. Mehta[1]; Arkabrata Bhattacharya[1]; A. Venugopal[1]; S.S. Prabhu[1]; Arkabrata Bhattacharya[1]
[1]Tata Institute of Fundamental Research, India; [2]Indian Institute of Technology, Bombay, India
In this contribution, we demonstrate a new technique for fabricating a mechanically stretchable metasurface with tunable response on an elastic polydimethylsiloxane (PDMS) membrane operating at Terahertz (THz) frequencies. The tunability of the response of the metasurface is based on the change of the physical dimensions of individual micro-structures due to the strain caused by mechanical stretching. The technique is fast, easy and uses high resolution e-beam patterning in contrast to

established screen-printing and other techniques reported in literature. Furthermore, the change in the response of the device shows linear dependence with strain over a broad range of strain with high repeatability. Thus, this technique has high potential for applications in communications technology, remote strain sensing and biological applications.

12:00 **Terahertz Artificial Material Based On Integrated Metal-rod-array For Phase Sensitive Fluid Detection** **Th-A2-1b-4**

Borwen You[1]; Ja-Yu Lu[2]
[1]University of Tsukuba, Japan; [2]Department of Photonics, National Cheng Kung University, Taiwan

Transverse-electric (TE) polarized terahertz (THz) waves along a three-layered metal-rod-array (MRA) are demonstrated to identify liquid molecular dipole moments based on the extended optical-path-lengths. The minute sensing ability is less than 0.1 mmol, equaling 2.7 μmol/mm^2 adsorption density.

12:15 **Narrowband Ultra-Thin Metasurface Absorbers For SubTHz Bandand Their Application In Spectrometric Pyroelectric Detectors** **Th-A2-1b-5**

Sergei Kuznetsov[1]; Andrey Arzhannikov[2]; Victor Fedorinin[1]
[1]Rzhanov Institute of Semiconductor Physics SB RAS, Russian Federation; [2]Budker Institute of Nuclear Physics SB RAS, Russian Federation

The results of theoretical and experimental investigations of high-performance ultra-thin metasurface-based radiation absorbers designed for narrow-band operation in the range of 0.1-1 THz are presented. Implemented in a high-impedance surface configuration with a deep-subwavelength thin metal-backed polypropylene substrate, the absorbers are further used as the photo-sensitive layers in wavelength-selective pyroelectric sensors. The discrete and 1D-aray pyrodetectors applicable to measuring spectra of broadband subTHz sources are described.

11:00 - 12:30 **Th-A2-1c Imaging and Remote Sensing IV** **Room 133+134**

Session Type: Oral

11:00 **[Keynote] Vectorial Properties Of A Terahertz Bessel Beam** **Th-A2-1c-1**

Xinke Wang[1]; Zhen Wu[2]; Yan Zhang[2]
[1]Capital Normal University, China; [2]Capital Normal Univeristy, China

As a kind of special beams, Bessel beams are always a research hot spot in optics due to its non-diffractive and self-healing properties. Here, a zero-order terahertz (THz) Bessel beam is generated by using a Teflon axicon. By applying a THz focal-plane imaging system, the evolutions of the transverse and longitudinal electric fields are coherently measured and analyzed during the propagation process of the THz Bessel beam. The work provides a comprehensive view for exactly understanding peculiar features of a THz Bessel beam.

11:30 **Characterization Of Vortex Beams Using Interference And Diffraction Techniques** **Th-A2-1c-2**

Natalya Osintseva[1]; Yulia Choporova[1]; Boris Knyazev[1]; Vladimir Pavelyev[2]; Boris Volodkin[2]
[1]Budker Institute of Nuclear Physics SB RAS, Russian Federation; [2]Samara National Research University, Russian Federation

Monochromatic vortex Bessel beams generated with diffractive optical elements were studied in the THz range. Since diffractive and interferometric techniques are sensitive to the phase profile, they were used to measure the total topological charge of these beams. Analytical study, simulations and experimental results are given

11:45 **Holography As An ATR THz Imaging Technique** **Th-A2-1c-3**

Yulia Choporova[1]; Boris Knyazev[2]
[1]Budker institute of nuclear physics, Russian Federation; [2]Budker institute of nuclear physics SB RAS, Russian Federation

Classical holography has been applied to real-time or single-shot imaging in attenuated total reflection systems. The Novosibirsk free electron laser has been used as a source of monochromatic coherent THz radiation. The applicability of reconstruction techniques has been discussed considering that the sensitive element size can be less than the wavelength.

12:00 **Object Feature Extraction With Focused Terahertz Plenoptic Imaging** **Th-A2-1c-4**

Ritesh Jain; Frank Landskron; Janusz Grzyb; Ullrich Pfeiffer
IHCT, University of Wuppertal, Germany
Novel THz plenoptic imaging for a spot-scanning system is proposed. The acquired plenoptic beam-profile for each spot generates rich details about the object structure beyond the conventional 2-D imaging. An example shows the extraction of curvature of a metal surface from reflection-mode imaging.

12:15 **Shape From Focus Applied To Real-Time Terahertz Imaging** **Th-A2-1c-5**

Jean-Baptiste Perraud[1]; Jean-Paul Guillet[1]; Maher Hamdi[2]; Olivier Redon[2]; Jérôme Meilhan[3]; François Simoens[3]; Patrick Mounaix[1]
[1]IMS - Bordeaux University, France; [2]CEATech Nouvelle Aquitaine, France; [3]CEA LETI, France
Thanks to significant advances in real-time terahertz imaging in term of resolution and image quality, the possibilities for 3D reconstruction are numerous. The Shape from Focus (SFF) algorithm is a post-processing tool used in optical microscopy to obtain the 3D object shape surface. We propose to apply this algorithm in active and real-time terahertz imaging. Thus, we report the investigation led on such an algorithm to manage 3D terahertz object reconstruction.

11:00 - 12:30 **Th-A2-1a Spectroscopy and Material Properties VIII** **Room 141+142**

Session Type: Oral

11:00 **[Keynote] Vacuum Bloch-Siegert Shift In Cyclotron Resonance** **Th-A2-1a-1**

Motoaki Bamba[1]; Xinwei Li[2]; Junichiro Kono[2]
[1]Osaka University & JST, Japan; [2]Rice University, United States
In a two-dimensional electron gas (2DEG) in GaAs quantum wells placed inside a terahertz (THz) cavity in the presence of an external perpendicular magnetic field, we observed a clear resonance-frequency shift originating from the counter-rotating coupling between the electrons' cyclotron resonance and THz cavity modes. This shift can be understood as a vacuum Bloch-Siegert shift, arising from the ultra-strong counter-rotating coupling between the cyclotron-orbiting 2DEG and the vacuum fluctuations of the THz cavity modes. While such a shift has been difficult to observe clearly and is usually neglected under the rotating-wave approximation, here an unambiguous observation was made possible by the broken time-reversal symmetry of the 2DEG in a magnetic field and the use of a high-mobility 2DEG, a high-quality-factor cavity, and circularly polarized THz radiation.

11:30 **Effect Of Magnetic Field On Terahertz Photoconductivity In Hg1-xCdxTe-Based Structures** **Th-A2-1a-2**

Alexandra Galeeva[1]; Alexey Artamkin[2]; Aleksei Kazakov[2]; Sergey Dvoretskii[3]; Nikolay Mikhailov[3]; Sergey Danilov[4]; Ludmila Ryabova[2]; Dmitry Khokhlov[2]
[1]Moscow State University, Russian Federation; [2]M.V. Lomonosov Moscow State University, Russian Federation; [3]Rzhanov Institute of Semiconductor Physics, Russian Federation; [4]Regensburg University, Germany
Mercury cadmium telluride $Hg_{1-x}Cd_xTe$, $x < \sim 0.16$ semiconductors demonstrate inverted band structure ordering which corresponds to the topological phase. The conduction band and the heavy hole subband touch each other providing a gapless state in the whole composition range $0 < x < \sim 0.16$. The positive energy gap opens, and the trivial state is realized at
$x > \sim 0.16$. In contrast to the most of 3D topological phases, the free carrier concentration in $Hg_{1-x}Cd_xTe$ topological phase is low enough to observe the photoconductivity effect in the terahertz spectral range.

In this work, we present our experimental results on the photoconductivity excited by terahertz laser pulses in $Hg_{1-x}Cd_xTe$ epitaxial films in a close vicinity to the band inversion point. We demonstrate that, for the topological phase, the photoresponse is an uneven function of the magnetic field applied. This behavior is atypical for the conductivity and photoconductivity which normally do not depend on the magnetic field polarity.

$Hg_{1-x}Cd_xTe$ films of ~5 mcm thickness were synthesized by the molecular beam epitaxy. The free electron concentration determined from Hall measurements is ~ $3*10^{14}$ cm^{-3} at T = 4.2 K. The photoconductivity measurements were performed for the Hall bar samples with x < 0.16 (topological phase, inverted band structure), and x > 0.16 (trivial phase, normal band structure) in the Faraday geometry at T = 4.2 K. The photoexcitation was carried out using pulsed laser radiation with a wavelength of 280 mcm. Duration of laser pulses was about 100 ns. Magnetic field applied was up to 4 T.

We have observed the positive and the negative photoconductivity effects in the absence of the magnetic field in the samples with the inverted and the direct energy spectrum, respectively. The negative photoresponse is related to the electron gas heating, while the positive photoconductivity is due to the interband transitions.

It has been found that the photoresponse in the samples being in the topological phase strongly depends on the combination of both the magnetic field polarity and the potential probe position. For a given pair of the potential probes, the photoconductivity in weak magnetic fields B < 1 T is featured by the positive contribution which is absolutely suppressed for the opposite magnetic field direction, as well as for the mirror-like potential probes across the sample. The negative photoconductivity prevails in strong magnetic fields B > ~ 1 T. The asymmetry in the photoresponse in magnetic field may be due to the spin-related features of the carriers in topological phase.
The photoresponse practically does not depend on the magnetic field and is insensitive to the magnetic field polarity and the probe position for samples being in the trivial phase.

Normally, the conductivity and photoconductivity do not depend on the magnetic field polarity. Mechanisms responsible for the effects observed and possible reasons for the asymmetry in the photoresponse are discussed.

11:45 **Bi-relaxor Behavior And Fe2+ Fine Structure In Single Crystalline Ba0.3Pb0.7Fe12O19 M-type Hexaferrite** **Th-A2-1a-3**

Liudmila Alyabyeva[1]; Victor Torgashev[2]; Elena Zhukova[1]; Denis Vinnik[3]; Svetlana Gudkova[3]; Anatoliy Prokhorov[4]; Tomislav Ivek[5]; Silvia Tomic[5]; Nikolina Novosel[5]; David Rivas Gongora[5]; Damir Staresinić[5]; Damir Dominko[5]; Zvonko Jagličić[6]; Martin Dressel[7]; Boris Gorshunov[1]
[1]Moscow Institute of Physics and Technology (State University), Russian Federation; [2]Southern Federal University, Russian Federation; [3]South Ural State University, Russian Federation; [4]A.M. Prokhorov General Physics Institute,, Russian Federation; [5]Institut za fiziku, Croatia; [6]University of Ljubljana, Slovenia; [7]1. Physikalisches Institut, Universität Stuttgart, Germany
Single crystalline lead-substituted barium hexaferrite are studied in a broadband spectral range 10^2 Hz to $2*10^{14}$ Hz. A bi-relaxor type dielectric behavior is observed as well as electronic transitions between the fine-structure components of the split Fe^{2+} ground state level.

12:00 **Electromagnon In The Y-type Hexaferrite $BaSrCoZnFe_{11}AlO_{22}$** **Th-A2-1a-4**

Filip Kadlec[1]; Jakub Vít[1]; Christelle Kadlec[1]; Fedir Borodavka[1]; Yi Sheng Chai[2]; Kun Zhai[2]; Young Sun[2]; Stanislav Kamba[1]
[1]Institute of Physics, Czech Academy of Sciences, Czech Republic; [2]Institute of Physics, Chinese Academy of Sciences, Beijing, China
Using THz time-domain spectroscopy in external magnetic field and a set of other complementary spectroscopic techniques, we studied single crystals of $BaSrCoZnFe_{11}AlO_{22}$, a multiferroic with the *Y*—hexaferrite crystal structure. A purely electric-dipole-active electromagnon near ca. 1.2 THz was observed in time-domain terahertz and Raman spectra. The electromagnon is sensitive to applied magnetic field, and its activity or disappearance can be correlated with the existence of various magnetic phases. We determined analytically the selection rules for the electromagnon, taking into account the crystal symmetry. Their comparison with the experiment shows that the electromagnon involves spins vibrating along the hexagonal axis c and that it is activated by exchange striction.

12:15 **Structural And Mechanical Properties Of Metal-Organic Frameworks Probed With Terahertz Time-Domain Spectroscopy** **Th-A2-1a-5**

Michael Ruggiero[1]; Qi Li[2]; Wei Zhang[3]; Jefferson Maul[4]; Alessandro Erba[4]; Daniel Mittleman[3]; Axel Zeitler[2]
[1]University of Vermont, United States; [2]University of Cambridge, United Kingdom; [3]Brown University, United States; [4]University of Torino, Italy

Metal-organic frameworks are an important class of porous materials exhibiting a variety of promising properties that are related to the unique atomic-level structural features found in the solids. Using terahertz time-domain spectroscopy, the relationship between the large-amplitude low-frequency vibrations and the mechanochemical features found in these materials can be elucidated, providing deep insight into the origins of the favourable phenomena.

11:00 - 12:30 Th-A2-R2 2D Materials for MMW, THz, IR applications I **Reception Hall**

Session Type: Oral

11:00 **[Keynote] Ultrafast Terahertz Modulator Based On Metamaterial-integrated WSe2 Thin-films** **Th-A2-R2-1**

Prashanth Gopalan; Ashish Chanana; Sriram Krishnamoorthy; Ajay Nahata; Michael Scarpulla; Berardi Sensale-Rodriguez
University of Utah, United States

Semiconducting TMDs are promising candidates for THz optoelectronic devices with their ultrafast carrier dynamics and large modulation depths stemming from high photo-induced carrier concentration. In this work, we exploit the ultrafast carrier recombination in photoexcited WSe2 thin films for active THz modulation. The THz absorption was modelled as a sum of a free carrier Drude term and a Lorentzian oscillator for excitonic bound carriers. Based on this, we explore a THz modulator based on a metamaterial structure capacitively coupled to a CVD grown WSe2 film. While the THz absorption upon photoexcitation is strong close to the exciton resonance, the modulation response is limited by free carriers.

11:30 **THz Band Gap In Encapsulated Graphene Quantum Dots** **Th-A2-R2-2**

Sylvain Massabeau; Elisa Riccardi; Michael Rosticher; Federico Valmora; Panhui Huang; Jérôme Tignon; Takis Kontos; Sukhdeep Dhillon; Robson Ferreira; Juliette Mangeney
1Laboratoire Pierre Aigrain, Ecole normale supérieure, France

Graphene possesses many exceptional properties that are highly attractive for THz technology. However, opening a band gap in graphene is a crucial step toward practical THz applications. Here, we report high-quality encapsulated graphene quantum dots of 240 nm diameter that possess a band gap within the THz range. The encapsulation of the graphene with hexagonal Boron Nitride layers provides reduced disorder by preserving the graphene from chemical contamination during nanopatterning process and also by a weak perturbation of the substrate. Encapsulated graphene quantum dots opens the way to achieve low doping regimes that is crucial for operation at THz frequency.

11:45 **Graphene Enhanced 2-D Nanoelectrode For Continuous Wave Terahertz Photomixers** **Th-A2-R2-3**

Alaa Jumaah[1]; Shihab Al-Daffaie[1]; Oktay Yilmazoglu[2]; Franko Küppers[1]
[1]Institute for Microwave Engineering and Photonics (IMP), TU Darmstadt, Germany; [2]Department of High Frequency Electronics (HFE), TU Darmstadt, Germany

New enhanced type photomixers for continuous wave (CW) terahertz (THz) generation were fabricated using 3-5 layers and 6-8 layers of graphene material. These multilayer graphene (MLG) sheets were used as 2-D nanoelectrodes on low-temperature-grown (LTG) GaAs photoconductor. The MLG nanoelectrode shows unique properties with high short-circuit current capabilities and reliable high photocurrents. Furthermore, due to the transparency of the MLG, the use of these graphene 2-D nanoelectrodes in THz photomixers allows an efficient optical power illumination for high photocurrent generation and shows a reliable CW THz emission.

12:00 **HgTe/CdTe Quantum Well Heterostructures For Far And Mid IR Lasers** **Th-A2-R2-4**

Sergey Morozov[1]; Vladimir Rumyantsev[2]; Vladimir Gavrilenko[2]; Aleksander Kadykov[2]; Mikhail Fadeev[2]; Frederic Teppe[3]
[1]Institute for Physics of Microstructures RAS, Russian Federation; [2]IPM RAS,

Russian Federation; [3]Laboratoire Charles Coulomb, UMR Centre National de la Recherche Scientifique, University of Montpel, France
We report on stimulated emission at wavelengths up to 20μm from HgTe/HgCdTe quantum well heterostructures with wide-gap HgCdTe dielectric waveguide, grown by molecular beam epitaxy on GaAs(013) substrates. The mitigation of Auger processes in structures under study is exemplified, and the promising routes towards the 20--50 μm wavelength range, where HgCdTe lasers may be competitive to the prominent emitters, are discussed.Structures under study were MBE-grown on semi-insulating GaAs (013) substrates with ZnTe and CdTe buffers. The active part of the structure includes several HgTe/CdHgTe QW grown inside a thick (several micron) wide-gap CdHgTe waveguide layer. Targeted QW thickness lying in 3.5 -- 4.3 nm were chosen according to calculations of the band spectrum in the framework of Kane 8x8 Hamiltonian model. Implementing such structures, we demonstrate stimulated emission (SE) under pulsed [1-3] and continuous wave (cw) optical pumping at wavelengths as long as 9.5 -- 19.5 μm, which is almost fourfold increase over previous works. Being recalculated to the equivalent threshold current, the threshold is only 500 A/cm^2 for λ = 20 μm at 8K -- 45K. In principle, such low threshold current density allows development of continuous wave diode lasers. We show that the side maxima, arising in the valence band when the QW width is increased, is a critical issue for radiative properties of the material since they enhance Auger processes. We show that a significant increase in operating temperature (by ~80 K) and wavelength is possible by introducing the additional strain in QW structure to modify the carrier spectrum in the valence band. Using Kane 8x8 Hamiltonian and Bernevig-Hugh-Zhang four-band model to calculate radiative and Auger recombination times, respectively. Carrier lifetime measurements agree well with the calculated data. The sub-nanosecond carrier lifetimes have been explored via the pump-probe measurements of a sample's transmission [3]. For HgCdTe QW with 20 meV, corresponding to 4.8 THz frequency, the carrier lifetime is no less than 100 ps for carrier density of 10^11 cm^-2 that is sufficient to achieve population inversion. One can estimate a threshold pumping intensity of 10 kW/cm2 for an optically pumped laser exploiting such QWs as an active media. Thus, implementing narrow HgTe/CdHgTe is the promising route to suppress the Auger recombination and increase the operating wavelength of HgCdTe based lasers in far-infrared/THz (20 -- 60 μm) range.[1]. S.V. Morozov et al, APL, 2017. 111(19): p. 192101.[2]. S.V. Morozov, et al, APL, 2016. 108, P. 092104.[3]. S. Ruffenach et al., APL Materials, 2017. 5(3): p. 035503

12:15 **Terahertz Light Amplification By Instability-Driven Stimulated Emission Of Graphene Plasmon Polaritons** **Th-A2-R2-5**

Stephane Boubanga-Tombet[1]; Deepika Yadav[1]; Wojciech Knap[2]; Vyacheslav Popov[3]; Taiichi Otsuji[1]
[1]Tohoku University, Japan; [2]Laboratory Charles Coulomb, University of Montpellier and CNRS, France; [3]Kotelnikov Institute of Radio Engineering and Electronics (Saratov Branch), RAS, Russian Federation
The generation and amplification of terahertz (THz) electromagnetic waves by plasmonic instabilities in conventional two-dimensional (2D) electron systems have been actively investigated since 1980. However, after about forty years, we are still a long way from the realization of efficient emitters/amplifiers based on the instability-driven mechanisms. The rise of graphene makes this work worth to be revisited. We experimentally demonstrate terahertz light amplification by instability-driven stimulated emission of graphene plasmon polaritons in an asymmetric dual-grating-gate transistor structure. D.C. channel current driven by the drain bias voltage induces plasmon instability, alternating the electromagnetic response from the resonant absorption to the resonant amplification (up to ~ 9 % gain) beyond the threshold leve at room temperature.

11:00 - 12:30 **Th-A2-4 Gyro-Oscillators and Amplifiers IV** **Room 432**
Session Type: Oral

11:00 **[Keynote] Recent Results In IAP/GYCOM Development Of Megawatt Gyrotrons** **Th-A2-4-1**

Grigory Denisov
Institute of Applied /GYCOM Ltd, Russian Federation
A brief summary of current developments in Russia of megawatt power gyrotrons is presented. The gyrotron developed are applied in experiments at several modern tokamaks. New demands to gyrotron parameters are discussed.

11:30 **Optimized Vertical Collector Sweeping For High Power CW Gyrotrons Using Advanced Current Waveforms** **Th-A2-4-2**

Stefan Illy[1]; Konstantinos Avramidis[2]; Lukas Jackowski[2]; Walid Kdous[2]; John Jelonnek[2]
[1]Karlsruhe Institute of Technology (KIT), Germany; [2]Karlsruhe Institute of Technology, Germany

For high power CW gyrotrons, it is mandatory to reduce the extreme power densities on the collector wall caused by the spent electron beam. A typical measure is the spreading of the electron trajectories using vertical sweeping driven by an oscillating magnetic field. Using a sinusoidal current to feed the sweeping coils has the drawback that the electron beam stays relatively long in the areas of the lower and upper turning points, which causes relatively high peaks of the average power density at these positions. A conceptual study is presented, which tries to mitigate this problem by using advanced current waveforms to speed up the turning process of the electron beam close to the critical areas and to give information to assist in the procurement of a possible sweeping power supply.

11:45 **Design And Experiment Of A 140 GHz 50kW Gyrotron** **Th-A2-4-3**

Linlin Hu; Guowu Ma; Dimin Sun; Tingting Zhuo; Hongbin Chen; Fanbao Meng
Institute of Applied Electronics, China Academy of Engineering Physics, China

A 140GHz 50kW gyrotron has been designed by the codes developed in CAEP. To validate the design, a prototype has been fabricated and the experiment is ongoing now. In the experiment, a Gaussian beam of 52kW/30s with a single-stage depressed collector operation has been achieved. The extension of pulse duration is underway with the aim of 50kW/60s, and now an output power of more than 30 kW for 60 s has been achieved. The design and the experimental results will pave the way for our future 140GHz MW gyrotron development.

12:00 **Development Of A 330-GHz Mini-Gyrotron** **Th-A2-4-4**

Chao-Hai Du; Shi Pan; Lu-Yao Bao; Zi-Chao Gao; Juan-Feng Zhu; Pu-Kun Liu
Peking University, China

This paper reports on our progress of developing a 330-GHz pulse mini-gyrotron. After previous interaction analysis, the component manufacture and system assembly are completed. A preliminary high-voltage test is carried out. Unfortunately, the experimental test was ceased due to the circuit opening of the electron gun heater filament. An optimized electron gun is under development to improve the gyrotron performance, and new measurement results will be reported soon.

12:15 **Experimental Study Of Terahertz Radiation Sources Based On A Planar Slow Wave Structure And A Pseudospark-sourced Sheet Electron Beam** **Th-A2-4-5**

Guoxiang Shu[1]; Liang Zhang[2]; Huabi Yin[2]; Junping Zhao[3]; Guo Liu[4]; Zhengfang Qian[1]; Alan D. R Phelps[2]; Adrian W. Cross[2]; W He[2]
[1]Shenzhen University, China; [2]University of Strathclyde, United Kingdom; [3]Xi'an Jiaotong University, China; [4]University of Electronic Science and Technology of China, China

Experimental results of two extended interaction oscillators (EIOs) based on a planar slow wave structure (SWS) and a pseudospark-sourced sheet electron beam (PS-SEB) are presented. Initial experimental results demonstrated that the 0.1 THz and 0.2 THz EIOs could provide an output power of 1.2 kW and 10 W, respectively. The idea of combining the advantages of a PS-SEB (high beam current density and large beam cross-sectional area) and a planar SWS (high gain per unit length) to generate powerful terahertz radiation was experimentally verified. Such a methodology provides a possible solution to achieve room-temperature operation, compact, low cost and high output power radiation sources.

14:00 - 16:00 **Th-P1-R1 Spectroscopy of Gases, Liquids, and Solids II** **Shirotori Hall**

Session Type: Oral

14:00 **Terahertz Hydration Dynamics In Aqueous Polysaccharides** **Th-P1-R1-1**

Abhishek Kumar Singh[1]; José Antonio Morales[2]; Nancy Abril Estrada Sierra[3]; Socorro Josefina Villanueva Rodriguebz[3]; Enrique Castro-Camus[4]
[1]Centro de Investigaciones en Optica, A.C., Mexico; [2]2Centro de Investigación y Asistencia en Tecnología y Diseño del Estado de Jalisco. A.C. Av. Normali, Mexico;

[3]Centro de Investigación y Asistencia en Tecnología y Diseño del Estado de Jalisco. A.C. Av. Normalis, Mexico; [4]Centro de Investigaciones en Optica A.C., Loma del Bosque 115, Lomas del Campestre, Leon, Guanajuato, Mexico
We study the hydration dynamics of polysaccharides of commercial and biological significance, namely, agave fructans,inulin, and maltodextrin, employing terahertz time-domain spectroscopy. In addition, we employ differential scanning calorimetryas a supporting technique. With the two techniques, we extract the hydration number for these polysaccharides in orderto estimate their hydration ability. We further discuss characteristics of the H-bond network in the hydration shell.

14:15 **Trace Gas Measurement For Security Applications With Injection-seeded Terahertz-wave Parametric Generation** **Th-P1-R1-2**

Kouji Nawata; Yuma Takida; Yu Tokizane; Takashi Notake; Zhengli Han; Andreas Karsaklian Dal Bosco; Mio Koyama; Hiroaki Minamide
RIKEN, Japan
We proposed trace gas measurement for security applications using an injection-seeded terahertz (THz)-wave parametric generation (is-TPG). To achieve high sensitivity and robustness, a monolithic cylinder as a multi-pass cell for THz waves was designed and the detectability of 0.5 ppm for methanol was achieved. The results indicate that is-TPG system provides sensitive detections and identifications for molecules in atmosphere to make secure society.TERAHERTZ (THZ)-WAVE can provide information unavailable through conventional technique such as X-ray, infrared, and microwave techniques. Detections and identifications of chemical, explosive, and biological compounds by THz-wave spectroscopic measurement are promising way for homeland security because various molecules have unique absorption spectra (fingerprints spectra) in THz region [1]. Moreover, several molecules such as H2S and NH3 have large absorption in THz-wave region compared with that in infrared or mid-infrared region. THz-wave sensing can provide homeland security at airports as well as stadiums, and stations. Recently, we have developed high power THz-wave generation and detection based on nonlinear conversion. The technique can offer THz-wave sensing with high dynamic range over 100 dB. Additionally, the broadband tunability from 0.8 to 4.7 THz can identify mixed molecules in atmosphere and there are many absorption windows of water vapor. Here, we applied the injection-seeded THz-wave parametric generator (is-TPG) to sensitive gas detection in atmosphere. We designed multi-pass gas cell to achieve sensitive detection. The monolithic cylinder cell offered high sensitivity and robustness in measurement. Effective pass lengths can select by the incident angles. The minimum detectability of 0.5 ppm for methanol was achieved. The results indicate that is-TPG system provides sensitive detections and identifications for molecules in atmosphere to make secure society.

14:30 **Terahertz Spectroscopy And Quantum Mechanical Simulations Of Crystalline Historical Pigments** **Th-P1-R1-3**

Timothy Korter[1]; Elyse Kleist[1]; Patrick Mounaix[2]; Corinna Koch Dandolo[2]
[1]Syracuse University, United States; [2]University of Bordeaux, France
Terahertz spectroscopy is an excellent tool for the nondestructive and non-invasive investigation of pigments in historical and art objects. The characteristic terahertz spectra of solid azurite, malachite, and verdigris are presented here, along with fully quantum mechanical simulations of their crystalline structures and lattice vibrations. The powerful combination of theory and experiment enables unambiguous spectral assignments to be made in these complex materials, which allows for the improved construction of reference pigment databases.

14:45 **[Keynote] Using Low-Frequency Vibrational Dynamics To Probe Disorder In Organic Molecular Materials** **Th-P1-R1-4**

Axel Zeitler
University of Cambridge, United Kingdom
In organic molecular crystals terahertz radiation interacts with vibrational modes that extend across large domains of a crystal lattice. This makes terahertz spectroscopy a very powerful technique to study the presence and nature of interactions between molecules. By directly exploring the dynamics in the far-infrared, i.e. at relatively low frequencies in the context of vibrational spectroscopy, terahertz spectroscopy is complementary to crystallography techniques that are long-established to resolve the molecular structure of organic crystals: in contrast to the average position of the different atoms that make up the crystal, terahertz spectroscopy can provide crucial insight into the molecular dynamics in condensed

matter. Given that the terahertz vibrations correspond to large amplitude vibrations that transverse large areas of the potential energy surface, subtle variations of mass or bond strength have significant impact on the spectral features. As a consequence, terahertz spectra serve as a highly sensitive probe of disorder, which is oftentimes very difficult to resolve with commonly used crystallographic techniques. With increasing disorder the coherent motions, that are characteristic for crystalline systems that exhibit long-range order, collapse into the vibrational density of states which, albeit universal to all disordered materials, still represents the vibrational dynamics of such amorphous materials. By measuring the terahertz spectra as a function of temperature it is possible to determine the onset and extent of molecular mobility in disordered molecular solids. This makes terahertz spectroscopy an ideal complementary technique to a range of scattering techniques, such as neutron inelastic scattering, as well as other spectroscopies such as dielectric spectroscopy.

15:15 **Detection Of Organic Crystallites In Ice Using Terahertz Time-Domain Spectroscopy** **Th-P1-R1-5**

Sergey Mitryukovskiy; Jean-Francois Lampin; Romain Peretti
Institut d'Electronique, de Microélectronique et de Nanotechnologie UMR CNRS 8520, France

We report on the detection of a narrow absorption signature of organic crystallites (α-lactose monohydrate) in ice using terahertz time-domain spectroscopy.

15:30 **Identifying Peptide Structures With THz Spectroscopy** **Th-P1-R1-6**

Jens Neu; Ayaka S. Hatano; Elizabeth A. Stone; Golo Storch; Jacob A. Spies; Scott J. Miller; Charles A. Schmuttenmaer
Yale University, United States

Short peptides composed of only a few amino acid residues are of great interest due to their biological activity as well as potentially functioning as enzyme mimics. Identifying their dynamic 3D structure is quintessential for studying structure -- activity relations. We present temperature-dependent THz spectroscopy of tetrameric peptides that exhibit catalytic activity. These THz spectra allow us to distinguish structural features of different peptides. These experimental findings are supported by DFT calculations.

15:45 **The Low Protein Concentration Study In An Extended THz Frequency Range** **Th-P1-R1-7**

Olga Cherkasova[1]; Maxim Nazarov[2]; Peter Solyankin[3]; Alexander Shkurinov[4]
[1]Institute of Laser Physics of SB RAS, Russian Federation; [2]Kurchatov Institute National Research Center, Russian Federation; [3]Institute on Laser and Information Technologies of RAS, Branch of the FSRC "Crystallography and Phot, Russian Federation; [4]Lomonosov Moscow State University;Institute on Laser and Information Technologies of RAS, Russian Federation

To reliably measure protein solutions spectra at low concentrations we optimized dynamic range of two time-domain spectrometers to low and to high frequencies. The transmission and the attenuated total internal reflection geometries data have been combined for precise analyzing of bovine serum albumin (BSA) aqueous solutions spectra at 0.05-3.2 THz. We compare BSA response in three spectral subregions, around 0.1, 1 and 3 THz, and confirmed that slow relaxation is the only process sensitive to biomolecules concentration in water.

14:00 - 16:00 **Th-P1-1b Ultrafast Measurements I** **Room 131+132**

Session Type: Oral

14:00 **All-optical Phase Control Of THz Waveforms** **Th-P1-1b-1**

Lauren Gingras[1]; Wei Cui[2]; Aidan W. Schiff-Kearn[2]; Jean-Michel Ménard[2]; David G. Cooke[1]
[1]McGill University, Canada; [2]University of Ottawa, Canada

We demonstrate all-optical broadband phase control of THz pulses. By spatially patterning a fs pump pulse we inject photoconductive regions inside a silicon-filled THz parallel-plate waveguide (PPWG), defining light-induced THz quasi-optical components within the waveguide. We show carrier envelope phase shifts of single-cycle THz pulses as well as synthesis of chirped waveforms, including a negative chirp of -11 GHz/ps between 0.3 and 0.5 THz.

14:15 **Terahertz Spectroscopy Of Metal Halide Perovskites** **Th-P1-1b-**

Michael Johnston
University of Oxford, United Kingdom
Metal halide perovskite semiconductors are currently showing great promise for use in thin-film photovoltaic cells. Transient terahertz conductivity spectroscopy of vapour deposited films of these materials is ideal for studying fundamental charge dynamics in these exciting materials. Parameters extracted in this way allow for the design and modelling of new perovskite solar cells and lasers.

14:30 **[Keynote] THz-Field-Driven Electron Tunneling On The Nanoscale** **Th-P1-1b-3**

Jun Takeda[1]; Katsumasa Yoshioka[1]; Yasuo Minami[2]; Yusuke Arashida[1]; Ikufumi Katayama[1]
[1]Yokohama National University, Japan; [2]Yokohama National University / Tokushima University, Japan
Improved control over the electromagnetic properties of metallic systems on the nanoscale is a key issue for the development of next-generation nanoelectronics. Here, we demonstrate that intense terahertz (THz) electric fields can manipulate the electron delocalization in ultrathin gold (Au) films with nanostructures; the ultrafast electron delocalization takes place through electron tunneling across the narrow insulating bridge between the Au nanostructures. For further manipulating the THz-field-driven electron tunneling, phase-controlled single-cycle THz near-fields have been utilized in a tunnel junction via THz scanning tunneling microscopy (THz-STM). This new technique allows us to unprecedented control of electrons -- sub-picosecond electron burst can be produced in a single tunnel junction with desirable direction and numbers.

15:00 **[Keynote] Progress And Challenges In Terahertz Scanning Tunneling Microscopy** **Th-P1-1b-4**

Frank Hegmann
University of Alberta, Canada
Coupling terahertz pulses to the sharp metal tip of a scanning tunneling microscope (THz-STM) has recently enabled imaging of ultrafast dynamics in materials with atomic spatial resolution. Progress in THz-STM, as well as current challenges and future directions, are discussed.

15:30 **Observation Of The Discharge Structure In 303 GHz Millimeter-Wave Air Breakdown** **Th-P1-1b-5**

Masafumi Fukunari; Tetsuo Yokoyama; Shunsuke Tanaka; Ryuji Shinbayashi; Takumi Hirobe; Yuusuke Yamaguchi; Yoshinori Tatematsu; Teruo Saito
Research Center for Development of Far-Infrared Region, University of Fukui, Japan
In this study, we present observations of the discharge structure in air breakdown using a high power millimeter wave beam at 303 GHz. The discharge is ignited by focusing the incident beam using a parabolic mirror. At the focal point, the discharge is under the overcritical condition. Plasma filaments extend along the electric filed vector of the incident beam. The pitch size of each filaments is one-quarter of the wavelength. After the ignition, the condition turns to be subcritical and the filaments begin to separate into granular plasmas. Filaments then extend in parallel to the incident beam in the E-k plane while in the H-k plane, a diffusive structure was formed. Dynamic evolutions of the complicated discharge structure were observed in both electric and magnetic field planes of the incident beam in high resolution and a clear difference between the structures in E-k field and H-k field planes was observed for the first time.

15:45 **Towards Single-Pulse Spectral Analysis Of MHz-Repetition Rate Sources** **Th-P1-1b-6**

Gudrun Niehues; Miriam Brosi; Erik Bründermann; Michele Caselle; Stefan Funkner; Benjamin Kehrer; Michael J. Nasse; Meghana Patil; Lorenzo Rota; Johannes L. Steinmann; Marc Weber; Anke-Susanne Müller
Karlsruhe Institute of Technology, Germany
A key bottleneck for investigations of ultrafast processes is a detection scheme to record all individual spectra with high repetition rates to avoid averaging and to improve the signal-to-noise ratio. Here, we present spectral measurements of fs laser sources used for electro-optical detection with a KITdeveloped linear sensor array and DAQ system adapted to light sources with MHz repetition rates. This system can be equipped with different sensor types covering a broad wavelength range. It can therefore be used for various applications and scientific questions. The

presented exemplary applications range from accelerator-based diagnostics to table-top laser experiments.

14:00 - 16:00 **Th-P1-1c Modeling and Analysis Techniques** **Room 133+134**

Session Type: Oral

14:00 **Modeling Of Under-Critical Millimeter-Wave Discharge Induced By High Excitation Temperature** **Th-P1-1c-1**

Yusuke Nakamura; Kimiya Komurasaki; Hiroyuki Koizumi
The University of Tokyo, Japan

Resent results of millimeter wave discharge experiments suggest that the high excitation temperature plays an important role in the ionization frond propagation in under-critical intensity. In this research, a simple model was proposed considering this high excitation temperature, and the theoretical propagation velocity was calculated using this model. The result gives good agreement with the experimental results.

14:15 **Investigation Of Metal-rod-array-based Hybrid Plasmonic Terahertz Field** **Th-P1-1c-2**

Dejun Liu[1]; Borwen You[1]; Ja-Yu Lu[2]; Toshiaki Hattori[1]
[1]Department of Applied Physics, University of Tsukuba, Japan; [2]Department of Photonics, National Cheng Kung University, Taiwan

One terahertz (THz) hybrid plasmonic waveguide based on a metal rod array (MRA) integrated with a dielectric ribbon is numerically investigated. Due to the approximate THz refractive indices between the ribbon- and MRA-waveguide modes, the longitudinal decay length and lateral confinement of MRA-guided THz waves can be enhanced while observing transmission loss and electric field distribution in the study.

14:30 **Predicting The Dry Thickness Of A Wet Paint Layer** **Th-P1-1c-3**

Dook van Mechelen
ABB Corporate Research, Switzerland

We report on a method to determine the dry thickness of a drying coating, probed in an arbitrary wet state using THz spectroscopy. Hereto, we successfully model the drying coating as an effective medium consisting of dry and wet regions. Our method provides the dry thickness with great accuracy and universally for all paint classes. Moreover, it reveals the inhomogeneous character of drying coatings, contrasting the established concept of film formation that assumes homogeneous layers.

14:45 **Retrieving Material And Metamaterial Parameters Directly from Time-domain Spectroscopy Time Trace** **Th-P1-1c-4**

Romain Perretti[1]; Sergey Mitryukovskiy[2]; Kevin Froberger[3]; Jean-François Lampin[3]
[1]IEMN, CNRS, Univ. Lille, France; [2]IEMN CNRS, France; [3]CNRS IEMN, France

We present the Fit@TDS software that enables the retrieving of the refractive index from a time-domain spectroscopy experiment. The software does not only use common methods of frequency-domain refractive index retrieving but also include a time-domain optimization algorithm that enables fitting directly the material parameters using of the Drude-Lorentz model or metamaterials through the time-domain couple mode theory.

15:00 **Terahertz Spectral Decomposition Method For Mixture Using Independent Component Analysis** **Th-P1-1c-5**

Xiaoping Zheng; Zhijie Li; Xiaojiao Deng
Tsinghua University, China

The independent component analysis (ICA) was applied on spectral decomposition with terahertz overlapped spectra in this paper. The binary mixtures of L-Glutamic Acid 5K and L-Glutamine 5K which have similar chemical structures and properties were studied. The performance of the ICA method was evaluated by correlation coefficient calculated between the resolved spectra and the component spectra. The spectrum of two constituent species can be extracted with very high correlation coefficients by using ICA in terahertz region. The ICA method gives a novel way for the identification of mixture component.

15:15 **Analysis Of The Hybrid Guided Mode Of The Parallel-Plate Ladder Waveguide With Inhomogeneous Dielectric Filling** **Th-P1-1c-6**

Navid Mohseny Tonekabony; Mehdi Ahmadi-Boroujeni
Sharif University of Technology, Iran

In this work, we present a full-wave modal analysis of the parallel-plate ladder waveguide (PPLWG) with inhomogeneous filling of high-resistivity silicon. The structure under study supports highly-confined surface waves with designable characteristics. The presence of the dielectric inhomogeneity can be inevitable due to fabrication limitations and results in a hybrid guided mode. The generalized multipole technique (GMT) is used to analyze this structure and to extract the dispersion diagram, mode field distribution and attenuation constant of the dominant hybrid guided mode. It is shown that this structure has the ability to be used in realizing mm-wave and terahertz guided-wave devices.

15:30 **[Keynote] Terahetz Detection In MOS-FET: A New Model By The Self-mixing** **Th-P1-1c-7**

Fabrizio Palma[1]; Rosario Rao[2]
[1]Università di Roma La sapienza, Italy; [2]Rome University La Sapienza, Italy
CMOS technology has been extensively used for the realization of image sensors at Terahertz frequencies [1-3]. The explanation of its strong efficiency was usually achieved using a mechanism described by the plasma wave detection theory [4]. When a high frequency signal is applied between gate and source electrodes of a MOSFET, oscillations of the 2D electron gas (located in the inversion layer) converts THz radiation into a DC voltage. As a consequence of this approach, universally accepted model, a strong down scaling of the gate length was assumed as necessary [5]. Recently, we developed a new model of the self-mixing process in order to study the new double barrier structure, suitable for high frequency radiation detection [6]. The model shows how self-mixing occur basically in semiconductor regions in which a potential barrier is present. In this paper we extend the model to the case of the channel-substrate barrier present in a MOS structure, demonstrating that the effect takes place also in a single barrier structures.The model is based on the hydrodynamic semiconductor equations, solved in the small signal approximation. The barrier is that one created by the surface depletion under a gate bias. As main result, we obtain the dependence of the self-mixing voltage as a function of the bias-gate voltage. Several experimental results present in literature can be invoked as validation of the result.

14:00 - 16:00 Th-P1-1a Sources, Detectors, and Receivers VI — Room 141+142

Session Type: Oral

14:00 **Enhancing The THz Emission Through Surface Patterning In Photo-Conductive Antenna** **Th-P1-1a-1**

Goutam Rana[1]; Abhishek Gupta[2]; Arkabrata Bhattacharya[2]; Ravikumar Jain[2]; S. P. Duttagupta[1]; S.S. Prabhu[2]
[1]Indian Institute of Technology Bombay, India; [2]Tata Institute of Fundamental Research, India
In this article we have investigated the effect of surface nano-patterns in THz Photo Conductive Antenna (PCA). The surface patterns help to localize the incident IR excitation thus reduces the reflection. It also reduces carrier recombination time by introducing defect states in current path. The combine effect enhances the THz emission from the device up to 220% when bias field is parallel to pump polarization.

14:15 **Terahertz Generation From Dirac Semimetals Surface Plasmon Polaritons Excited By An Electron Beam** **Th-P1-1a-2**

Tao Zhao; Min Hu; Renbin Zhong; Sen Gong; Chao Zhang; Shenggang Liu; Shenggang Liu
University of Electronic Science and Technology of China, China
A physical mechanism of coherent terahertz (THz) generation from surface plasmon polaritons (SPPs) is presented. In a structure of bulk Dirac semimetals (BDSs) film with dielectric medium loading, the excited SPPs by an electron beam can be directly transformed into THz radiation when meeting the Cherenkov radiation condition. The radiation frequency can be widely tuned by adjusting the beam energy and chemical potential. The radiation power density is enhanced over two orders, up to 105 W/cm2. This mechanism could provide a promising way to develop room temperature, tunable, coherent and intense THz radiation sources to cover the whole THz band.

14:30 **High Power Continuously Frequency-tunable Terahertz Radiation Sources And Transmission Lines For DNP-enhanced NMR System** **Th-P1-1a-3**

Diwei Liu[1]; Tao Song[2]; Hao Shen[2]; Jie Huang[2]; Ning Zhang[2]; ChengHai Wang[2];

Wei Wang[2]

[1] University of Electronic Science and Technology of China, China; [2]University of Electronic Science and Technology of China, China

The effect of the electron beam quality of a 250GHz continuously frequency-tunable gyrotron used for Dynamic Nuclear Polarization enhanced Nuclear Magnetic Resonance is tuned by changing the operating voltage V0 or the operating magnetic field B0 on the operating frequency and the beam-wave interaction efficiency is investigated. Meanwhile, an improved transmission and mirror system with a well-focused Gaussian-like output beam is designed to match the DNP-NMR sample.

14:45 **Enhance Of Impurity Related Terahertz Emission In Optically Pumped GaAs/AlGaAs Quantum Well Structures** **Th-P1-1a-4**

Dmitry Firsov[1]; Ivan Makhov[1]; Vadim Panevin[1]; Maxim Vinnichenko[1]; Leonid Vorobjev[1]; Alexey Vasil'ev[2]; Nikolay Maleev[3]

[1]Peter the Great Saint Petersburg Polytechnic University, Russian Federation; [2]Submicron Heterostructures for Microelectronics Research and Engineering Center of the RAS, Russian Federation; [3]Ioffe Institute, 194021 St. Petersburg, Russia, Russian Federation

The terahertz radiation associated with electron transitions between impurity levels in GaAs/AlGaAs quantum wells is investigated in conditions of optical interband excitation. It has been shown that the near-infrared interband stimulated emission arising in the structure under intense pumping contributes to an increase in the terahertz radiation intensity. This phenomenon is associated with an intense depopulation of the donor level with stimulated interband radiation.

15:00 **Leaky Lens Antenna As Optically Pumped Pulsed THz Emitter** **Th-P1-1a-5**

Alessandro Garufo[1]; Paolo Sberna[1]; Giorgio Carluccio[1]; Juan Bueno[2]; Joshua Freeman[3]; Nuria Llombart[1]; Edmund Linfield[3]; Alexander Davies[3]; Andrea Neto[1]

[1]Delft University of Technology, Netherlands; [2]SRON Netherlands Institute for Space Research, Netherlands; [3]University of Leeds, United Kingdom

Optically pumped pulsed THz emitters exploit the transient motion of photo-generated charge carriers in semiconductors, to produce, coupled to micro-antenna, radiated power over a wide bandwidth up to the THz frequencies. The radiation performance of the antenna greatly affects dispersion of the energy spectrum generated by the photoconductive source and if not properly designed it causes low radiated power. This work presents the design, the fabrication process, the electromagnetic and the thermal analyses of a pulsed photoconductive micro-antenna based on the leaky lens antenna concept. This device shows high radiation efficiency over a band ranging from 0.1 to 1.5 THz, thus being a suitable emitter for THz time-domain sensing system.

15:15 **Local Oscillator Arrays At 1.46 THz & 1.9 THz For GUSTO** **Th-P1-1a-6**

Steven Retzloff[1]; Daniel Koller[1]; Jeffrey Hesler[2]; Cliff Rowland[2]; Thomas Crowe[2]

[1]Virginia Diodes Inc, United States; [2]Virginia Diodes Inc., United States

The GUSTO mission (Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory) is a long duration balloon astronomy mission led by the University of Arizona and scheduled to be launched from Antarctica in 2021. Incorporated in the instruments for the mission are several HEB receiver arrays, including one at 1.46 THz and one at 1.9 THz. This article will describe the development and testing of the local oscillator chains that will be used to drive these two receiver. A key challenge is how to achieve sufficient THz power to drive the HEB mixers while keeping the size and DC power low enough so that the system can be used on the balloon gondola. Initial off-the-shelf prototypes have generated more that the 15 uW required by the HEB mixer elements, while requiring sufficiently low DC power. Compact source elements that can be arrayed in a 15 mm 2xN spacing have been designed and will be described at the conference.

15:30 **Terahertz Radiation From Graphene Based Hyperbolic Medium** **Th-P1-1a-7**

Sen Gong[1]; Xiaodong Feng[2]; Min Hu[2]; Renbin Zhong[2]; Shenggang Liu[2]

[1]University of Electronic Science and Technology of China, China; [2]Terahertz Research Center, School of Electronic Science and Engineering, University of Electronic Sc, China

In summary, the wide band, power enhanced terahertz radiation from graphene based hyperbolic medium is presented here. The promising characters of this

radiation show that it is of great significance for terahertz science and technology. The revealed physical mechanism shows that this terahertz radiation comes from the special TR for electron beam excitation, which are transformed from the excited coupled SPPs modes in the hyperbolic GMS directly. This indicates several promising properties of the terahertz radiation sources based on this proposed mechanism. First, high field intensity, which is enhanced by 2 orders of magnitude compared with the normal TR, can be obtained. Second, the operating frequency can cover almost the whole terahertz region by adjusting the gate voltage of the graphene sheets. Third, the required energy of the free electrons is very low, about hundreds of eV, and the size of the structure is in the order of micrometers. This shows that it can be manufactured on a chip easily. Accordingly, this special TR in hyperbolic GMS presented here can be the basis for developing the miniature, integratable, high-power-density and wide band terahertz radiation sources at room temperature.

15:45 **Quantum Theory Of Surface Polariton Cherenkov Light Radiation Source** **Th-P1-1a-8**

Chengpeng Yu; Shenggang Liu
University of Electronic Science and Technology of China, China
A quantum theory of Surface Polariton Cherenkov Light Radiation Source has been worked out. The electromagnetic field of the Surface Plasmon Polaritons and the associated Cherenkov Radiation is quantized as photons through the Green's tensor approach, and the electron bunch excitation of the photons is calculated. The average field amplitude is obtained and compared with the classical calculation. The results show that, besides the first few oscillation periods when the excitation process starts, the main part of the Cherenkov radiation is similar to that calculated by classical theory.

14:00 - 16:00 **Th-P1-R2 2D Materials for MMW, THz, IR applications II** **Reception Hall**

Session Type: Oral

14:00 **Enhancement Of Terahertz-Induced Photothermoelectric Effect In A Carbon Nanotube Fiber By 3D Porous Graphene** **Th-P1-R2-1**

Yingxin Wang[1]; Meng Chen[1]; Fei Fan[2]; Yi Huang[2]; Ziran Zhao[1]
[1]Tsinghua University, China; [2]Nankai University, China
For the photothermoelectric (PTE) effect occurring in carbon nanomaterials, the responsivity and speed usually compete with each other due to the substrate influence. In this work we report on the improvement of the PTE response of a carbon nanotube fiber under terahertz (THz) illumination by using 3D porous graphene as the substrate benefiting from its perfect absorption to THz radiation and fast thermal diffusion process. About ten times enhancement of the responsivity and five times increase in response speed were observed in a preliminary experimental demonstration. Our work paves the way to develop high-performance carbon nanomaterial-based THz detectors.

14:15 **Low-frequency Noise Characterization Of Graphene FET THz Detectors** **Th-P1-R2-2**

Xinxin Yang[1]; Andrei Vorobiev[1]; Kjell Jeppson[1]; Jan Stake[1]; Luca Banszerus[2]; Christoph Stampfer[2]; Martin Otto[3]; Daniel Neumaier[3]
[1]Chalmers University of Technology, Sweden; [2]RWTH Aachen University, Germany; [3]AMO GmbH, Germany
Graphene field-effect transistors are promising for direct detection of THz signals at room temperature. The sensitivity of such detectors can be in part limited by the low-frequency noise. Here, we report on the characterization of the low-frequency noise of graphene field-effect transistor THz detectors in the frequency range from 1 Hz to 1 MHz. The room-temperature Hooge parameter is extracted to be around 2×10-3. The voltage responsivity at room-temperature and the corresponding minimum noise equivalent power at 0.3 THz are estimated to be 11 V/W and 0.2 nW/Hz0.5, respectively, at a modulation frequency of 333 Hz, which shows comparable results with other detector technologies.

14:30 **[Keynote] Highly Sensitive, Ultrafast Photo-thermoelectric Graphene THz Detector** **Th-P1-R2-3**

Klaas-Jan Tielrooij[1]; Sebastian Castilla[1]; Bernat Terres[1]; Marta Autore[2]; Leonardo Viti[3]; Jian Li[4]; Alexey Nikitin[2]; Miriam Vitiello[3]; Rainer Hillenbrand[2]; Frank Koppens[1]
[1]ICFO - the Insitute of Photonic Sciences, Spain; [2]CIC NanoGUNE, Spain; [3]NEST, CNR, Italy; [4]Nanjing University, China
We demonstrate a THz detector that is made of high-quality graphene and is based

on the photo-thermoelectric (PTE) effect: absorbed THz light leads to hot-carriers that generate a photoresponse at a junction between two graphene regions with different carrier density, ideally a pn-junction. Our photodetector combines a device geometry that is optimized for the PTE effect with an antenna that focuses the THz light at the pn-junction. We find that the noise-equivalent power (NEP) at room temperature is <200 pW/√Hz, while the response time is <40 ns (limited by the measurement setup) -- many orders of magnitude faster than commercial room temperature detectors.

15:00 **[Keynote] An Integrated 200 GHz Graphene FET Based Receiver** **Th-P1-R2-4**

Marlene Bonmann; Michael Andersson; Yaxin Zhang; Xinxin Yang; Andrei Vorobiev; Jan Stake
Chalmers University of Technology, Sweden
A receiver composed by a graphene FET 200-GHz mixer and a 1-GHz intermediate frequency amplifier integrated on a silicon substrate was modelled, fabricated and characterized. This is the first demonstration of a millimeter wave integrated receiver based on graphene FETs. The receiver conversion loss is measured to be 25 dB across the 185-205-GHz band with 16 dBm of local oscillator pump power, which is in good agreement with the circuit simulations. The simulations show that the receiver conversion loss can be significantly reduced to 16 dB by reducing the contact resistance and by realizing a higher charge carrier mobility in the mixer transistor.

15:30 **Optimized Bending Stable Carbon Nanotube - Polymer Composite For Room Temperature Thermal Detection** **Th-P1-R2-5**

Mingyu Zhang; John Yeow
University of Waterloo, Canada
A flexible and wearable detector based on Carbon nanotubes (CNT) and Poly vinyl alcohol (PVA) composite is investigated in Mid-infrared and Terahertz region. Optimal photo responsivity is found at 25 wt% CNT content device which also shows highly stable response at bending radius down to 3.5 mm. Significant non-contact human-body thermal response at room temperature is demonstrated in 60 wt% CNT device with detectivity up to 4.9 x 106 cm Hz1/2 W-1.

15:45 **(Withdrawn)** **Th-P1-R2-6**

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14:00 - 16:00 **Th-P1-4 Gyro-Oscillators and Amplifiers V** **Room 432**
Session Type: Oral

14:00 **Towards A Tunable Sub-THz Gyrotron For Spectroscopy Of Positronium** **Th-P1-4-1**

Alexey Fedotov[1]; Mikhail Glyavin[1]; Toshitaka Idehara[2]; Roman Rozental[1]; Alexander Sergeev[3]; Naum Ginzburg[1]; Vladimir Manuilov[1]; Irina Zotova[1]
[1]Institute of Applied Physics RAS, Russian Federation; [2]Research Center for Development of Far-Infrared Region, University of Fukui, Japan; [3]IAP RAS, Russian Federation
We propose a simple method of increasing the bandwidth of smooth frequency tuning in gyrotron by the use of a short cavity driven by an electron beam with high current. Analytical estimates of the achievable band of frequency tuning are presented. Numerical simulations based on both averaged equations and PIC-code show a feasibility of the gyrotron with the output power of 1 kW within a 10-GHz band at the frequency of 0.2 THz. The radiation source with such parameters is needed for testing quantum electrodynamics predictions through the spectroscopy of positronium.

14:15 **Observation Of FID On BDPA By Pulsed ESR Using A Gyrotron As High-power Millimeter Wave Source** **Th-P1-4-2**

Seitaro Mitsudo; Kenshi Hiiragi; Kaishi Kono; Kazuki Dono; Yuya Ishikawa; Yutaka Fujii
Research Center for Development of Far-Infrared Region, University of Fukui, Japan
In order to realize pulsed ESR measurements by using a gyrotron oscillator, 154 GHz gyrotron output had been successfully sliced to intense and short millimeter wave pulses. A quasi-optical transmission system has been developed to be led these short pulses to ESR measurement probe. FID signal of BDPA radical was successfully observed by using this system.

14:30 **Design Of A Gridded Cusp Gun For A W-band Gyro-TWA** **Th-P1-4-3**

Liang Zhang; Craig W. Donaldson; Adrian W. Cross; Alan D.R. Phelps; Wenlong He
University of Strathclyde, United Kingdom
This paper reports the design and optimization of a gridded cusp electron gun for a W-band gyrotron traveling wave amplifier. By applying positive or negative biasing potentials to additional electrodes that are placed in front of the emitter, the electron beam can be switched on and off quickly and easily. In simulations, an optimal velocity ratio (alpha) of 1.12 with an alpha spread of ~10.7% was achieved when the gridded-type gun was operated at a beam voltage of 40 kV and a current of 1.7 A.

14:45 **Influence Of Electron Beam Misalignment On The Performance Of A 0.24 THz, 1.5 MW Hollow-Cavity Gyrotron Design For DEMO** **Th-P1-4-4**

Parth Chandulal Kalaria; Konstantinos Avramidis; Gerd Gantenbein; stefan illy; Ioannis Pagonakis; Manfred Thumm; John Jelonnek
Institute for pulsed power and microwave technology, Germany
After ITER, a DEMOnstration power plant (DEMO) is planned to prove technical feasibility of controlled thermonuclear fusion energy. High-frequency (≥ 0.2 THz), high-power (2 MW) gyrotrons are planned as RF sources for Electron Cyclotron Resonance Heating and Current Drive (ECRH&CD) applications in DEMO. At such a high frequency, the effect of a possible electron beam misalignment could be critical for the gyrotron performance. For this reason, the beam misalignment tolerance has been numerically studied for a 236 GHz, 1.5 MW hollow-cavity gyrotron design using a macro-electron based simulation approach. Spread in the electron perpendicular velocity and the radial width of the electron beam are considered too. The results suggest a stable excitation of the selected $TE_{-52,18}$ - operating mode assuming a maximum electron beam misalignment (D) of 0.225 mm ($D/\lambda = 0.18$).

15:00 **Progress In The Development Of A Multistage Depressed Collector System For High Power Gyrotrons** **Th-P1-4-5**

Ioannis Pagonakis; Chuanren Wu; Benjamin Ell; Konstantinos Avramidis; Gerd Gantenbein; Stefan Illy; Manfred Thumm; John Jelonnek
Karlsruhe Institute of Technology, Germany
The development of a highly efficient multistage depressed collector system for the recovery of the major part of the spent electron beam energy is the key to increase the gyrotron efficiency. For several years there has been a significant effort at Karlsruhe Institute of Technology (KIT) in order to design a reliable, robust and efficient multistage depressed collector system for high power gyrotrons. The progress and the recent results of these studies will be presented.

15:15 **Radial Bragg Resonators For THz Gyrotrons** **Th-P1-4-6**

Alexander Vikharev[1]; Sergey Kuzikov[2]; Sergey Antipov[2]
[1]Institute of Applied Physics RAS, Russian Federation; [2]Euclid Techlabs LLC, United States
We propose open-side resonators for THz gyrotrons. These resonators could be based on metallic radial Bragg reflectors for short pulse devices driven by high-voltage beams or on diamond Bragg reflectors for CW operation. Resonators of both types can be produced using femtosecond laser ablation technology developed in Euclid Techlabs LLC.

15:30 **[Keynote] Amplification Of W-band Multi-frequency Signals Using A Gyro-TWA** **Th-P1-4-7**

Wenlong He[1]; Craig Donaldson[1]; Liang Zhang[1]; Peter Cain[2]; Huabi Yin[1]; Kevin Ronald[1]; Adrian Cross[1]; Alan Phelps[1]
[1]The University of Strathclyde, United Kingdom; [2]Keysight Technologies UK Ltd, United Kingdom
A W-band gyrotron traveling wave amplifier (gyro-TWA) based on a helically corrugated interaction region achieved an unsaturated output power of 3.4 kW with a gain of up to 37 dB and a 3 dB frequency bandwidth of at least 5.5 GHz. In this paper we report that this gyro-TWA can be operated in different beam parameter regions. Also the frequency agility of the gyro-TWA was demonstrated by the amplification of multi-frequency signals.

16:30 - 18:00 **Th-P2-R1 Spectroscopy of Gases, Liquids, and Solids III** **Shirotori Hall**

Session Type: Oral

16:30 **Porous Polymers As A Substrate For Terahertz Spectroscopy** **Th-P2-R1-1**

Anwen Smith; Andreas Klein; Claudio Balocco; Natasha Shirshova

Durham University, United Kingdom
A macroporous polymer prepared by radical polymerization of high internal phase emulsions (HIPE) is evaluated as a substrate for THz spectroscopy of aqueous solutions. The synthesis, microstructure and THz properties of these polymerized HIPEs (polyHIPEs) are discussed. Their performance is evaluated by measuring the insecticide methomyl in an aqueous solution with a THz Network Analyzer and THz-TDS.

16:45 **Hydration Of Aqueous Polymers Investigated By Terahertz Spectroscopy And Principal Component Analysis** **Th-P2-R1-2**

Katsuyoshi Aoki[1]; Ryusuke Hata[2]; Junya Kaneyasu[2]; Gerhard Schwaab[1]; Kentaro Shiraki[2]; Toshiaki Hattori[2]
[1]Ruhr-University Bochum, Germany; [2]University of Tsukuba, Japan
Hydration in aqueous solutions of poly(ethylene glycol) (PEG) and poly(propylene glycol) (PPG) was studied using terahertz spectroscopy and principal component analysis (PCA). An addition of a methyl group to a PEG repeat unit increases the number of hydration water per repeat unit. With the result of PCA, the fast relaxation process of hydration water is discussed, and the dielectric loss spectra of PEG and PPG hydration water were estimated.

17:00 **Observation Of Unusual Electronic Phases In Structurally Modulated PrNiO3 Thin Films Via Terahertz Time-domain Spectroscopy** **Th-P2-R1-3**

Dhanvir Rana; Eswara phanindra V
IISER bhopal, India
Rare-earth nickelates RNiO3 (R = La to Lu) exhibit a wide range of exotic ground states. The first two compounds in these series are known to display most contrasting behavior; the LaNiO3 (LNO) lacks any phase transition, while the second compound PrNiO3 (PNO) exhibits concomitant insulator-metal transition (I-M) at 130 K. To understand this, we studied the novel electronic phase behaviors in structurally modified PNO thin films via terahertz spectroscopy. We observed that the THz conductivity of compressive film sans any I-M transition and follows the extended Drude model whereas the tensile films exhibit Drude-Smith (D-S) type THz conductivity behavior. Such distinct THz spectral features, are in turn accompanied by novel electronic phase crossovers such as transition from non-Fermi liquid (implying proximity to a quantum critical point) to Fermi liquid behavior as one traverses from compressive to tensile PNO films thus, revealing a novel facet of structure-property relationship in PNO.

17:15 **Theoretical Investigation On The Terahertz Vibrational Spectroscopy Of Amino Acid Crystal** **Th-P2-R1-4**

Ling Jiang; Qi Yu
Nanjing Forestry University, China
The terahertz (THz) theoretical spectra of solid-state amino acids were investigated in this paper. Based on the dispersion-corrected density functionals, the periodic crystal structures were constructed. It is found that B3LYP-D2 can produce more accurate simulation results, however, it also greatly increases the cost of calculations. The combination of PBE with the 6-311G(d,p) basis set is accurate enough to reproduce the experimental THz spectra of solid-state amino acids with much higher simulation speed. The observed spectral features were assigned as primarily external lattice translations and rotations with lesser contributions due to intramolecular torsions.

17:30 **[Keynote] Massively Parallel Sensing Of Trace Molecules And Isotopologues With Subharmonic Mid-IR Frequency Combs** **Th-P2-R1-5**

Konstantin Vodopyanov
CREOL, The College of Optics and Photonics, Univ. of Central Florida, United States
We introduce a new platform for mid-infrared dual comb spectroscopy, based on a pair of broadband subharmonic optical parametric oscillators pumped by two phase-locked thulium-fibre combs. Our system provides fast (7 ms for a single interferogram), moving-parts-free, simultaneous acquisition of 350,000 spectral data points, spaced by 115-MHz intermodal interval over 3.1--5.5 micron spectral range. Parallel detection of 22 trace molecules in a gas mixture, including isotopologues containing such isotopes as 13C, 18O, 17O, 15N, 34S, 33S and deuterium, with part-per-billion sensitivity and sub-Doppler resolution has been demonstrated.

16:30 - 18:00 **Th-P2-1b Free Electron Lasers and Synchrotron Radiation I** **Room 131+132**

Session Type: Oral

16:30 **Present Status Of Infrared FEL Facility At Kyoto University** **Th-P2-1b-1**

Heishun Zen; Siriwan Krainara; Shuya Chatani; Toshiteru Kii; Kai Masuda; Hideaki Ohgaki
Institute of Advanced Energy, Kyoto University, Japan
An infrared Free Electron Laser (FEL) facility has been developed for energy-related researches at Institute of Advanced Energy, Kyoto University. The facility has two accelerator based infrared light sources. One is the mid-infrared FEL (MIR-FEL) which consists of a RF gun, a 3-m accelerator tube, a 1.8-m undulator and a 5-m optical resonator. The tunable range of the MIR-FEL is from 3.5 to 23 μm. The RF gun can be operated with thermionic emission and photoelectron emission. The other one is the THz Coherent Undulator Radiation (THz-CUR) source which consists of a photocathode RF gun, a bunch compression chicane and a 70-cm undulator with the period length of 7 cm. The present statuses of those accelerator based light sources are reported.

16:45 **Terahertz Activities At KAERI Ultrafast Electron Diffraction Facility** **Th-P2-1b-2**

In Hyung Baek[1]; Hyun Woo Kim[1]; Young Chan Kim[1]; Mihye Kim[1]; Sun Jeong Park[1]; Key Young Oang[1]; Kyuha Jang[1]; Kitae Lee[1]; Young Uk Jeong[1]; Nikolay Vinokurov[2]; Thomas Feurer[3]
[1]Korea Atomic Energy Research Institute, Korea, Republic of; [2]Budker Institute of Nuclear Physics, Russian Federation; [3]Institute of Applied Physics, University of Bern, Switzerland
In this talk, we will introduce the performance of the ultrafast electron diffraction facility at KAERI. Also our recent efforts to measure an electron bunch length and a timing jitter will be shown. Now we are carrying out a terahertz streaking experiment of electron bunch to observe them more precisely. Its design and experimental plan or results will be introduced as well.

17:00 **FELBE - Upgrades And Status Of The IR/THz FEL User Facility At HZDR** **Th-P2-1b-3**

J. Michael Klopf[1]; Manfred Helm[1]; Susanne C. Kehr[2]; Ulf Lehnert[1]; Peter Michel[1]; Alexej Pashkin[1]; Harald Schneider[1]; Wolfgang Seidel[1]; Stephan Winnerl[1]; Sergei Zvyagin[1]
[1]Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany; [2]Technische Universität Dresden, Germany
The FELBE User Facility at the ELBE Center for High Power Radiation Sources offers two FELs dedicated to optical studies of materials over a wide range of the THz and IR spectrum. In 2016, the installation and commissioning of a new U37 undulator was completed, resulting in enhanced performance over the spectral range of 7.5 -- 60 THz (5 -- 40 um). Operation of the new FEL for User operation began during the 2nd half of 2016. Results of the commissioning and early User runs are reported here.

17:15 **High Power THz Free Electron Laser In China Academy Of Engineering Physics** **Th-P2-1b-4**

Dai Wu[1]; MIng Li[1]; Xinfan Yang[1]; Hanbin Wang[1]; Dexin Xiao[1]; Xiaojian Shu[2]; Xiangyang Lu[3]; Wenhui Huang[4]; Yuhuan Dou[2]
[1]Institute of Applied Electronics, China Academy of Engineering Physics, China; [2]Institute of Applied Physics and Computational Mathematics, China; [3]Institute of Heavy Ion Physics, Peking University, China; [4]Department of Engineering Physics, Tsinghua University, China
China Academy of Engineering Physics tera-hertz free electron laser (CAEP THz FEL, CTFEL) is the first THz FEL oscillator in China, which was jointly built by CAEP, Peking university and Tsinghua university. The stimulated saturation of the CTFEL was reached in August, 2017. This THz FEL mainly consists of a gallium arsenide (GaAs) photocathode high-voltage DC gun, a superconducting RF linac, a planar undulator and a quasi-concentric optical resonator. The DC gun provides high brightness high repetition electron bunch with a charge of about 100 pC, and a repetition of 54.167 MHz. The normalized emittance of the electron beam is less than 10 μm, and the energy spread is less than 0.75%. A 2Ã—4-CELL super-conducting radio frequency (RF) accelerator provides an effective accelerating field gradient about 10 MV/m and boosts the electron beam to 6 MeV~8 MeV. The beam then goes through the undulator and generates the spontaneous radiation, which is reflected back and forth in the optical resonator and then stimulated by the electron

beam.The terahertz laser's frequency is continuous adjustable from 2 THz to 3 THz. The average power is more than 10 W and the micro-pulse power is more than 0.5 MW. This facility is now working in macro-pulse mode in the first step, so called the "step one". The minimum macro-pulse duration is about 50 μs and the maximum is about 2 ms. The macro-pulse repetition is 1 Hz or 5 Hz. The typical output in this "step one" is 1 ms and 1Hz. In the middle of 2018, the duty cycle will update to more than 10 % as the "step two". And the continuous wave (CW) operation will be reached in the "step three", by the end of 2018. The spectrum adjustment range will also be expanded to cover from 1 THz to 4 THz by then.

17:30 **[Keynote] Lasing And Saturation Of CAEP THz FEL Facility** **Th-P2-1b-5**

yuhuan dou[1]; Xiaojian Shu[1]; Xingfan Yang[2]; Ming Li[2]; Dai Wu[2]; Derong Deng[2]; hanbin Wang[2]; Xiangyang Lu[3]; Zhou Xu[2]
[1]Institute of Applied Physics and Computational Mathematics, China; [2]Institute of Applied Electronics, CAEP, China; [3]Institute of Heavy Ion Physics, Peking University, China
A high power THz free electron laser (FEL) facility is under construction at China Academy of Engineering Physics (CAEP) since October, 2011. The radiation frequency of the FEL facility is designed in range of 1~3 THz and the average output power is about 10 W. First lasing of the CAEP THz FEL (CTFEL) facility was obtained in August 29, 2017. Then the saturation operation is observed in September 20, 2017. The radiation frequency is sequentially as 1.99THz, 2.41THz and 2.92THz. And the average output power is larger than 10 W; the largest output power is about 17.9W. The peak power of micro-pulse is larger than 0.5MW. In this paper, the present status of the facility is given.

16:30 - 18:00 **Th-P2-1c MMW and THz Wave Radar and Communications I** **Room 133+134**

Session Type: Oral

16:30 **Terahertz Focusing Reflectarray With Enhanced Bandwidth** **Th-P2-1c-1**

Xiaolong You; Christophe Fumeaux; Withawat Withayachumnankul
University of Adelaide, Australia
This paper presents a planar terahertz reflectarray that employs stub-loaded square patches on a grounded substrate for efficient beam focusing at 1 THz. The proposed patch element can achieve a nearly linear and smooth phase response at the operating frequency through variation of its stub length. This feature is of great importance to enhance the bandwidth performance of a reflectarray made of such elements. By the principle of reciprocity, the designed focusing device can also function as a collimator. The numerical results confirm the focusing capability of the designed reflectarray with a 3 dB bandwidth of 0.34 THz at 1 THz. This design can achieve over twice the operation bandwidth compared with existing designs.

16:45 **An Active Multiplier-by-Six S-MMIC For 500 GHz** **Th-P2-1c-2**

Christopher Groetsch[1]; Hermann Massler[2]; Arnulf Leuther[2]; Ingmar Kallfass[1]
[1]University of Stuttgart, Germany; [2]Fraunhofer Institute for Applied Solid State Physics, Germany
A frequency multiplier-by-six based on a 35 nm gate-length metamorphic HEMT technology is presented. The S-MMIC offers an average output power of -15 dBm in the frequency range of 480 to 506 GHz and a maximum output power of -9 dBm at 506 GHz without additional amplification stages at an input power of 5 dBm. A spurious suppression of 35 dBc at 500 GHz was achieved.

17:00 **[Keynote] Filling The THz Gap With Sand: THz Systems On CMOS** **Th-P2-1c-3**

Ehsan Afshari; Saghar Seyedabbaszadeh
University of Michigan, United States
In this paper, we review the applications and design challenges of the THz frequency band. Furthermore, we discuss some of our recent achievements in designing efficient high-power systems. In doing so, new methods and topologies which enable THz systems to achieve both high output power and efficiency are proposed.

17:30 **Simultaneous DoA Estimation And Ranging Of Multiple Objects Using An FMCW Radar With 60 GHz Leaky-Wave Antennas** **Th-P2-1c-4**

Matthias Steeg; Asmaa Al Assad; Andreas Stöhr

University of Duisburg-Essen, Germany
In this paper an FMCW radar system for simultaneous distance and direction estimation of multiple objects with a single sweep is reported. Therefore, a frequency scanning leaky-wave antenna (LWA), providing 60° beam steering from 50 to 60 GHz and over 110° within the V-band, is utilized. The radar is operated to cover the full section within a single frequency sweep. Thus, fast radar operation is enabled, and the distance and direction of multiple objects is obtained from the time dependent spectral components of the received IF signal.

17:45 **Sub-Sampling Of RF And THz Waves Using LT-GaAs Fabry-Pérot Cavity Photoconductors Under 1550 Nm Light Excitation** **Th-P2-1c-5**

Maximilien Billet[1]; Yann Desmet[1]; Fuanki Bavedilla[1]; Stefano Barbieri[1]; Wolfgang Hänsel[2]; Ronald Holzwarth[2]; Guillaume Ducournau[1]; Jean-François Lampin[1]; Emilien Peytavit[1]

[1]IEMN CNRS/Lille University, France; [2]Menlo Systems GmbH, Germany

We study low-temperature-grown, GaAs-based Fabry-Pérot cavity photoconductors, designed for RF and THz optoelectronics applications using 1550 nm lasers. We present here the sub-sampling of continuous waves at frequencies up to 300 GHz with a SNR of 70 dB.

16:30 - 18:00 **Th-P2-1a Sources, Detectors, and Receivers VII** **Room 141+142**

Session Type: Oral

16:30 **In-line Medicine Inspection By Carbon Nanotube Terahertz Scanners** **Th-P2-1a-1**

Meiling Sun[1]; Daichi Suzuki[2]; Yuki Ochiai[2]; Yukio Kawano[2]

[1]Tokyo Institute of Technology, China; [2]Tokyo Institute of Technology, Japan

Abstract--We report on a real-time one-dimensional medicine inspection with a carbon nanotube (CNT) terahertz (THz) scanner. On the basis of different THz transmittance of medicines, we demonstrated in-line identification of different types of medicine pills. The bendable feature of the CNT scanner is expected to lead to multi-view examinations in the future, enabling more accurate whole surface imaging.

16:45 **Strain Tuning In MEMS Beam Resonators For Terahertz Bolometer Applications** **Th-P2-1a-2**

Boqi Qiu[1]; Ya Zhang[1]; Kouichi Akahane[2]; Naomi Nagai[1]; Kazuhiko Hirakawa[1]

[1]Institute of Industrial Science, University of Tokyo, Japan; [2]National Institute of Information and Communications Technology, Japan

We proposed a room temperature, all electrical driving and detecting, THz bolometer using a doubly clamped MEMS beam resonator. It has been known that the THz input power is limited by beam buckling due to thermally induced compressive strain. In this work, we use strained GaAsP for the beam structure to introduce a preloaded tensile strain in the MEMS beam. We have reduced the thermal compressive strain and enlarged the dynamic range for THz detection.

17:00 **Performance Improvements Of THz Imagers Based On Uncooled Antenna-Coupled Bolometer** **Th-P2-1a-3**

Jerome Meilhan[1]; Getachew-tilahun Ayenew[1]; Laurent Dussopt[1]; Maher Hamdi[1]; Antoine Hamelin[1]; Bruno Hiberty[2]; Jérémy Lalanne-Dera[1]; Amalya Minasyan[2]; Olivier Redon[1]; François Simoens[1]

[1]LETI, France; [2]I2S, France

The intrinsic performance of the antenna-coupled bolometer array developed at CEA-LETI was hampered by the noise of the readout chain. Recent improvements of the camera electronics have made possible the optimization of the sensor operation in bias and integration time. It results in a real-time uncooled imager with a sensor-limited minimum detectable power that is improved by a factor of 3, i.e. close to 10 pW, at 2.5 THz.

17:15 **Near-Quantum-Limited Double-Sideband Noise Temperature Through Room-Temperature Plasmonic Heterodyne Terahertz Spectrometers** **Th-P2-1a-4**

Mona Jarrahi; Ning Wang; Semih Cakmakyapan; Yen-Ju Lin

UCLA, United States

A new type of terahertz spectrometer is presented, which uses a plasmonic photomixer as a frequency downconverter to offer near-quantum-limited sensitivity levels at room temperature. We demonstrate DSB noise temperatures of 120-270 K (10hv/k -2hv/k) over 0.1-2 THz. Our results indicate the superior performance of

this terahertz spectrometer in offering lower noise temperatures than cryogenic-cooled HEB mixers and SIS mixers at frequencies above 0.8 THz, while operating at room temperature, without any need for a terahertz local oscillator.

17:30 **[Keynote] Novel Bolometric THz Detection By MEMS Resonators** **Th-P2-1a-5**

Ya Zhang; Surugu Hosono; Naomi Nagai; Kazuhiko Hirakawa
University of Tokyo, Japan
We have developed an uncooled, sensitive, and fast THz bolometer by using a doubly clamped GaAs MEMS beam resonator as a sensitive thermistor. Owing to its ultra-high temperature sensitivity, the present bolometer achieves not only a high sensitivity but also an operation bandwidth of several kHz, which is ~100 times faster than other uncooled THz thermal sensors. The obtained electrical noise equivalent power (NEP) is as low as ~20 pW/√Hz, which is close to the limit set by the thermal fluctuation noise. The MEMS bolometers are fabricated by the standard semiconductor fabrication processes and are well suited for making detector arrays for realizing THz cameras.

16:30 - 18:00 Th-P2-R2 MM and sub-MM wave systems I — Reception Hall

Session Type: Oral

16:30 **Developments Of Millimeter Wave Backscattering Systems For Fusion Plasma Turbulence Measurements** **Th-P2-R2-1**

Tokihiko Tokuzawa[1]; Kazuki Oguri[2]; Shin Kubo[1]; Kenji Tanaka[1]; Hiroshi Yamada[1]; Kiyomasa Watanabe[1]; Akira Ejiri[3]; Shigeru Inagaki[4]; Teruo Saito[5]; Junko Kohagura[6]
[1]National Institute for Fusion Science, Japan; [2]Nagoya University, Japan; [3]The University of Tokyo, Japan; [4]Kyushu University, Japan; [5]Fukui University, Japan; [6]University of Tsukuba, Japan
TWO TYPES OF BACKSCATTERING SYSTEM ARE DESIGNED FOR HIGH TEMPERATURE FUSION PLASMA TURBULENCE MEASUREMENTS. The ion scale turbulence measurements were carried out by the ka-band and U-band Doppler backscattering system. The W-band system is designed for measuring the electron scale turbulence.

I. INTRODUCTION

Controlled nuclear fusion plasmas are studied as the future electric power supply in the worldwide. One of the most important physical issues is the turbulence control in the plasma. For this aim, we have developed several diagnostics by using an infrared / far-infrared laser or microwave / millimeter wave, because the observed turbulence characteristics are related by the probing wavelength and the scattering angle. From the point of view of the accessibility to the complicated magnetic confined plasma device, the backscattering configuration is suitable. Both simultaneous the ion and the electron scale turbulences are interested nowadays. We have developed microwave and millimeter wave backscattering systems applying to the Large Helical Device (LHD) plasma.

II. DOPPLER BACKSCATTERING SYSTEM

Microwave Doppler backscattering is very powerful tool for the turbulence study, because it can measure the turbulence intensity and also the flow velocity, simultaneously. We develop ka- and U-band multi-frequency system using the frequency comb as a source [1, 2]. Frequency comb can generate a number of frequency components at the same time. We can obtain the turbulence intensity profile.

III. W-BAND BACKSCATTERING SYSTEM

The 95 GHz wave is just matched for the higher turbulence wavenumber (~ 30 cm^{-1}) measurements. Since the probing wave needs to focus to 20 mm width at the plasma center which is around 3 meters away from the vacuum window, the Cassegrain antenna with Fresnel zone-plate mirror is planed to apply. The overall system design will be presented at the conference.

ACKNOWLEDGEMENTS

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16:45 **Reducing Losses Of Terahertz Surface Plasmons By Submicron Dielectric Coatings** **Th-P2-R2-2**

Vasily Gerasimov[1]; Alexey Nikitin[2]; Boris Knyazev[1]; Alexey Lemzyakov[1]; Ivan Azarov[3]

[1]Budker Institute of nuclear physics SB RAS, Russian Federation; [2]Scientific and Technological Center for Unique Instrumentation of RAS, Russian Federation; [3]Rjanov Institute of Semiconductor Physics of the Siberian Branch of the RAS, Russian Federation

Study of energy losses during propagation of surface plasmons (SPs) plays an important role for many applications. We measured the attenuation of terahertz (λ=130 μm) SPs generated by the Novosibirsk free-electron laser along plane and convex gold surfaces coated with submicron dielectric (ZnS) layers. The optimal dielectric thicknesses d*, corresponding to the minimum energy losses of SPs, were found. A ZnS coating with d_1*=0.025 μm on a plane gold surface reduced the SP attenuation coefficient by 20 % as compared with bare gold; coating with d_2*=1 μm on a convex surface lowered the coefficient three-fold.

17:00 **A Photonics Enabled Millimetre Wave Frequency Domain Spectrometer For Glucose Concentration Sensing** **Th-P2-R2-3**

James Seddon; Katarzyna Balakier; Xiaoli Lin; Chris Graham; Alwyn Seeds; Cyril Renaud

UCL, United Kingdom

This study reports the experimental demonstration of a free space frequency domain self-heterodyne spectrometer utilising a high-speed Uni-Travelling Carrier photodiode (UTC-PD) as a coherent receiver. The transmission signal through the glucose solution was measured in the V-band (50 -- 75 GHz) frequency range with the frequency resolution step of 40 MHz. Variations in glucose concentrations of 1% weight and above were resolved.

17:15 **Optically Pumped Mixing In Photonically Integrated Uni-Travelling Carrier Photodiode** **Th-P2-R2-4**

ahmad mohammad[1]; Andrzej Jankowski[2]; Frederic van Dijk[2]; cyril renaud[1]

[1]University College London, United Kingdom; [2]III-V Lab, France

We report the first demonstration of optically pumped mixing using a monolithically integrated photonic chip. On that chip, uni-traveling carrier photodiodes (UTC-PDs) were monolithically integrated with two lasers to generate the optical heterodyne that will drive the optically pumped mixing. The lasers were operating in single mode, and the spacing between their optical tones was widely tuneable: from 73 GHz to 86 GHz. When an RF signal at 70 GHz was supplied to the UTC-PD with the optimum voltage bias, the UTC-PD successfully down-converted the RF signal to an intermediate frequency (IF) that was tuneable from 3 GHz to 16 GHz. These results demonstrate the potential of this photonic integrated circuit for spectroscopy, sensing and as millimeter wave wireless receivers.

17:30 **[Keynote] Sensitive Millimeter-Wave/Terahertz Gas Spectroscopy Based On SiGe BiCMOS Technology** **Th-P2-R2-5**

Dietmar Kissinger[1]; Nick Rothbart[2]; Klaus Schmalz[1]; Johannes Borngräber[1]; Heinz-Wilhelm Hübers[3]

[1]IHP, Germany; [2]Humboldt-Universität zu Berlin, Germany; [3]German Aerospace Center (DLR), Germany

We present a millimeter-wave/terahertz (mmW/THz) gas spectroscopy sensor system based on SiGe BiCMOS technology. We demonstrate spatial combining of two transmitters which allows for a total spectral coverage of up to 50 GHz. SiGe

technology can achieve a high integration level and low costs in case of large scale production. MmW/THz gas sensors can be used for instance for the medical analysis of human breath or for the detection of toxic industrial chemicals.

16:30 - 18:00 **Th-P2-4 2D Materials for MMW, THz, IR applications III** **Room 432**
Session Type: Oral

16:30 **Phase-resolved Terahertz Near-field Nanoscopy Of A Topological Insulator Phonon-polariton Mode** **Th-P2-4-1**

Maria Caterina Giordano[1]; Leonardo Viti[1]; Lorenzo Columbo[2]; Massimo Brambilla[2]; Gaetano Scamarcio[2]; Miriam Serena Vitiello[1]
[1]CNR-NANO, Italy; [2]Università di Bari, Italy

A novel scattering-type near-field optical microscopy (s-SNOM) system based on a terahertz (THz) quantum cascade laser operating in self-detection mode is here demonstrated and employed to probe a resonant phonon-polariton mode of a thin topological insulator flake ($Bi_2Te_{2.2}Se_{0.8}$). Background-free near-field imaging with nanoscale spatial resolution is demonstrated.

16:45 **Analysis Of A Plasmonic Graphene Antenna For Microeletronic Applications** **Th-P2-4-2**

Christoph Suessmeier[1]; Sergi Abadal[2]; Luca Banszerus[3]; Felix Thiel[1]; Eduard Alarcon[2]; Anna Katharina Wigger[1]; Albert Cabellos-Aparicio[2]; Christoph Stampfer[3]; Max Lemme[4]; Peter Haring Bolivar[1]
[1]University of Siegen, Germany; [2]NaNoNetworking Center in Catalunya (N3Cat), Spain; [3]RWTH Aachen University, Germany; [4]AMO GmbH, Germany

Graphene offers large potential to downscale antennas to micrometers size, due to their special dispersion relation and their ability to support plasmons in the THz frequency range. For the functionality of the antenna, the graphene quality is crucial. A high chemical potential, as well as high relaxation time are needed for reasonable performance. Fabrication and processing, as well as the environment configuration are very critical for high graphene quality and a good emissivity of the antenna. We demonstrate the simulation, fabrication and analysis of a graphene based plasmonic antenna structure acting as an active THz emission device.

17:00 **Millimeter Wave Phase Shifter Based On Optically Controlled Carbon Nanotube Layers** **Th-P2-4-3**

Serguei Smirnov; Ilya V. Anoshkin; Dmitri V. Lioubtchenko; Joachim Oberhammer
KTH Royal Institute of Technology, Sweden

Surfaces with tunable impedance are usually lossy at high frequencies, which limits the design of millimeter wave and Terahertz devices. This work experimentally demonstrates a phase shifter based on carbon nanotubes and dielectric rod waveguides in the 220-330 GHz frequency range. Thin carbon nanotube layers are used as a tunable impedance surface with the dielectric properties optically controlled by laser illumination.

17:15 **Millimeter Wave Beam Steering Based On Optically Controlled Carbon Nanotube Layers** **Th-P2-4-4**

Dmitri Lioubtchenko; Serguei Smirnov; Ilya Anoshkin; Joachim Oberhammer
KTH Royal Institute of Technology, Sweden

In this paper the dielectric constant changing of carbon nanotube effect layers under light illumination was employed for phase shifter development in the dielectric rod waveguides. This phase shifter was introduced to the dielectric rod waveguide dual-antenna array. The measurements of the beam steering at 90 GHz of the dielectric rod antenna array covered with carbon nanotubes were carried out.

17:30 **2D Materials Coupled To Hybrid Metal-dielectric Waveguides For THz Technology** **Th-P2-4-5**

Panhui Huang[1]; Sylvain Massabeau[1]; Jerome Tignon[1]; Sukhdeep Dhillon[1]; Aloyse Degiron[2]; Juliette Mangeney[3]
[1]Laboratoire Pierre Aigrain, France; [2]C2N, France; [3]1Laboratoire Pierre Aigrain, Ecole normale supérieure, France

In recent years, several strategies have been proposed to enhance the interaction between THz optical field and 2D materials, However, these approaches rely on relatively complex structures to ensure optimal placement of the 2D material, such as based on coupler with a graphene sheet between two waveguides, on a graphene layer buried within a silicon waveguide or on a graphene sheet into the cavity of a quantum cascade laser. Here, we present hybrid metal-dielectric waveguides coupled to 2D materials that provide strong light-matter interaction at THz frequencies. We show that the strength of in-plane electric field components of

the propagating modes are maximized at the top of the dielectric strip on which the 2D material is deposited. We predict 100 % modulation of THz light by tuning the Fermi level of a graphene sheet deposited onto an 1mm-long hybrid metal-dielectric waveguide. We also show the potential of graphene multilayers coupled to these waveguides for achieving lasing at THz frequency. These waveguides are easy to fabricate with state-of-the-art fabrication techniques. They open new perspectives for the development of THz photonic circuits compatible with CMOS or quantum cascade lasers technologies.

17:45 **Influence Of Optical Pumping On Properties Of Carbon Nanotubes With Different Geometric Parameters In THz Frequency Range** **Th-P2-4-6**

Mikhail Khodzitsky[1]; Petr Demchenko[1]; Daniel Gomon[1]; Dmitrii Lioubtchenko[2]; Ilya Anoshkin[2]
[1]ITMO University, Russian Federation; [2]KTH - Royal Institute of Technology, Sweden

Impact of infrared radiation illumination (980 nm) on the properties of cabon nanotubes (CNT), such as complex conductivity and permittivity, with different geometric parameters (lengths, diameters and with presence/absence graphene oxide layer) in the frequency range of 0.2-1.0 THz was studied.

18:00 - 19:30 **Th-POS Poster Session** **Event Hall**

Session Type: Poster

18:00 **Noise Analysis And Parameters Optimization Of VLWIR Detector Pre-amplifier Based On FTS Technology** **Th-POS-01**

Yugui Zhang; Weigang WANG; Jianjie YIN
Beijing Institute of Space Mechanics & Electricity, China

Fourier Transform Spectrum technology, featured with wide frequency range and spectral resolution, is becoming the research focus in spectrum analysis and measurement field, and is spreading in atmosphere detection applications in the aerospace field. In detecting technology based on FTS, high detecting precision and large dynamic range (DR), which are mostly determined by pre- amplifier, are usually required by interference signal. In this paper, noise model is setup for the very long wave infrared (VLWIR) detector pre-amplifier, and the parameters influencing to the circuit noise performance are simulated and optimized. Finally, ideal results are obtained. Thus, theoretical foundation can be supported to the operational amplifiers selection and circuit operating parameters design.

18:00 **Terahertz Pump—Terahertz Probe Spectroscopy Of Multilayer Graphene** **Th-POS-02**

Kosaku Kato; Junki Asai; Thanh Nhat Khoa Phan; Masashi Yoshimura; Makoto Nakajima
Osaka University, Japan

We report the result of the terahertz pump—terahertz probe spectroscopy of multilayer graphene. The amplitude of the probe pulses deceases after the arrival of the pump pulses with the peak electric field of ~100 kV/cm. This indicates that the impact ionization and the resulting carrier multiplication process are induced by the pump pulse irradiation in the multilayer graphene.

18:00 **The Data Analysis Of Continuous Wave Terahertz Spectrometer In Time Domain** **Th-POS-03**

Deyin Kong; Xiaojun Wu; Jun Dai; Cunjun Ruan
SCHOOL OF ELECTRONICS INFORMATION ENGINEERING, China

Oscillations caused by the Fabry-Pérot interference in the amplitude of the coherent continuous wave terahertz frequency-domain spectrometer (THz-FDS) are always the largest noise. By Hilbert transformation, the complete spectrum can be calculated, and the homologous time-domain signal can also be acquired by inverse fast Fourier transform (IFFT). The oscillations in the amplitude of signal can be restrained by processes in time domain.

18:00 **THz-TDS Study On Tetrabutylammonium Bromide Hydrate** **Th-POS-04**

Yasuhiro Miwa[1]; Keisuke Matsumura[2]; Kei Takeya[2]; Atsushi Tani[1]
[1]Kobe University, Japan; [2]Nagoya University, Japan

Tetrabutylammonium bromide (TBAB) hydrate, a semi-clathrate hydrate was investigated by terahertz time-domain spectroscopy (THz-TDS) in the region from 0.1 to 1.5 THz. The high absorption was observed in the whole region in comparison with that in ice and propane hydrate. In addition, absorption band was clearly observed around 1.1 THz, though ice and propane hydrate does not have such a peak at this frequency. This peak in TBAB hydrate may be caused by

intermolecular vibration of tetrabutylammonium ion because TBAB crystal also has infrared activity at 1.4 THz. In TBAB hydrate, tetrabutylammonium ion is isolated by hydrogen-bonded water molecules, which might cause the absorption peak shift to lower frequency. THz-TDS is worthwhile to observe the interaction of guest-guest and/or guest-host molecules.

18:00 **Hydration Dynamics Around Hydrophobic Solutes: A Terahertz Spectroscopic Investigation** **Th-POS-05**

RAJIB MITRA[1]; RAJIB MITRA[2]
[1]SNBNCBS, India; [2]S N Bose National Centre for Basic Sciences, India

We report the dielectric relaxation of water in presence of some biologically relevant molecules e.g. alkali metal chlorides, amino acids, alkyl-ammonium salts etc. as well as their effect on protein stability (either as protein structure 'enhancer' or 'denaturant') using THz time domain spectroscopy (in the frequency domain of 0.4-1.5 THz) and complementary techniques. The various optical parameters (e.g. absorption coefficient, complex refractive index, dielectric constant etc.) are found to be dependent on the nature of the individual solutes and their specific interaction with water.

18:00 **Ultrafast Photocarrier Dynamics In Cd3As2 Film In Terahertz Band** **Th-POS-06**

Guohong Ma[1]; Wenjie Zhang[2]; Gang Chen[3]; Zuanming Jin[1]; Xian Lin[1]
[1]Shanghai University, China; [2]Shanghai university, China; [3]Shanghai Institute of Technical Physics, China

Cd_3As_2 was reported recently to be a stable three-dimensional topological Dirac semimetal: the Dirac fermions disperse linearly along all three momentum directions, conduction and valence bands touch at the Dirac nodes, and the carriers have ultrahigh mobility up to ~10^6 cm/s. Latest, ultrafast spectroscopy has been used to investigate the electron-electron, and electron-phonon scattering in the Cd_3As_2 bulk crystal, film and nanomaterials. Upon photoexcitation, Cd_3As_2 exhibits photoinduced ultrafast bleaching followed by a fast recovery process from visible to mid-infrared wavelength. Considering the semimetal characteristics of band structure, THz radiation has advantages of lower photon energy (a few meV), ultrafast time resolution (~ 1 ps) and broad spectroscopy (0.2~3 THz), which is an ideal spectroscopy to understand the photocarrier dynamics in this novel quantum material.In this study, we employed optical pump (400 and 800 nm) and THz probe to study the photocarrier dynamics in Cd_3As_2 thin film on mica. Several interesting results are obtained from the time resolved THz spectroscopy: (i) Photoinduced THz absorption was observed, rather than a bleaching signal observed in visible and infrared wavelength. (ii) The bleaching takes places around 40 ps after photoexcitation, which lasts for several nanoseconds before reaching equilibrium. (iii) The photoinduced conductivity from 0.2 to 2.0 THz shows at a peak around 1.2 THz for the absorption signal, and a dip around 1.2 THz for the bleaching signal, respectively. The frequencies for peak and dip signals are fixed at 1.2 THz under different pump intensity.

18:00 **THz-TDS Transmission Measurements Of Spectroscopic Lamps Plasma** **Th-POS-07**

Giuseppe Galatola Teka[1]; Marco Zerbini[2]; Francesca Bombarda[2]; Djamshid Damry[3]
[1]ENEA - Padova, Italy; [2]ENEA, Italy; [3]Department of Physics,Clarendon Laboratory, United Kingdom

We will discuss the transmission spectra of plasmas generated by spectroscopic lamps filled with different gas compounds. The spectral response is measured with a standard THz-TDS spectrometer with 2 THz bandwidth. The experiments will improve the understanding of THz radiation interaction with plasmas These discharge lamps generate plasma with densities up to $10^{13}cm^{-3}$. Under basic assumptions, such as a homogeneous plasma slab, plasma electron density and collision rates can be obtained from the spectral data.

18:00 **Microwave Spectroscopy Of Highly Excited 5snf 1F3 Rydberg States Of Sr Atom** **Th-POS-08**

Rio Ito; Kentaro Tsurui; Tetsuya Sugawara; Kenta Kitano; Haruka Maeda
Aoyama Gakuin Univ., Japan

Optical lattice, which is one of the state-of-the-art technologies using ultra-cold neutral atoms, is expected to play a central role in the atomic clock of the next generation. When implementing a strontium (Sr) lattice clock, accuracy of determining transition frequency between the ground-state $5s^2\ {}^1S_0$ and the excited

$5s5p\ ^3P_0$ state is responsible for the reliability of the atomic clock. From the atomic physics viewpoint, however, we are still on the way to comprehensive understanding of the electronic structure of Sr, as it has two active valence electrons in the optical energy region. In that respect spectroscopic studies of Sr are still quite important after all to get deeper insights into the energy structures of the two-electron atoms.

Microwave (MW) spectroscopy of highly excited Rydberg states is a sort of traditional yet still powerful experimental method to deeply understand the electronic structure of atoms. As typical resonance frequencies between Rydberg states of atoms lie in the millimeter-microwave region, we could easily drive Rydberg-Rydberg transitions with MW of tiny power. More importantly, Doppler width in the MW transition spectrum, whose typical value can be estimated to be a few hundred kHz, is negligible, and the width of the spectrum is mostly determined by the interaction time of atoms with microwave pulse, because Rydberg atoms, whose typical natural life times are on the order of a few tens of Âµs or so, stay there during the time of interaction with MW. Overall, one can easily conduct Doppler-free high-resolution spectroscopy of Rydberg atoms. In the present study we have made microwave spectroscopy of Sr $5snf\ ^1F_3$ Rydberg states in the region of $40 \leq n \leq 49$, systematic measurements of which have not been reported, to our knowledge.

18:00 **Ultrafast Solvation Dynamics Probed By Optical-Pump THz-Probe Spectroscopy** **Th-POS-09**

Claudius Hoberg; Patrick Balzerowski; Thorsten Ockelmann; Martina Havenith
Ruhr-Universität Bochum, Germany

Using optical-pump THz-probe (OPTP) experiments we investigate the ultrafast solvent response subsequent to optical excitation of molecules in aqueous solutions.Here we present our setup design for highly sensitive OPTP measurements in liquid phase as well as first systematic results.

18:00 **N2O Gas Detection Away From 93 M Using THz Time-Domain Spectroscopy** **Th-POS-10**

Tae-In Jeon; Gyeong-Ryul Kim; Hyeon-Sang Bark; Hwa-Bin Lee; Seng-Bo Lee
Korea Maritime and Ocean University, Korea, Republic of

After the THz pulse passes through a chamber filled with N2O with atmosphere pressure, the amplitude is reduced to 1/3, and many absorption lines appear in the spectrum. By measuring the resonance N2O, it is possible to detect the gas and to estimate the amount of gas at a distance. These studies can monitor pollutants and detect hazardous gases.

18:00 **THz Time-Domain Coherent Raman Spectroscopy Of Aqueous NaCl Solutions** **Th-POS-11**

Shoji Hayashi[1]; Shun Nakae[1]; Kunji Takemura[1]; Stefan Funkner[2]; Hideaki Kitahara[1]; Takashi Furuya[1]; Kohji Yamamoto[1]; Jessica Afalla[1]; Valynn Mag-usara[1]; Dmitry Bulgarevich[1]; Masahiko Tani[1]
[1]Research Center for Development of Far-Infrared Region, University of Fukui, Japan; [2]Institute for Photon Science and Synchrotron Radiation, Karlsruhe Institute of Technology, Germany

We performed polarization-dependent terahertz (THz) time-domain coherent Raman spectroscopy on varying concentrations of aqueous NaCl solutions. Using this technique, the bending and stretching vibrational modes of water molecules under influence of electrolytic ions were observed.

18:00 **AlAs Based Heterostructures For THz Plasmonics** **Th-POS-12**

Anton Shchepetilnikov[1]; Alina Khisameeva[1]; Vyacheslav Muravev[1]; Sergey Gubarev[1]; Pavel Gusikhin[1]; Dmitriy Frolov[1]; Yuri Nefyodov[1]; Igor Kukushkin[1]; Christian Reichl[2]; Lars Tiemann[2]; Werner Dietsche[2]; Werner Wegscheider[2]
[1]Institute of Solid State Physics RAS, Russian Federation; [2]ETH Zurich, Switzerland

Studies of plasma excitations play an increasingly important role in modern research due to the potential application of plasmonics for the detection and generation of electromagnetic radiation in the terahertz range (0.1 - 1 THz). The AlAs QWs provide an important research opportunity by combining a strong native 2D electron mass anisotropy with the ability to tune valley occupations. Despite

these unique properties, the plasmon phenomena in AlAs 2DESs have remained largely unexplored.

18:00 **Spectroscopic Sensing Of Opioids In The THz Region** **Th-POS-13**

W-D Zhang[1]; A. Bykhovski[2]; E. Brown[2]
[1]TeraPico LLC, United States; [2]Wright State University, United States
We present a study of the THz electromagnetic signatures of opioids by computer modeling and experimentation. We conduct investigations of oxycodone, Vicodin, and fentanyl.

18:00 **Origins Of Heat Generation On Mixing Water And Dimethyl Sulfoxide** **Th-POS-14**

Kazuko Mizuno[1]; Takashi Sumikama[2]; Yoshinori Tamai[3]; Masahiko Tani[1]
[1]Research Center for Far Infrared Region, University of Fukui, Japan; [2]WPI Nano Life Science Institute, Kanazawa University, Japan; [3]Graduate School of Engineering, University of Fukui, Japan
Dimethyl sulfoxide (DMSO) is one of small amphiphiles composed of both hydrophobic and polar groups. DMSO and water mix uniformly accompanied by intense heat evolution but molecular reasons of the negative molar excess enthalpy and entropy remain ambiguous since the 1940s. We present an interpretation on the origins, based on our results of IR and NMR measurements and simulations. Our interpretation can shed new light on the roles of water molecules in biological systems.

18:00 **Experimental Binary Optimisation Of Resonant Dipole Antennas For Remote Sensing Below 2THz** **Th-POS-15**

Christian Sørensen; Thomas Søndergaard; Esben Skovsen
Aalborg University, Denmark
We test the tuneable elements in the center-fed dipole antenna geometry described by Duffy and co-workers [1], to increase the antenna gain in the 1.5THz transmission window. The elements we test are capacitive and inductive transmission line elements (chokes), the dipole length, the number of discrete dipole antennas, the specific geometry of the excitation point, the transmission line layout and the dipole antenna impedance matching. For reference, we also test the dipole lengths and the capacitive transmission line geometry, which are parameters reported in [1].
The study compares the performance of the antennas, with and without the specified elements, in both relative intensity and bandwidth of emitted radiation, in a conventional time-domain spectroscopy setup in ambient atmosphere.

[1]. S. M. Duffy et al., ***"Accurate modeling of dual dipole and slot elements used with photomixers for coherent terahertz output power,"*** *in IEEE Transactions on Microwave Theory and Techniques, vol. 49, no. 6, pp. 1032-1038, Jun 2001.*

18:00 **Cascode Enhanced Junctionless Field Effect Transistor THz Detector** **Th-POS-16**

Michal Zaborowski[1]; Przemyslaw Zagrajek[2]; Daniel Tomaszewski[1]; Jerzy Zajac[1]; Jacek Marczewski[1]
[1]Institute of Electron Technology, Poland; [2]Military University of Technology, Poland
This paper describes a THz detector based on junctionless FET with integrated 340GHz patch antenna and cascode preamplifier. 20dB cascode gain was measured. It is essential that the preamplifier can work with a single bias and consume small power of several microwatts.

18:00 **Bloch Oscillations Signature Of THz Electroluminescence From SiC Natural Superlattices** **Th-POS-17**

Vladimir Sankin; Alexander Andrianov; Alexey Petrov; Alexey Zakhar'in; Pavel Shkrebiy; Sergey Nagalyuk
Ioffe Institute, Russian Federation
Results of the study of the terahertz electroluminescence from 8H-, 6H- and 4H-SiC natural superlattices under action of strong electrical field applied along the natural superlattice axis are reported. It is shown that the threshold field of the appearance of terahertz emission induced by the Bloch oscillations and the threshold field for the negative differential conductivity for these SiC natural superlattices increase linearly with the width of the first miniband of these natural superlattices. This observation is a crucial factor in support of the Bloch oscillation nature of the terahertz electroluminescence from SiC natural superlattices.

18:00 **Multi-band Integrated Quantum Well Infrared Photodetectors** **Th-POS-**

Zhifeng Li; YouLiang Jing; YuWei Zhou; Ning Li; XiaoShuang Chen; Wei Lu; XueChu Shen
Shanghai Institute of Technical Physics, Chinese Academy of Sciences, China
A multi-band integrated quantum well infrared photodetector chip has been demonstrated with the peak wavelengths in seven bands modulated from 13.0 to 15.2 μm. The wavelength modulation is realized by changing the top metal patch width of the metal-insulator-metal plasmonic microcavity coupling structures, due to the dependence of the resonant peak wavelength upon the patch width. This might provide a new way for multispectral imaging focal plane arrays.

18:00 **2D Plasmonic Terahertz Detection Under Static Magnetic Field** **Th-POS-19**

Lei Cao; Jing Ding; Qiang Fu; Bang Wu
Huazhong University of Science and Technology, China
The AlGaN/GaN material shows the strongest resonance due to its highest electron concentration, while InAlN/GaN material has slightly lower absorption because of lower electron mobility. The AlGaAs/GaAs material has the minimum absorption owning to its lowest electron density. The performance of the SiGe/Si material falls in between the GaN and GaAs based materials. By sweeping the magnetic field from 0.2 to 10 tesla, the frequency shift for the first resonance is 0.55 THz (GaN based material), 3.55 THz (AlGaAs/GaAs) and 0.65 THz (SiGe/Si). The AlGaAs/GaAs material achieves the most wide frequency shift due to its lowest electron effective mass (m* = 0.063m0) and it is almost three times the frequency change (1.3 THz) via traditionally applying an electric potential on the grating coupler. The absorption amplitude decreases slowly as the increase of magnetic field for all the four materials.The detection performances for these heterostructures could be further optimized through the variation of grating period (L = 0.5 ~ 5 μm), grating aspect ratio (W/L = 0.25 ~ 0.9) and the barrier layer thickness (d = 10 ~ 200 nm). It can be concluded that the GaN based material is most suitable for room temperature detection, while the GaAs material has the property of the most wide frequency tunability by changing the external magnetic field.

18:00 **Development And Modeling Of Folded-Waveguide Slow-Wave Structures For Millimeter-Band Traveling-Wave Tubes** **Th-POS-20**

Artem Terentyuk[1]; Andrey Rozhnev[2]; Nikita Ryskin[2]; Andrey Starodubov[1]; Viktor Galushka[1]; Anton Pavlov[1]
[1]Saratov State University, Russian Federation; [2]Saratov Branch, Institute of Radio Engineering and Electronics RAS, Russian Federation
Folded waveguide (FW) is a promising type of slow-wave structure (SWS) for millimeter-wave traveling-wave tubes. Results of development of several millimeter-band FW SWSs are presented. SWS circuits at Q- and V-band are fabricated by CNC-machining. Cold electromagnetic parameters of the SWSs characteristics are simulated and reasonable agreement with the results of measurements is observed. Small-signal and large-signal gain is calculated.

18:00 **Generation Of Quantum Correlated Optical - Terahertz Photon Pairs And Calibration Of Nonlinear-Optical Detectors Via Parametric Down-Conversion** **Th-POS-21**

Galiya Kitaeva[1]; Vladimir Kornienko[2]; Kirill Kuznetsov[1]; Andrey Leontyev[1]; Tatiana Novikova[1]
[1]Lomonosov Moscow State University, Russian Federation; [2]Lomonosov Moscow State University, All-Russia Research Institute of Automatics (VNIIA), Russian Federation
Quantum effect of parametric down-conversion is studied in a strongly frequency non-degenerate regime, when pairs of correlated optical and terahertz photons are generated along with parametric amplification and frequency conversion of thermal fluctuations and external radiation at terahertz frequencies. The terahertz photon fluxes emitted due to parametric down-conversion are registered for the first time. Direct incoherent nonlinear-optical detection is demonstrated for continuous wave sources at 0.2-0.4 THz.

18:00 **Investigation On Stability Of The Beam-wave Interactions for G-band Staggered Double Vane TWT** **Th-POS-22**

Cunjun Ruan; Huafeng Zhang; Jian Tao; Yanbin He
SCHOOL OF ELECTRONICS INFORMATION ENGINEERING, China
The Bragg reflector and two stage staggered double vane slow wave structure (SDV-SWS) are bring forward to suppress the reflection travelling wave interaction

with nonworking mode oscillating in ultra-wide G-band travelling wave tube (TWT). The 580-590W peak power can be achieved for both of scheme with 90 periods sheet beam SDV-TWT, which is corresponding to the gain of 40.6dB, electronic efficiency of 5.5- 5.6%, and bandwidth of 35-70GHz in G-band.

18:00 **Real-time Detection Of Terahertz Wave From Quantum Cascade Laser By Frequency Up-conversion In A Nonlinear Crystal** **Th-POS-23**

Shingo Saito[1]; Kouji Nawata[2]; Shin'ichiro Hayashi[3]; Yoshinori Uzawa[3]; Hiroaki Minamide[2]; Norihiko Sekine[3]

[1]1National Institute for Information and Communications Technology, Japan; [2]RIKEN Center for Advanced Photonics, Japan; [3]National Institute of Information and Communications Technology, Japan

Terahertz wave is expected to be used in such wireless communication systems due to its potentially broad bandwidth. In this presentation, we report on the detection of terahertz radiations from terahertz quantum cascade lasers (THz-QCLs) by up-conversion using the intense near-infrared with $MgO:LiNbO_3$ crystal as a nonlinear crystal. The intense near-infrared beam is generated from the microchip Nd:YAG laser based MOPA system. The up-converted signal was observed when the injection of the pulse current and the optical pulse pumping occurred at the same time. From these results, it is shown that the frequency up-conversion technique is useful to investigate the lasing dynamics of THz-QCLs.

18:00 **Sensitivity Improvement Of Heterodyne Electro-Optic Sampling** **Th-POS-24**

Hideaki Kitahara[1]; Takuro Yasumoto[1]; Daiki Goto[1]; Hiroyuki Kato[1]; Masaki Shiihara[1]; Jessica Afalla[1]; Valynn Mag-usara[1]; Kohji Yamamoto[1]; Takashi Furuya[1]; Elmer Estacio[2]; Michael Bakunov[3]; Masahiko Tani[1]

[1]Research Center for Development of Far-Infrared Region, University of Fukui, Japan; [2]National Institute of Physics, University of the Philippines, Philippines; [3]University of Nizhny Novgorod, Russian Federation

We propose and experimentally demonstrate a technique for improving the sensitivity of electro-optic sampling (EOS) detection of terahertz waves. The technique is based on polarization filtering of the probe optical beam after the nonlinear detector crystal. By applying the technique to heterodyne EOS scheme, the sensitivity was increased by 8 times.

18:00 **Compact Electro-Optical Frequency Tunable Sensors For Accelerator Diagnostics Based On Telecommunication Technology** **Th-POS-25**

Erik Bruendermann[1]; Isao Morohashi[2]; Shinya Nakajima[2]; Shingo Saito[2]; Norihiko Sekine[2]; Anke-Susanne Mueller[1]; Iwao Hosako[2]

[1]Karlsruhe Institute of Technology (KIT), Institute for Beam Physics and Technology (IBPT), Germany; [2]National Institute of Information and Communications Technology (NICT), Japan

Electron accelerator-based light sources to study dynamic processes in materials science and life sciences rely on short pulse generation originating from picosecond long to femtoseconds short electron bunch structures. Terahertz and electro-optical diagnostics is an ideal tool to investigate these electron beams and their emitted photons with the potential to devise methods for controlled and tailored radiation emission. Advances in information and communications technology promise compact sensors based on industry standards. We have manufactured $LiNbO_3$-based modulators to evaluate their potential for THz and laser-based diagnostics at accelerators.

18:00 **AlGaN/GaN Field Effect Transistors Based On Lateral Schottky Barrier Gates As Millimeter Wave Detectors** **Th-POS-26**

Pavel Sai[1]; Dmytro But[1]; Krzesimir Nowakowski-Szkudlarek[1]; Jacek Przybytek[1]; Pavel Prystawko[1]; Ivan Yahniuk[1]; Piotr Wiśniewski[2]; Bartlomiej Stonio[2]; Mateusz Słowikowski[2]; Sergey Rumyantsev[3]; Wojciech Knap[4]; Grzegorz Cywiński[1]

[1]Institute of High Pressure Physics PAS, Poland; [2]CEZAMAT Warsaw University of Technology, Poland; [3]National Research University of Information Technologies, Russian Federation; [4]Laboratoire Charles Coulomb (L2C), University of Montpellier, CNRS, France

We report on comparison studies between a novel transistor-like device and two dimensional Fin Field-Effect transistor towards their applications in a terahertz resonant detector. Both device structures have been fabricated on the same wafer

of GaN/AlGaN epistructure during one processing run. The proposed here the transistor-like structure has two side Schottky gates, which can be biased towards complete pinch-off the 2DEG channel in this device. At certain conditions, near to pinch-off region, it is possible to obtain one-dimensional current flow. This feature is especially attractive for THz resonant detector approach, which will be discussed in details.

18:00 **Terahertz Pulses Emitters With Full Electrical Control On Polarization For THz-TDS** **Th-POS-27**

Kenneth Maussang[1]; José Palomo[2]; Juliette Mangeney[2]; Sukhdeep Dhillon[2]; Jérôme Tignon[2]
[1]University of Montpellier - Institut d'Electronique et des Systèmes, France; [2]Laboratoire Pierre Aigrain (Ecole Normale Supérieure, Université Pierre et Marie Curie, Université D, France

Photoconductive switches are widely used for emission and/or detection of terahertz pulses. The emitted polarization is fixed by the design of the electrodes. In this work, innovative designs of photoconductive switches are proposed providing full electrical control on the direction of polarization of the emitted field. These designs are based on a monolithic on-chip solution with an interdigitated scalable geometry, and might be used either for emission or detection. Without the need of external mechanical components, it allows fast polarization modulation and polarimetry measurements with a large area receiver. It opens the field of precision terahertz polarimetry.

18:00 **A Compact Schottky Heterodyne Receiver For 2.06 THz Neutral Oxygen [OI]** **Th-POS-28**

Darren Hayton[1]; Christine Chen[1]; Jeanne Treuttel[2]; Erich Schlecht[1]; Jose Siles[1]; Robert Lin[1]; Imran Mehdi[1]
[1]JPL, United States; [2]LERMA, France

In this paper we present the latest results on the performance of a compact, low power, solid-state heterodyne receiver that is being developed to target the 2.06 THz neutral oxygen [OI] line. The receiver front end features a subharmonic Schottky diode mixer that is driven by a high output all-Schottky multiplier local oscillator (LO) source. The multiplier chain consists of a 38 GHz oscillator followed by cascaded triplers at 114 GHz, 343 GHz and 1.03 THz to produce ~ 1 mW of LO power. The receiver is characterized for sensitivity between room temperature and 70 K. Additional data is presented demonstrating the receiver stability in terms of Allan time.

18:00 **Reliability Improvement Of High-power THz GaN Gunn Sources For Active Imaging Systems** **Th-POS-29**

Ahid S. Hajo[1]; Oktay Yilmazoglu[1]; Armin Dadgar[2]; Franko Küppers[1]
[1]Technische Universität Darmstadt, Germany; [2]Otto-von-Guericke-Universität Magdeburg, Germany

In this paper we report a new technology for the THz Gunn source based on gallium nitride (GaN). This source works stabile at the operation of 32 V due to better heat sink and field plate (Fp) technology. A stabile operation at 32 V and 1.5 A was achieved with higher output power than for diodes with the former technology.

18:00 **Research Progress On High Gain GaAs Terahertz Emitter** **Th-POS-30**

Hong Liu; Wei Shi; Lei Hou; Cheng Ma; Chengang Dong; Lei Yang; Shaoqiang Wang
Xi'an University of Technology;Key Laboratory of Ultrafast Photoelectric Technology and Terahertz Sc, China

In this paper, the research progress on the generation of intense terahertz radiation by avalanche multiplication GaAs photoconductive antennas is reported. When the GaAs is triggered by femtosecond laser under the high electric field, experiments show that the intense THz radiation power can be realized by the GaAs PCA operating in the quenched high gain mode, compare to the GaAs PCA operating in the linear mode.

18:00 **45 T Pulsed Magnets For THz Gyrotrons** **Th-POS-31**

Houxiu Xiao
Huazhong University of Science and technology, China

TMagnets are key parts of gyrotrons. This paper proposes a repeatable 45 T pulsed magnet for THz gyrotrons, which has internal high strength metal reinforcement for faster cooling speed and longer service time. The mechanical and thermal analysis of the pulsed magnet will be presented in this paper.

18:00 **Double-Beam Millimeter-Wave Band BWT And TWT On A Spirally Bent Rectangular Waveguide** **Th-POS-32**

Alexander Kurayev[1]; Alexey Rak[1]; Artem Badarin[2]; Semen Kurkin[2]; Alexey Koronovskii[2]; Alexander Hramov[3]
[1]Belarusian State University of Informatics and Radioelectronics, Belarus; [2]Saratov State University, Russian Federation; [3]Yuri Gagarin State Technical University of Saratov, Russian Federation

The designs of BWT and TWT of a millimeter range with two wide tape electron beams are proposed and investigated. It is proposed to use a spirally bent rectangular waveguide on fundamental H10 mode as an electrodynamic structure of the tubes. Unlike existing designs on wavy bent waveguides, the proposed schemes allow to significantly increase the current of electron optics, which improves significantly the output characteristics. Analytical estimates have shown the possibility of effective interaction of the electron beam with both direct and backward electromagnetic waves for the certain values of control parameters of the systems.

18:00 **First Demonstration Of Continuous Wave Terahertz Radiation From Semi-Insulating GaAs Photomixer With Nanowire** **Th-POS-33**

Shihab Al-Daffaie; Oktay Yilmazoglu; Alaa Jumaah; Franko Küppers
Technische Universität Darmstadt, Germany

A new terahertz (THz) photomixer based on semi-insulating GaAs (SI-GaAs) with silver nanowire (Ag-NW) is for the first time demonstrated for continuous wave (CW) THz radiation. The use of the Ag-NW greatly enhanced the THz output power (~ two order of magnitude) and compensated the large carrier lifetime of the SI-GaAs photoconductor.

18:00 **Strategic Design Of Room Temperature Terahertz Photodetectors** **Th-POS-34**

José Gustavo Méndez Lara[1]; Peinan Ni[2]; Manuel Alejandro Justo Guerrero[1]; Maxime Hugues[2]; Yvon Cordier[2]; Andrés De Luna Bugallo[1]; Patrice Genevet[2]; Elodie Strupiechonski[1]
[1]Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, Mexico; [2]Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications, France

An array of double-split-ring resonators is designed to emulate the spectral characteristics of a log-periodic antenna. When coupled to a 2D electron gas in a FET configuration, the array is expected to exhibit an enhanced signal compared to that from a single log-antenna FET under the same conditions. Numerical and experimental comparison will be presented, as well as the advantages and drawbacks of the two configurations

18:00 **Nonparallel Mirrors Fast Scanning For Security Imaging With Terahertz-waves** **Th-POS-35**

Congjing Hao; Peipei Hou; Shichao Li; zhuo wang; qu Jia
Beijing Aerospace Yilian Science & Technology Development co., ltd., China

Satisfying fast scanning focus and high resolution at the same time is still a great challenge to terahertz imaging technologies for large passenger flow. In this work, a new approach of fast scanning quasi-optical antenna has been proposed. With this design of nonparallel mirrors, double of information can be collected with the same time. In addition, one linear feed array is introduced to realize real-time scanning imaging and high resolution of 5mm for object distances of 1-1.5 m. All the results of simulations and measurements validate the quasi-optical design and potential applications of the antenna system in the large passenger flow security environment.

18:00 **A Robust And Fast Algorithm For ALMA Local Oscillator Power Amplifiers Optimization** **Th-POS-36**

Giorgio Siringo
Joint ALMA Observatory & European Southern Observatory, Chile

I present here a new algorithm for the optimization of the local oscillator power amplifiers of all receivers in use at the Atacama Large Millimeter/submm Array, ALMA. The configuration of ALMA receivers (SIS mixers) is done by applying frequency-dependent pre-defined values of voltage and current extracted from a look-up table. The bias voltage is applied to the mixer by the bias voltage controller. The bias current, instead, is optimized indirectly by adjusting the power from the local oscillator. The algorithm presented here is able to guarantee fast and reliable optimization even with noisy control and response variables. This new algorithm

has been implemented in the ALMA main control software starting from Cycle-5 (October 2017).

18:00 **Compact Antennas Pattern Measurement Setup At 240 GHz** **Th-POS-37**

Cybelle Goncalves[1]; Elsa Lacombe[2]; Carlos del Río[3]; Frederic GIANESELLO[2]; Cyril Luxey[4]; Guillaume Ducournau[5]
[1]IEMN, France; [2]STMicroelectronics, France; [3]Public University of Navarre, Spain; [4]Laboratory of Polytech Nice-Sophia, France; [5]Institute of Electronics, Microelectronics and Nanotechnology, France

In this paper a compact radiation pattern measurement setup at 240 GHz is investigated. It consists on a millimeter-wave source as transmitter (Tx) and a Schottky diode as receiver (Rx). Three different horn antennas fabricated with different techniques are presented: Stereolithography Apparatus (A2), Selective Laser Sintering (A3) and commercial metallic (A1). Radiation patterns are discussed and compared, as well as dynamic range.

18:00 **The Study Of Q-band Sheet Beam Backward Wave Oscillator Based On A Planar U-shaped Slot-line Slow-wave Structure** **Th-POS-38**

Ruichao Yang[1]; Chong Ding[1]; Gangxiong Wu[1]; Lingna Yue[1]; Jin Xu[1]; Qian Li[1]; Xia Lei[1]; Xuebin Jiang[1]; Shuanzhu Fang[1]; Hairong Yin[1]; Guoqing Zhao[1]; Zhanliang Wang[1]; Yubin Gong[1]; Yang Liu[2]; Hailong Wang[2]; Wenxiang Wang[1]; Yanyu Wei[1]
[1]School of Electronic Science and Engineering, University of Electronic Science and Technology of Chi, China; [2]Southwest China Research Institute of Electronic Equipment, China

This paper reported a Q-band sheet beam slot-line backward wave oscillator (BWO). The characteristics of slot-line slow wave structure (SL-SWS) has been investigated and the result shows that it's much more suitable to be designed as a BWO than a traveling wave tube (TWT). The slot-line backward wave oscillator is driven by a 0.19A sheet beam whose rectangular cross section is 0.9mm*0.12mm. While the beam voltage ranges from 6000V to 10000V, the frequency of output signal varies from 40.275GHz to 43.925GHz, and the output power is over 40W.

18:00 **220 GHz Dual Beam Photonic Crystal Loaded Folded Waveguide TWT** **Th-POS-39**

Ningjie Shi[1]; Duo Xu[1]; Hexin Wang[1]; Zhanliang Wang[1]; Huarong Gong[1]; Zhaoyun Duan[1]; Zhigang Lu[1]; Yanyu Wei[1]; Yubin Gong[1]; Jinjun Feng[2]
[1]University of Electronic Science and Technology of China, China; [2]Beijing Vacuum Electronics Research Institute, China

The paper puts forward a novel dual beam folded waveguide (FW) slow wave structure (SWS), which is loaded by photonic crystals. In this novel structure, the two electron beams pass through the small gaps between the photonic crystal structures and the folded waveguide. According to Particle-in-cell simulations by the CST Particle Studio, the designed traveling wave tube (TWT) can generate a peak power of 210W at 220GHz, corresponding to the maximum gain and efficiency of 16.3dB and 5%, respectively.

18:00 **Corrugated Diamond Window For ECRH Transmission Line** **Th-POS-40**

Alexander Vikharev[1]; Sergey Kuzikov[2]; Sergey Antipov[2]
[1]Institute of Applied Physics RAS, Russian Federation; [2]Euclid Techlabs LLC, United States

We propose a 170 GHz corrugated diamond window (CDW), which can provide 1-2 MW CW power transmission in broadband reflectionless regime for the window as a whole, as well as for each of the diamond surfaces, since the corrugations work like the well-known quarter-wave matching coatings used for optical windows. This design allows for arbitrary window thickness, which is beneficial for thermal stress management. The corrugation will be produced on diamond surface by means of femtosecond laser ablation using protocols developed at Euclid over the years.

18:00 **Photonics Wireless Terahertz Wave System For Space Exploration** **Th-POS-41**

Christine P. Chen; Darren J. Hayton; Lorene Samoska; Robert Dengler; Imran Mehdi
JPL, United States

NASA planetary missions involve communications between a central orbiter and a number of lander or daughter ships. Given this scenario, large bandwidth data links with compact topologies are required. In this investigation, a photonic-based-transmission link is examined in the extremely high frequency (EHF) regime to scale

wireless bandwidth communications given the low power constraints of a system in space. This novel multi-wavelength photonic wireless terahertz wave system incorporates RF transmission up to several hundred GHz and utilizes state-of-the-art low noise receivers for detection.

18:00 **Investigation Of Staggered Double Grating Slow Wave Structure Loaded By Photonic Crystals** **Th-POS-42**

Duo Xu; Ningjie Shi; Hexin Wang; Zhangliang Wang; Zhaoyun Duan; Huarong Gong; Yubin Gong
University of Electronic Science and Technology of China, China

A novel Staggered Double Grating (SDG) slow wave structure (SWS) loaded by photonic crystal for 220GHz traveling wave tube is presented in this paper. Compared with traditional SDG SWS, the novel SWS can form more flat electric field distribution in the transverse direction. The simulation results show the novel SWS is more suitable for sheet electron beam with higher aspect ratio and lower operating voltage at terahertz wave band.

18:00 **Millimeter Wave, 1 MW, CW Water Load** **Th-POS-43**

Alexander Vikharev[1]; Sergey Kuzikov[2]; Sergey Antipov[2]
[1]Institute of Applied Physics RAS, Russian Federation; [2]Euclid Techlabs LLC, United States

A high-power load capable of dissipating 1 MW at 170 GHz is proposed for full-power testing of ITER gyrotrons. The load, consisted of non-moving elements only, was designed with features which allow compact sizes and shorten required set-up time. The load consists of water pumped vessel, separated from vacuum by diamond disk, and a set of dielectric plates which provides distributed absorption of millimeter wave radiation propagating in it.

18:00 **Design Of The Optical Components In The ITER Equatorial EC H& CD Launcher** **Th-POS-44**

Ken Kajiwara[1]; Ganji Abe[2]; Noriyuki Kobayashi[2]; Ryosuke Ikeda[1]; Yasuhisa Oda[1]; Takayuki Kobayashi[1]; Koji Takahashi[1]
[1]National Institutes for Quantum and Radiological Science and Technology,, Japan; [2]National Institutes for Quantum and Radiological Science and Technology, Japan

The optical components in the ITER Equatorial EC H&CD Launcher, i.e., the two mirrors including one steering mirror, are designed by considering the heat load on the mirrors, RF loss during the propagation from the Launcher inlet to outlet and the Electron Cyclotron Current Drive (ECCD) profile in the plasma. The allowable heat load on the steering mirror, which consists of stainless steel cooling pipe and CuCrZr body, is calculated for the optimization. The ECCD profile is also calculated. Both calculations are integrated into the launcher optimization program.

18:00 **Improved ESD Protection Design For High-Frequency Applications In CMOS Technology** **Th-POS-45**

Chun-Yu Lin
NTNU, Taiwan

An improved electrostatic discharge (ESD) protection design by using stacked diodes and silicon-controlled rectifier (SCR) as power-rail ESD clamp circuit is presented to protect the high-frequency integrated circuits in CMOS process. Experimental results show that the improved design can achieve higher ESD robustness without degrading the high-frequency performance. Based on its good performances during ESD stress and high-frequency operating conditions, the improved design is very suitable for ESD protection.

18:00 **0.22 THz Ridged Sine Waveguide BWO And Sheet Beam Electron Optical System** **Th-POS-46**

Pengcheng Yin[1]; Jin Xu[1]; Shuanzhu Fang[1]; Guoqing Zhao[1]; Wenxiang Wang[1]; Hairong Yin[1]; Linna Yue[1]; Yanyu Wei[1]; Ningjie Shi[1]; Luqi Zhang[2]; Dazhi Li[3]
[1]University of Electronic Science and Technology of China, China; [2]Huawei Technologies Co., Ltd. Chengdu, Sichuan, China, China; [3]Institute for Laser Technology Suito, Osaka 656-0817, Japan

This paper introduces beam-wave interaction of ridged sine waveguide and the design of sheet beam electron optical for 0.22THz backward wave oscillator (BWO). The electron gun which could create a sheet electron beam with thickness 0.05mm and width 0.4mm at waist position is used. The simulation result shows that the transmission current in the tunnel with 0.09mm thick and 1.2mm width is 15mA with 100% transmission. The result of beam-wave interaction shows that the signal

with 1W and 16.4GHz bandwidth could be achieved by the ridged sine waveguide BWO.

18:00 **Magnetron Injection Gun For 203GHz Reflective Gyro-BWO System** **Th-POS-47**

Cheng-Hung Tsai[1]; Tsun-Hsu Chang[1]; Toshitaka Idehara[2]
[1]Department of Physics, National Tsing Hua University, Taiwan; [2]Research Center for Development of Far-Infrared Region, Fukui University, Japan
We design a low beam voltage MIG of the reflective gyro-BWO system for studying the positronium HFS. Our MIG can provide electron beam with the pitch factor of 1.5 and transversal velocity spread less than 8% in simulations. The high quality with a wide working range of the beam voltage and main coil magnetic field implies that this MIG is suitable for the proposed system.

18:00 **Gyrotron Operation In The 'no-start-current' Zone** **Th-POS-48**

Olgerts Dumbrajs[1]; Gregory Nusinovich[2]
[1]Institute of Solid State Physics, University of Latvia, Latvia; [2]University of Maryland, United States
It is conventionally assumed that the gyrotrons can operate either in the regime of soft self-excitation, where the beam current exceeds the start current, or in the regime of hard excitation, where the beam current is lower than the start current. The authors have found one more possibility of gyrotron operation: in the region where there is no start current at all. Although it is not clear whether this region represents a special interest for gyrotron operation, it can be useful to learn that such opportunity may exist and can be used for interpreting some experimental results.

18:00 **Generation Of Powerful Pulses In Gyrotrons With The Backward Output Of The Radiated Wave** **Th-POS-49**

Andrei Savilov; Ivan Osharin
Institute of Applied Physics of Russian Academy of Sciences, Russian Federation
It is shown that the use of the backward extraction of radiation from the operating gyrotron cavity can be a way to obtain short powerful pulses of output radiation. The peak power of these pulses can exceed the electron beam power. Such regime is provided due to cooperation of two waves with different longitudinal structures. Proper addition of signals corresponding to these two waves can be provided in a cavity with the radiation output in the direction of the cathode end.

18:00 **High-harmonic-gyrotron Cavities With Short Irregularities** **Th-POS-50**

Andrei Savilov; Ivan Osharin; Ilya Bandurkin; Yuriy Kalynov; Nikolay Zavolsky; Yulia Oparina
Institute of Applied Physics of Russian Academy of Sciences, Russian Federation
An important problem in realization of gyrotrons operating at high cyclotron harmonics is discrimination of parasitic oscillations exited at lower harmonics. In this work, we describe various schemes of gyrotron cavities with short irregularities providing an improved selectivity of the high-harmonic operation.

18:00 **Magnetron Injection Gun For The 2 MW 170 GHz Modular Coaxial Cavity Gyrotron** **Th-POS-51**

Ioannis Pagonakis[1]; Konstantinos Avramidis[1]; Gerd Gantenbein[1]; Stefan Illy[1]; Zisis Ioannidis[1]; Francois Legrand[2]; Sebastian Ruess[1]; Tobias Ruess[1]; Tomasz Rzesnicki[1]; Manfred Thumm[1]; John Jelonnek[1]
[1]Karlsruhe Institute of Technology, Germany; [2]Thales Electron Devices, France
A new magnetron injection gun has been designed and manufactured for the upgrade of the 2 MW 170 GHz modular coaxial cavity gyrotron. Many important novelties have been considered in this new gun.

18:00 **Design Of A 140 GHz, 1MW Gyrotron At UESTC** **Th-POS-52**

Ying-hui Liu[1]; Chao-jun Lei[2]; Xin-jian Niu[1]; Hui Wang[1]; Guo Guo[1]; Jian-wei Liu[1]; Shuangshi Zhang[2]; Hongfu Li[1]
[1]University of Electronic Science and Technology of China, China; [2]The Chinese People's Armed Police Force Academy, China
In this paper, a kind of gradually tapered cavity for a high-order mode 140 GHz, 1MW gyrotron has been designed to effectively suppress the parasitic modes. Under the condition that the beam current and DC magnetic field are of 45 A and 5.64 T respectively, the calculated results show that an interaction efficiency of about

35.5% can be achieved for the gyrotron design when the TE29,8 operating mode is chosen for the 140 GHz gyrotron. The operating mode reaches a power level of 1.2 MW.

18:00 **Wideband Chaotic Sub-THz Generation Based On Excitation Of Rogue Waves In Gyrotron** **Th-POS-53**

Roman Rozental[1]; Irina Zotova[1]; Naum Ginzburg[1]; Alexander Sergeev[1]; Mikhail Morozkin[1]; Vladimir Tarakanov[2]

[1]Institute of Applied Physics RAS, Russian Federation; [2]Moscow Engineering Physics Institute, Russian Federation

We demonstrate a method for production of ultrawideband (UWB) terahertz radiation, based on the rogue waves generation in gyrotrons. Previously it was shown, that gyrotrons operating in the regime of developed turbulence can sporadically emit "giant" spikes, which can be interpreted as rogue waves generation. Such spikes have a short length and, correspondingly, a wide spectrum. Within the framework of the average approach and direct 3D PIC (particle-in-cell) simulations it is shown that the 260 GHz gyrotron excited by the 30kV/10A helical electron beam can produce chaotic radiation with relative spectrum width of about 10%.

18:00 **A Simple Approach To Wideband Frequency Tuning In Gyrotron: Proof-of-Principle Demonstration** **Th-POS-54**

Ilya Bandurkin; Alexey Fedotov; Mikhail Glyavin; Alexey Luchinin; Mikhail Morozkin; Roman Rozental; Mikhail Proyavin; Irina Zotova

Institute of Applied Physics RAS, Russian Federation

Analytical estimates of the possibility to increas the bandwidth of smooth frequency tuning in gyrotrons show that using of short cavity driven by high-current electron beam could provide a very wide tuning band through the excitation of a series of axial modes. To demonstrate this approach, the proof-of-principle experiment was performed using low-frequency gyrotron, and the 4 % tuning band was demonstrated at the 1-kW power level which is in good agreement with simulations.

18:00 **Spontaneous Coherent Cyclotron THz Super-radiation From A Dense Electron Bunch** **Th-POS-55**

Yuliya Oparina[1]; Andrei Savilov[2]

[1]Institute of Applied Physics RAS, Russian Federation; [2]Institute of Applied Physics of the Russian Academy of Sciences, Russian Federation

Short dense electron bunches produced by modern photo-injectors are attractive from the viewpoint of realization of powerful and effective sources of THz radiation based on spontaneous coherent radiation from bunches. This type of emission is realized, if the effective phase bunch size with respect to the wave is small enough. Therefore, the duration of the radiation process is limited due to the increase in the bunch size under effect of the Coulomb repulsion. In this work we show that this problem can be solved by using the cyclotron mechanism of the spontaneous radiation due to the compensation of the Coulomb repulsion in the cyclotron phase space.

18:00 **Project Of An Intense Terahertz-wave Source Based On Coherent Cherenkov Radiation Matched To Circle Plane Wave** **Th-POS-56**

Norihiro Sei[1]; Takeshi Sakai[2]; Toshinari Tanaka[2]; Yasushi Hayakawa[2]; Yoske Sumitomo[2]; Yumiko Takahashi[2]; Ken Hayakawa[2]; Kyoko Nogami[2]

[1]Research Institute for Measurement and Analytical Instrumentation, National Institute of Advanced In, Japan; [2]Laboratory for Electron Beam Research and Application, Nihon University, Japan

Nihon University and National Institute of Advanced Industrial Science and Technology have jointly developed intense terahertz-wave (THz-wave) sources based on coherent radiations at Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University. At the beginning, we observed coherent synchrotron radiation (CSR) emitted from the upstream bending magnet in the FEL undulator line. By using a Schottky diode detector with a time resolution of a few nanoseconds, it was found that the CSR beam extracted from a vacuum window had a damping structure which was characterized by scale of the vacuum chamber. Because the bunch length of the electron beam was approximately 2 ps long at the radiation point of the CSR beam, the radiation energy of the CSR beam was 0.4 μJ per macropulse. Then, to obtain intense THz-wave source, we developed coherent transition radiation (CTR) using a thin titanium foil in the PXR line. Because the bunch length could be less than 1 ps in the straight section, the radiation energy of

the CTR beam was up to 1 mJ per macropulse whose duration was 4.5 μs. Although the CTR beam was intense THz-wave source, the peak power of the CTR beam was approximately 100 kW. It was not sufficiently intense for observing nonlinear phenomenon in the THz region. We, therefore, planned to develop a wave source based on coherent Cherenkov radiation (CCR) in the PXR line. By converting the wave front of the CCR to a plane wave using a hollow conical dielectric, it is possible to obtain an intense THz-wave source whose energy is 10 times that of the CTR beam. In the presentation, we will report the project of the intense THz-wave source based on the CCR at LEBRA.

18:00 **Simulation For Combination Of Velocity Bunchings And Coherent THz Undulator Radiation** **Th-POS-57**

Yoske Sumitomo; Ken Hayakawa; Yasushi Hayakawa; Kyoko Nogami; Takeshi Sakai; Yumiko Takahashi; Toshinari Tanaka
Nihon University, Japan

We study a combination of velocity bunchings and the coherent undulator radiation at THz region by simulation. The combination of velocity bunchings brings some freedom in energy choice while keeping the bunch length shorter efficiently. Hence the coherent condition can be met for THz radiation at undulator allowing some range of radiation wavelength.

18:00 **Electron Acceleration By Intense THz Pulses** **Th-POS-58**

Zoltan Tibai; Szabolcs Turnar; Jozsef Andras Fulop; Gabor Almasi; Janos Hebling
University of Pecs, Hungary

Accelerating effect of THz pulse pairs on electron bunches has been investigated numerically. Electron bunches can be accelerated from rest to 80 keV and post-accelerated from 80 keV to 355 keV using four single-cycle THz pulses, each of 1 mJ energy. Various electron bunch sizes and charges were investigated during the acceleration process.

18:00 **High Power Coherent Terahertz Wave Sources At LEBRA Linac In Nihon University** **Th-POS-59**

Takeshi Sakai[1]; Norihiro Sei[2]; Toshinari Tanaka[1]; Yasushi Hayakawa[1]; Yoske Sumitomo[1]; Ken Hayakawa[1]; Kyoko Nogami[1]; Hiroshi Ogawa[2]
[1]Nihon University, Japan; [2]National Institute of Advanced Industrial Science and Technology, Japan

Research and development of a high performance electron linac for the generation of Free Electron Laser (FEL), Parametric X-ray Radiation (PXR) and THz waves has been continued at the Laboratory for Electron Beam Research and Application of Nihon University as a joint research with the High Energy Accelerator Research Organization and National Institute of Advanced Industrial Science and Technology. The coherent THz wave source development in the FEL beam-line has been carried out since 2011.This THz wave of FEL beam-line has been used for non-destructive testing of concealed metals and biological imaging. Based on the results of the THz wave source development in the FEL line, higher power THz wave sources has been constructed in the PXR beam-line since 2016.The PXR generating system is connected to the linac through two 45 degrees bending sections. The transport system of the THz wave was installed in the vacuum chamber on the back edge of the bending magnet of the PXR beam-line. The coherent edge radiation (CER) and the coherent synchrotron radiation (CSR) is generated by the bending magnet of the PXR beam line. In addition, the coherent transition radiation (CTR) using thin titanium foil is also generated. Titanium foil was used for CTR wave source. In order to transport the CER, the CSR and the CER waves generated in source points of the PXR beam-line, the transport system can be switched according to the purpose. The energy measurement of the CTR wave was carried out using a power sensor. The average power of the CTR wave was measured approximately 1 mJ/macro-pulse (pulse width 4.5 μs) near the CTR wave beam source point in the frequency range of 0.1 - 2.5 THz. Additionally, the energy of the coherent edge radiation (CER) as high as 0.2 mJ/macro-pulse were achieved with the experimental room. These THz waves has been used for user experiments for the imaging in addition to measurement of the spectrum.

18:00 **Evaluation Of Thermal Leakage In WR-5 Waveguide Calorimeter** **Th-POS-60**

Yuya Tojima[1]; Moto Kinoshita[1]; Hitoshi Iida[1]; Katsumi Fujii[2]
[1]National Institute of Advanced Industrial Science and Technology(AIST), Japan; [2]National Institute of Information and Communications Technology(NICT), Japan

In this study, an accurate calorimeter was developed for measuring radio-frequency power in the WR-5 waveguide band (140—220 GHz). To demonstrate a high-precision calorimetric measurement, the influence of heat leakage in an adiabatic waveguide (AW) of the calorimeter was investigated. Thermal responses by heat generation due to loss of the AW were independently measured using a gold foil shield. The index ρ that represents the ratio of heat leakage to the total generated heat in the AW was estimated by analyzing the thermal response and scattering parameters of the AW. As a result, the index ρ was found to be 0.50 ± 0.05 in the frequency range of 140—220 GHz.

18:00 **Calibration Of Power Meter With Tapered Waveguide At Frequency Range Of 110--170 GHz** **Th-POS-61**

Moto Kinoshita; Yuya Tojima; Hitoshi Iida
National Institute of Advanced Industrial Science and Technology, Japan

For millimeter (mm) wave power measurement at frequencies above 110 GHz, the use of a lower frequency power meter such as a W-band power meter with a tapered waveguide (PM_T) is convenient and practical. However, a complex analysis of the multiple-mode in the W-band waveguide is required for precise power measurement. Therefore, we calibrated a PM_T by directly comparing it with a D-band single-mode calorimeter. This comparison does not need complex analysis because the D-band calorimeter can measure the absolute value of mm-wave power at a frequency above 110 GHz.The uncertainty of the calibration was approximately 4%. This result can be a good reference for the measurement capacity of a PM_T.

18:00 **Current Status Of Terahertz Frequency Standard And Metrology At NICT** **Th-POS-62**

Shigeo Nagano; Hiroyuki Ito; Masatoshi Kajita; Yuko Hanado; Tetsuya Ido
National Institute of Information and Communications Technology, Japan

Frequency standard is requested to allocate the THz spectrum among a huge range of users, nevertheless there exists no standard between 0.1 THz and 10 THz. National Institute of Information and Communications Technology (NICT) plans to establish a new THz frequency standard, which is continuous-wave THz radiation stabilized to a quantum transition frequency of molecules in the THz band and evaluated its frequency uncertainty. Besides the development of such THz standard, THz frequency metrology must be studied since the absolute frequency measurement, comparison with other standards and distribution to remote users are prerequisite processes for the establishment. We have developed key technologies regarding THz frequency measurement and dissemination. Their uncertainty and instability were reached to 10^{-17} level. Contrary to the remarkble progress of THz frequency metrology, many researches required for the THz standards are remained to be challenged.Here we present current status of research and development of THz frequency metrology and standard at NICT.

18:00 **Terahertz Wave Heterodyne Detection Based On Parametric Up-conversion At Room Temperature** **Th-POS-63**

Shin'ichiro Hayashi; Yoshinori Uzawa
National Institute of Information and Communications Technology, Japan

We propose an optical heterodyne detection method of terahertz wave using parametric up-conversion in a nonlinear $LiNbO_3$ crystal at room temperature.

Nonlinear wavelength up-conversion techniques allow the terahertz waves to be visualized and their frequency and intensity determined directly. These are very promising for extending applied research into the terahertz region, and we expect that these will open up new research fields such as information communications and nonlinear optics in the terahertz region.

18:00 **Random Error Estimation In Complex Refractive Index Measured By Transmission Mode Terahertz Time Domain Spectroscopy** **Th-POS-64**

Kentaro Kurake; Kento Kinumura; Shun Takagi; Norihisa Hiromoto; Saroj Tripathi
Shizuoka University, Japan

The refractive index (n) and absorption coefficient (α) of sample measured by terahertz time-domain spectroscopy (THz-TDS) are affected by random errors. Therefore, it is necessary to measure the sample under investigation multiple times to evaluate the random errors in optical constants by computing their standard deviation (σ). However, it takes long measurement time to measure the sample multiple times. Here, we propose an efficient method to estimate standard deviation in optical constants from a single measurement of sample based upon the

number of reference measurements. We confirmed the excellent agreement in standard deviations of n and α obtained by proposed and conventional method.

18:00 **Fabry-Pérot Interferometer Scanned By Geometric Phase** **Th-POS-65**

Seigo OHNO
Tohoku University, Japan

The axis modes in a Fabry-Pérot (FP) cavity has been used as a ruler on the spectral region for the spectroscopy due to the regular frequency interval of the mode and the narrow linewidth. In this paper, a novel method to scan a Fabry-Pérot (FP) interferometer is proposed. It is supposed that a geometric phase shifter consisting a rotating half wave plate (HWP) sandwiched between two fixed quarter wave plates is inserted within a FP cavity. The rotation angle dependence of the axis modes are calculated with the Jones matrix method. When the HWP is rotated, the axis modes of the FP cavity shift one-way in the spectral region without any mirror scanning. The scanning range by a 2π rotation is four times wider than the free spectral range of the cavity. This method will provide a methodology for the precise measurement of frequency resolved spectra under the situation that the absorption loss during the round trip changes if a mirror is scanned, such as the absorption by the environmental water vapor can not be ignored.

18:00 **Amplitude-Modulated Continuous-Wave Ranging System With Resonant-Tunneling-Diode Terahertz Oscillator** **Th-POS-67**

Jiyu Hu; Ryotaka Wakasugi; Safumi Suzuki; Masahiro Asada
Tokyo Institute of Technology, Japan

We demonstrate amplitude-modulated continuous- wave (AMCW) ranging system using resonant-tunneling-diode (RTD) THz oscillator. The reflected signal of amplitude- modulated output of the RTD from an object was received and demodulated. The distance to the object was determined by measuring the phase difference between the demodulated signal and the reference of the modulation signal. The carrier frequency is 522 GHz, and the modulation frequency is 1.2 GHz. The error of the measured distances was less than 10 mm. The resolution can be improved by increasing the modulation frequency.

18:00 **Spectroscopic Range Points Migration Method For Wide-beam Terahertz Imaging** **Th-POS-68**

Takamaru Matsui[1]; Shouhei Kidera[2]
[1]Graduate School of Informatics and Engineering, University of Electro-Communications, Japan; [2]1.Graduate School of Informatics and Engineering, The University of Electro-Communications,, Japan

This paper introduces a new spectroscopic imaging method for terahertz (THz) imaging applications. The inherent problem in the conventional THz imaging system is that the azimuth resolution depends on the penetration range due to the lens based dielectric focusing. This problem is efficiently solved by the synthetic aperture (SA) process assuming wider THz beam. Furthermore, the range points migration (RPM) method has a numerous advantages from the usual SA approaches, in terms of accuracy, resolution or computational cost. Moreover, focusing on the feature of RPM, spectroscopic data can be associated to each reflection point. The finite difference time domain (FDTD) based numerical analysis demonstrates that our method accurately reconstructs object boundary with frequency dependent characteristic.

18:00 **0.65 THz Sheet Beam Traveling Wave Tube Based Upon Truncated Sinewaveguide** **Th-POS-69**

Shuanzhu Fang[1]; Jin Xu[1]; Xuebing Jiang[1]; Xia Lei[1]; Pengcheng Yin[1]; Quan Yang[1]; Tingting Guo[1]; Gangxiong Wu[1]; Qian Li[1]; Chong Ding[1]; Ruichao Yang[1]; Guoqing Zhao[1]; Hairong Yin[1]; Lingna Yue[1]; Dazhi Li[2]; Wenxiang Wang[1]; Yanyu Wei[1]
[1]University of Electronic Science and Technology of China, China; [2]Institute for Laser Technology Suito, Osaka 656-0817, Japan, Japan

A 0.65 THz traveling-wave tube was designed based upon truncated sine waveguide slow-wave structure. The highfrequency characteristics and transmission characteristics are analyzed and calculated by Ansoft High frequency simulation software. We have also studied and simulated the beam-wave interaction of this truncated sine waveguide traveling-wave tube. The results show that the peak output power is 270 mW from 640 GHz to 660 GHz with synchronous voltage of 18.9 kV, operation current of 11 mA and input power of 1.25 mW.

18:00 **A High-gain Antenna With Polarization-Division Multiplexing For Terahertz Wireless Communications** **Th-POS-70**

Chao Shu[1]; Shaoqing Hu[1]; Yuan Yao[2]; Xiaodong Chen[1]
[1]Queen Mary University of London, United Kingdom; [2]Beijing University of Posts and Telecommunications, China
A high-gain offset reflector antenna with Polarization-Division Multiplexing capability is proposed and designed in this paper. The performance over a wide bandwidth will be studied based on this preliminary design and presented in the full paper.

18:00 **Propagation Measurements For Indoor Wireless Communications At 350/650 GHz** **Th-POS-71**

Heng Zhao; Leihao Wei; Mona Jarrahi; Gregory Pottie
University of California, Los Angeles, United States
We have performed a propagation measurement campaign at 350/650 GHz in a typical indoor environment. The measured path loss shows a strong association between the spatially resolvable paths and the room geometry. The line-of-sight path loss and reflection loss are also characterized to support the wave propagation modeling.

18:00 **Fast Switching And Double Resonance Of Nonlinear Transistors In Terahertz Regime** **Th-POS-72**

Chao Zhang[1]; Yee Sin Ang[2]; L. K. Ang[2]; Zhongshui Ma[3]
[1]University of Wollongong, Australia; [2]Singapore University of Technology and Design, Singapore; [3]Peking University, China
We show that pure crossed Andreev reflection can be generated in an N/S/N device exclusively without the parasitic local Andreev reflection and elastic co tunnelling over a wide range of bias and Fermi levels. The pure non-local conductance exhibits rapid on/off switching and terahertz oscillation when the Fermi levels in the normal and the superconducting leads are varied. The transport characteristics exhibit double resonance in terahertz regime.

18:00 **Graphene Conductivity Mapping Using Terahertz Time-domain Reflection Spectroscopy** **Th-POS-73**

Hungyen Lin[1]; Philipp Braeuninger-Weimer[2]; Varun Kamboj[3]; David Jessop[3]; Riccardo Degl'Innocenti[1]; Harvey Beere[3]; David Ritchie[3]; Stephan Hofmann[2]; Axel Zeitler[4]
[1]Department of Engineering, Lancaster University, United Kingdom; [2]Department of Engineering, University of Cambridge, United Kingdom; [3]Cavendish Laboratory, University of Cambridge, United Kingdom; [4]Department of Chemical Engineering and Biotechnology, University of Cambridge, United Kingdom
Graphene conductivity mapping was successfully demonstrated using terahertz time-domain spectroscopy (THz-TDS) operating in transmission geometry. In order to cater for a greater range of substrates and scenarios where transmission geometry becomes prohibitive, here we demonstrate conductivity mapping of large area chemical vapor deposited (CVD) graphene films on sapphire. We validate the technique against measurements performed using the transmission based THz-TDS.

18:00 **Tunable Fano Resonance Using Graphene Integrated Metasurface** **Th-POS-74**

Quan Li; Shuang Wang
Tianjin University of Technology and Education, China
We propose a highly tunable Fano resonance in a graphene-silicon hybrid metasurface through a combination of very low bias voltages and continuous wave (CW). By using Drude model, the modulation process has been well described. The highly tunable characteristics of the hybrid Fano metasurface show a new and promising way to design a controllable non-linearity offered by the highly sensitive Fano metasurface.

18:00 **Spin-polarized GaAs Surface Studied By First-principles Method With SO Interaction For THz Emission Application** **Th-POS-75**

Mary Clare Escano[1]; Hideaki Kasai[2]; Masahiko Tani[1]
[1]Research Center for Development of Far Infrared Region, University of Fukui, Japan; [2]National Institute of Technology, Akashi, Japan
Since the understanding of spin-current's relation to THz radiation, spin-based THz emission sources have recently attracted attention. To date, conventional semiconductors are hardly spin-based sources unless doped with magnetic atoms (e.g. diluted magnetic semiconductor quantum well, $Ga_{1-x}Mn_xAs$ QW) or formed into heterostructures (e.g. topological insulator (TI) /GaAs). The general idea for the former material includes precession of available spins in QW around the dopant magnetic atoms due to spin-orbit (SO) interaction and the possible inverse spin hall

effect arising from such spin waves. In the latter material, a similar idea of spin waves has been considered, where the metallic surface states of TI have spin-helical structure. Thus, fundamentally, in these systems, the confinement of spin-polarized electrons in 2D and its helical structure, are vital for spin-based THz emission sources. GaAs, in its native form (uncombined and undoped), has broken inversion symmetry. Thus, in this present work, by employing first-principles methods with SO interaction, we demonstrate that, because of symmetry-breaking, the unreconstructed GaAs(001), can be a 2D spin source. We found that in the Γ to X dispersion of the bandstructure, the highest-energy valence band is split. Using partial charge density, the location of the spin-polarized electrons is derived. We note that the valence band originate mainly from the surface, leading to a 2D electron spin source. Our future work incorporates helical nature of these spins due to SO.

18:00 **Microfluidic Chip With Sandwich Structure For Terahertz Spectra Of Glycerol** **Th-POS-76**

Bo Su; Yaxiong Wu; Yiwei Wen; Jingsuo He; Shengbo Zhang; Cunlin Zhang
Capital Normal University, China

we adopt the microfluidic chip technique to detect liquid samples through THz-TDS system. The microfluidic chip has a sandwich structure which comprises cover, substrate and microchannel layer. The materials of cover and substrate is cycloolefin copolymers (zeonor 1420R), which has a very high transmittance for THz wave, and the microchannel layer is polydimethylsiloxane (PDMS). Through van der Waals force, the cover, substrate and microchannel layer are sealed together. The cover and substrate have the same thickness, that is, 1.5mm, and the length, width and depth of the microchannel are 30mm, 80um and 50um, respectively. The size of detection area of THz wave in the microchannel is 3.5mm in diameter. Using the microfluidic chip to detect the glycerol with a concentration of 98%, and the experimental results prove the feasibility of this method.

18:00 **Photothermal Conversion And Fast Response Properties Of 3D Graphene Foam In The Terahertz Range** **Th-POS-77**

Meng Chen[1]; Yinxin Wang[1]; Fei Fan[2]; Yi Huang[3]; Ziran Zhao[1]
[1]Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Tsinghua University, China; [2]Institute of Modern Optics, Nankai University, China; [3]Key Laboratory of Functional Polymer Materials, Nankai University, China

Fast terahertz response of three dimensional graphene foam through photothermoelectric effect is reported in this work with its photothermal conversion property investigated by infrared thermal imaging. A great temperature rise of 70 K (1.25 W/cm2, 2.52 THz) was obtained with a small thermal diffusion length scale of 0.7 mm and a short response time of 21 ms. This material can be used as an ideal absorber for terahertz thermal detector and experiment results proved that the photothermoelectric response of a single-layer graphene can be enhanced six times with a small block of three dimensional graphene foam adhering to it.

18:00 **Stimulated Emission In 2.8 - 3.5 Mm Wavelength Range From Peltier Cooled HgTe/CdHgTe Quantum Well Heterostructures** **Th-POS-78**

Sergey Morozov
Institute for Physics of Microstructures, Russian Federation

We report stimulated emission in 2.8 -- 3.5 μm wavelength range from HgTe/CdHgTe quantum well (QW) heterostructures grown on GaAs substrates at temperatures available with thermoelectric cooling. The structures were designed to suppress the Auger recombination by implementing narrow (1.5 -- 2 nm wide) QWs. We conclude that Peltier cooled operation is feasible in lasers based on such structures, making them of interest for spectroscopy applications in the atmospheric transparency window from 3 to 5 μm.This work aims to demonstrate that the potential of MCT structures for mid-infrared lasers in not exhausted. At the very least, wavelength range of 3.2 -- 3.4 μm seems to be feasible at operating temperature around 230 K. In contrast to previous works, this operating temperature can be achieved with a single Peltier element, making structures under study of interest for applications in gas analysis and methane detection, in particular. Strong temperature dependence of the bandgap enables effective wavelength tuning. Recently we have shown that obtaining MCT epitaxial structures with overall thickness of ~20 μm is technologically feasible, which is sufficient to grow the Bragg reflectors. High-quality MCT structures grown on alternative substrates, like GaAs in the present work, can pave the way towards cheap optical converters and/or MCT lasers with current pumping.

18:00 **The Bias Voltage And Photon Frequency Effects On The Negative Optical Conductance Of A Gapped Single Layer Graphene P-n Junction In THz To IR Regime** **Th-POS-79**

Shareef Al-Tikrity
University of Wollongong, Australia

In this paper we study the real part of total optical conductance of a gapped single layer graphene p-n junction (GGPNJ) in terahertz to infrared regime and The bias voltage and photon frequency effects on the negative optical conductance of (GGPNJ) in THz to infrared regime . It is shown that negative connectivity of (GGPNJ) can be affected by THz frequency and the bias voltage and that can be important to application of graphene in coherent terahertz radiation sources and optoelectronics devices.

18:00 **Carrier Dynamics In SnS2 Single Crystals And Vertical Nanostructures: Role Of Edges** **Th-POS-80**

KATERYNA KUSHNIR[1]; Erin Morissette[2]; Binod Giri[1]; Curtis Doiron[1]; Ronald Grimm[1]; Pratap Rao[1]; Lyubov Titova[1]
[1]WPI, United States; [2]wpi, United States

SnS2 is a member of van der Waals 2D layered materials family. Its moderate bandgap, environmental stability and high carrier mobility makes it attractive for solar energy conversion application. We explore how nanostructuring SnS2 in the form of vertically-aligned nanoflakes to increase the surface area impacts the lifetime and microscopic conductivity of photoinjected carriers compared to the bulk SnS2. Increased surface area and the presence of edges is beneficial to the efficiency of SnS2 photoanode performance but it comes at a cost of increased carrier trapping at surface and edge states.

18:00 **Tunable Polarization-Independent Terahertz Band-Stop Filter Based On Graphene Metasurface** **Th-POS-81**

Jiang-Yu Liu; Tie-Jun Huang; Pu-Kun Liu
Peking University, China

In this paper, a tunable terahertz filter is proposed. The filter shows band-stop feature around 6.4THz. The working frequency is blue shifting with the increase of chemical potential of graphene. The filter works both for TE and TM polarizations. It may be applied to high-sensitivity sensors.

18:00 **Terahertz Conductivity Of Photoexcited Multi-layer Graphene** **Th-POS-82**

Alexander Grebenchukov[1]; Anton Zaitsev[1]; Petr Demchenko[1]; Egor Kornilov[1]; Mikhail Novoselov[1]; Evgeniya Kovalska[2]; Anna Baldycheva[2]; Mikhail Khodzitsky[1]
[1]ITMO University, Russian Federation; [2]University of Exeter, United Kingdom

Our study has shown that the complex conductivity dispersion of 80-layered graphene can be effectively controlled by external low intensity infrared optical pumping. Wherein, the underlying substrate has a significant impact on the character of tunability. We hope that the present study would enable the 80-layered graphene to be used as an alternative high effective reconfigurable part in THz metamaterials.

Friday, September 14, 2018

08:45 - 09:00 **Announcements** **Shirotori Hall**

Session Type: Others

09:00 - 09:45 **Fr-A1-S Plenary Session** **Shirotori Hall**

Session Type: Plenary
Chair(s)/Convenor(s)/Facilitator(s): Taiichi Otsuji
Discussant(s):

09:00 **Tailored Nano-electronics And Photonics With 2D Materials** **Fr-A1-S-1**

Miriam Serena Vitiello
Consiglio Nazionale delle Ricerche-Istituto Nanoscienze, Italy

Bi-dimensional nano-materials and related heterostructures are establishing themselves as intriguing material systems for the development of a new class of electronic, photonic and plasmonic devices with ad hoc-properties, that can be engineered "from scratch". Huge potential can be envisaged in a variety of application fields, ranging from saturable absorbers to optical modulators, from optical communication modules to spintronics, from near-field components to

photodetectors. Their peculiar band-structure and electron transport characteristics, which can be easily manipulated via layer thickness control, suggest they could also form the basis for a new generation of high-performance devices operating in the Terahertz frequency range (1-10 THz) of the electromagnetic spectrum. This talk will review latest achievements in the developments of active and passive THz photonic and nano-electronic devices exploiting 2D nano-materials and combined heterostructures and will discuss future perspectives of this rapidly developing research field.

10:15 - 12:15 **Fr-A2-R1 Metrology** **Shirotori Hall**

Session Type: Oral

10:15 **[Keynote] Nanothermometry Of Electrons And Phonons** **Fr-A2-R1-1**

Qianchun Weng[1]; Robb Puttock[2]; Craig Barton[2]; Vishal Panchal[2]; Le Yang[3]; Zhenghua An[3]; Yusuke Kajihara[1]; Wei Lu[4]; Alexander Tzalenchuk[2]; Susumu Komiyama[1]

[1]The University of Tokyo, Japan; [2]National Physical Laboratory, United Kingdom; [3]Fudan University, China; [4]Shanghai Institute of Technical Physics, China

Infrared radiation thermometry, which derives temperature of an object from the intensity of emitted radiation, suffers from diffraction-limited insufficient spatial resolution. This limit is overcome by introducing a terahertz near-field technique to locally probe fluctuating electromagnetic (EM) evanescent fields. We report here nanoscale hot electron temperature distribution directly mapped with a newly developed near-field technique, called scanning noise microscope (SNoiM). Nanoscale lattice temperature distribution in the same sample wasalso mapped with a commercially available contact-type scanning thermal microscope (SThM). By comparison, subtle but essential difference has been found between the distributions of the lattice temperature and the electron temperature, leading to detailed understanding of the hot electron kinetics along with the phonon-relaxation process.

10:45 **[Keynote] Frequency Noise Power Spectral Density Of A Molecular THz-laser Using A Fs-fibre Laser Comb With 1GHz Repetition Rate** **Fr-A2-R1-2**

Stefano Barbieri[1]; Antoine Pagies[1]; Sophie Eliet[1]; Jean-Francois Lampin[1]; Giorgio Santarelli[2]; Wolfgang Hänsel[3]; Ronald Holzwarth[3]

[1]IEMN Laboratory, CNRS and University of Lille, France; [2]Laboratoire LP2N, IOGS - CNRS - Université de Bordeaux, France; [3]Menlo Systems GmbH, Germany

We report the measurement of the frequency noise power spectral density (FNPSD) of a CO2 pumped molecular-laser emitting at 2.5THz. The measurement relies on the generation of a beatnote between the THz frequency and the harmonic of the 1GHz repetition rate of a fs-fiber comb. We obtain a frequency noise of ~0.1 Hz2/Hz at 50kHz, limited by the phase noise of the frequency comb. This shows the potential of (i) molecular lasers as ultra-low phase noise sources of THz radiation, and of (ii) fs-fiber combs, in combination with electro-optic detection, as frequency-agile and low phase-noise THz local oscillators.

11:15 **All-optical Vector Network Analyzer With 500 GHz Bandwidth And 76 MHz Frequency Resolution** **Fr-A2-R1-3**

Paul Struszewski[1]; Mark Bieler[2]

[1]Physikalische-Technische Bundesanstalt, Germany; [2]Physikalisch-Technische Bundesanstalt, Germany

We demonstrate an all-optical time-domain vector network analyzer with a frequency resolution of 76 MHz and a bandwidth exceeding 500 GHz in a single measurement configuration. Electrical reflection coefficients are obtained from measurements of ultra-short voltage pulses at different positions on a coplanar waveguide using femtosecond laser pulses and an asynchronous optical sampling technique. In contrast to our previous synchronous sampling experiments, the new technique leads to a significant improvement of the frequency resolution and potentially more accurate measurements being important for future calibration tasks.

11:30 **Total Internal Reflection Geometry For Sensitive THz Material Characterization** **Fr-A2-R1-4**

Xudong Liu[1]; Qiushuo Sun[2]; Yiwen Sun[1]; Emma Pickwell-MacPherson[3]

[1]Shenzhen University, China; [2]The Chinese University of Hong Kong, China; [3]The

University of Warwick, United Kingdom
We proposed and experimentally demonstrated a sensitive THz material characterization method by exploiting thin-film total internal reflection geometry, which performed high sensitivity in characterizing conductive materials, e.g. graphene and PEDOT:PSS, and non-conductive materials, e.g. α-lactose. Our method can be developed into a high sensitive and low sample consumption technique for THz material characterization and spectroscopy in the future.

11:45 **Time-Unresolvable Thin Film Characterization Using A Genetic Algorithm** **Fr-A2-R1-5**

XUEQUAN CHEN[1]; Emma Pickwell-MacPherson[2]
[1]The Chinese University of Hong Kong, China; [2]Warwick University, United Kingdom
Measurements of materials with optically thin thickness result in unresolvable time-domain signals, which bring difficulties in property characterization and accurate thickness determination. A genetic algorithm is creatively introduced in this work to accurately determine both the optical property and the thickness of samples with time-unresolvable characteristics. Experimental results demonstrated excellent accuracy of the algorithm for samples as thin as 50 μm.

12:00 **A Reference Material For Accurate THz Measurements** **Fr-A2-R1-6**

Andreas Steiger[1]; Mathias Kehrt[1]; Anselm Deniger[2]
[1]PTB, Germany; [2]Toptica Photonics AG, Germany
A well-characterized reference material for accurate transmission and reflection measurements in the THz spectral range is presented.

10:15 - 12:15 **Fr-A2-1b Free Electron Lasers and Synchrotron Radiation II** **Room 131+132**

Session Type: Oral

10:15 **[Keynote] Free Electron Laser Based On A Multi-Stage System Of RF Wigglers** **Fr-A2-1b-1**

Andrei Savilov; Ilya Bandurkin; Sergey Kuzikov
Institute of Applied Physics of Russian Academy of Sciences, Russian Federation
We propose a high-efficiency regime of a "multistage" trapping in FELs. This FEL scheme use strongly tapered flying RF undulator sections to be fed by short (nanosecond) high-power RF pulses produced by already existing BWOs. In this regime, phase locking of the RF sources is not necessary. The proposed method allows efficiency at level of several per cents in X-ray FELs driven by modern laser-plasma accelerators producing bunches of high energy spread.

10:45 **Powerful Two-stage THz-range FEL Based On Intense Parallel Sheet Beams: Design, Simulations And Recent Results** **Fr-A2-1b-2**

Nikolai Peskov[1]; Andrey Arzhannikov[2]; Naum Ginzburg[1]; Petr Kalinin[2]; Alexander Sergeev[1]; Stanislav Sinitsky[1]; Vasily Stepanov[2]; Vladislav Zaslavsky[1]; Evgeny Sandalov[2]
[1]Institute of Applied Physics RAS, Russian Federation; [2]Budker Institute of Nuclear Physics RAS, Russian Federation
Project of a two-stage cascade THz FEL driven by two intense parallel sheet beams is under development at the ELMI accelerator. Planar 75 GHz FEM-oscillator with 2D distributed feedback, which was successfully realized in previous experiments, is planned to be used for powering this two-channel scheme. Pumping wave generated in the FEM-oscillator would be transported by the coupling waveguides to the second cascade and transformed into the THz radiation when scattering on the second parallel electron beam. Results of theoretical analysis, computer simulations and recent experimental studies of this cascade FEL scheme are presented.

11:00 **NovoFEL As Source Of Powerful Ultramonochromatic Tunable Terahertz Radiation** **Fr-A2-1b-3**

Vitaly Kubarev[1]; Yaroslav Getmanov[2]
[1]BINP, Russian Federation; [2]Budker Institute of Nuclear Physics, Russian Federation
Laser nature of a continuous pulse-periodical radiation of the Novosibirsk free-electron laser (NovoFEL) appears in a good coherency of its pulses and very narrow synchronized longitudinal modes. Filtration of one of the modes by a system of three resonance Fabry-Perot interferometers allows to create laser source with monochromaticity which is sufficient for typical high-resolution THz spectroscopy ($\Delta f/f \leq 5 \bullet 10^{-8}$, $\Delta f \leq 0.1$ MHz). Features of the source compared to other alternative

devices are a wide tuning range (1.5-3 THz) and much more high output power (up to 50-100 mW).

11:15 **Long-Term Turn-by-Turn Measurements Of Electron Bunch Profiles At MHz Repetition Rates In A Storage Ring With Single-Shot Electro-Optical Sampling** **Fr-A2-1b-4**

Stefan Funkner; Miriam Brosi; Erik Bründermann; Michele Caselle; Michael J. Nasse; Gudrun Niehues; Lorenzo Rota; Patrik Schönfeldt; Marc Weber; Anke-Susanne Müller
Karlsruhe Institute of Technology, Germany

At the KArlsruhe Research Accelerator (KARA), we use electro-optical sampling to measures profiles of compressed electron bunches during the microbunching instability. The observation of the complex dynamics of this instability is of special interest because it leads to intense THz radiation bursts. As the revolution frequency of the storage ring is 2.72 MHz, high detection rates are required to record the bunch profiles for every revolution with single-shot measurements. To achieve fast detection rates, we implemented a KIT-developed ultra-fast line array and recorded the electron bunch charge density for every revolution for 3.6 s with a data throughput of 1.4 GBytes/s.

11:30 **Lase Induced Fine Structure On Si By THz-FEL Irradiation** **Fr-A2-1b-5**

Akinori Irizawa
ISIR/Osaka Univ., Japan

We report the first observation of a laser induced periodic surface structure (LIPSS) by THz-FEL (THz free electron laser) irradiation on the surface of semiconductor Si. So far LIPSS has been studied only in NIR region by fs-laser, but LIPSS found in THz-FIR region by THz-FEL shows new features, such as, the fineness of the periodic interval is close to 1/25 of the wavelength.

11:45 **[Keynote] Linear Detection Of Coherent Synchrotron Radiation Emitted By Single Electron Bunches Using Zero-biased InGaAs Schottky Diode Detectors.** **Fr-A2-1b-6**

Nart Daghestani[1]; Kai Parow-Souchon[1]; Diego Pardo[1]; Fiachra Cahill[1]; Mark Frogley[2]; Joe Langston[3]; Byron Alderman[1]; Gianfelice Cinque[2]; Peter Huggard[1]
[1]STFC, United Kingdom; [2]Diamond Light Source, United Kingdom; [3]Tektronix Ltd, United Kingdom

Using a range of zero-biased InGaAs Schottky diode detectors, terahertz coherent synchrotron radiation emitted by individual electron bunches has been detected. The source was the UK's Diamond Light Source synchrotron operating in low-alpha THz mode. Detected signals have a FWHM of <50 picoseconds, and a spectral bandwidth of 0.2 - 3 THz. Due to the sensitivity, high linearity and fast recovery of the detectors, we were able to record the THz emission from a series of bunches over several synchrotron round trips.

10:15 - 12:15 **Fr-A2-1c MMW and THz Wave Radar and Communications II** **Room 133+134**

Session Type: Oral

10:15 **[Keynote] Turning THz Communications Into Reality: Status On Technology, Standardization And Regulation** **Fr-A2-1c-1**

Thomas Kuerner
TU Braunschweig, Germany

Already a couple of years ago THz communications have not only become an attractive new research area on channel modeling but also triggered a couple of projects heading to develop appropriate technological solutions to enable the set-up of hardware demonstrators. In parallel discussions and activities in standardization and regulation already took off. In October 2017, IEEE published Std. IEEE 802.15.3d-2017 the worldwide first wireless communications standard operating in the 300 GHz frequency band. In parallel to the standardization process activities at the ITU-R level targeting on the provision of an appropriate regulatory framework at the World Radio Conference 2019 (WRC-2019) via a dedicated agenda item have taken off. This paper provides a brief overview on the current status of the development of THz Communication systems focusing on recent results on advanced channel characterization at 300 GHz, hardware demonstrators operating in this frequency range, the past and current activities at IEEE 802 and the WRC 2019 preparations.

10:45 **[Keynote] Channel Characteristics For Terahertz Wireless Communications** **Fr-A2-1c-2**

Jianjun Ma[1]; Rabi Shrestha[1]; Lothar Moeller[2]; Daniel Mittleman[1]

[1]Brown University, United States; [2]New Jersey Institute of Technology, United States
We investigate channel performances for indoor and outdoor terahertz (THz) wireless links with carrier frequencies of 100, 200, 300 and 400 GHz. Both line-of-sight and non-line-of-sight (specular reflection) data streams off of building walls are demonstrated.

11:15 **Single Channel 100 Gbit/s Link In The 300 GHz Band** **Fr-A2-1c-3**

Vinay-Kumar Chinni[1]; Philipp Latzel[1]; Malek Zegaoui[1]; Christophe Coinon[1]; Xavier Wallart[1]; Emilien Peytavit[1]; Jean-François Lampin[1]; Klaus Engenhardt[2]; Pascal Szriftgiser[3]; Mohammed Zaknoune[1]; Guillaume Ducournau[4]
[1]IEMN, France; [2]Tektronix, Germany; [3]PhLAM, France; [4]IEMN - Univ Lille, France
We report on the achievement of single channel 100 Gbit/s transmission, using linear resonant cavity enhanced unitravelling carrier photodiodes and QAM-16 modulation format. The indoor wireless link has been validated for up to 100 Gbit/s and 280 GHz carrier frequency.

11:30 **A High-Speed QPSK/16-QAM 1-m Wireless Link With A Tunable 220-260 GHz LO Carrier In SiGe HBT Technology** **Fr-A2-1c-4**

Janusz Grzyb[1]; Pedro Rodriguez-Vazquez[1]; Bernd Heinemann[2]; Ullrich Pfeiffer[1]
[1]University of Wuppertal, Germany; [2]IHP, Germany
This paper demonstrates a fully-electronic 1-m wireless link with two highly-integrated zero-IF quadrature TX and RX modules in 130nm SiGe HBT technology operating with a tunable 220-260 GHz LO carrier and supporting complex digital modulation formats. Each of the modules employs a low-cost chip-on-board packaging with a silicon lens-integrated on-chip antenna for THz signal escape and a wire-bonded interconnection to access high-speed baseband signals at the board level. With the limited BB link bandwidth of 15 GHz, the maximum achieved data rates for QPSK/16-QAM modulation schemes are 65 Gbps with an EVM of 31.5% and 90 Gbps with an EVM of 14.6%.

11:45 **Considerations On Local Oscillator Isolation In A Terahertz Wireless Link Used For Future Communication Systems** **Fr-A2-1c-5**

Iulia Dan[1]; Christopher Grötsch[1]; Shoichi Shiba[2]; Ingmar Kallfass[1]
[1]University of Stuttgart, Institute for Robust Power Semiconductor Systems, Germany; [2]Fujitsu Laboratories Ltd., Japan
Monolithic integrated circuits operating in the low terahertz region, at frequencies beyond 275 GHz, have been successfully employed in communication systems, demonstrating that high data rates can be achieved. This paper analyzes and identifies the main factors that influence one important impairment of a 300 GHz wireless system: the isolation of the local oscillator. Improving this isolation will have a positive effect on the quality of the data transmissions, allowing better figures of merit, like error vector magnitude and bit error rates and higher order modulation formats, which will result in an even higher data rate. The continuously increasing demand for higher data rates and as a direct consequence for higher bandwidths is the main motivation for aiming at frequencies above 275 GHz when planning future wireless systems. An overview of successful data transmissions at these frequencies done with different technologies can be found in literature. Frontends operating at such high frequencies need to meet very high requirements and even small variations of non-idealities can disturb the performance of the data transmission. One important non-ideality, which is the main topic of this paper, is the isolation of the local oscillator (LO). In the transmitter a low LO to the radio frequency signal (RF) isolation causes bit errors and, with increasing energy, could lead to an early saturation of the subsequent amplifier stages. On the receiver side an LO leaked into the received RF signal leads to the self-biasing of the mixer resulting in a strong DC offset at the IF. Another effect of a low LO to RF isolation appears if the leaked LO signal reaches the antenna and is sent and intercepted by other receivers. But the LO leakage has been proven to be not only a disturbing factor but also a useful one. Using the leaked LO signal a new analog carrier recovery method has been recently developed. In all cases it is important to have a reliable measurement of the LO isolation and to be able to estimate its effect on the transmission.

12:00 **Compact J-band Oscillators With 1 MW RF Output Power And Over 110 GHz Modulation Bandwidth** **Fr-A2-1c-6**

Abdullah Al-Khalidi; Jue Wang; Edward Wasige

University of Glasgow, United Kingdom
We report a compact resonant tunneling diode (RTD) oscillator with 1 mW output power at 260 GHz and a modulation bandwidth of over 110 GHz. The oscillator employs an RTD device size of 4 × 4 μm^2 resonating with an 88 μm long microstrip inductor. The total chip size is 470 × 530 μm^2. All fabrication was done using the low cost photolithography technique.

10:15 - 12:15 **Fr-A2-1a Sources, Detectors, and Receivers VIII** **Room 141+142**

Session Type: Oral

10:15 **A Novel 300-520 GHz Tripler With 50 % Bandwidth For Multi-pixel Heterodyne SIS Array Local Oscillator Signal** **Fr-A2-1a-1**

Jeanne Treuttel[1]; Choonsup Lee[2]; Jacob Kooi[3]; Imran Mehdi[4]
[1]Observatory of Paris, France; [2]Jet Priopulsion Laboratory, United States; [3]Jet Propulsion Laboratory, United States; [4]Jet Propulsion laboratory, United States
Terahertz (THz) heterodyne receivers have provided technical applications for astronomical ground observations in the frequencies from 0.1 to 10 THz, in which local oscillators must provide sufficient pump power to superconductor mixers up to nearly a THz. Generating this LO signal is recognized as a major technological challenge because they should be tunable over broad ranges, phase-locked to a reference signal common to the whole array with phase stability sufficient to perform highly coherent interferometry at 950 GHz over distances up to 20 km. Moreover, system upgrade can lead to the merging the detection channels as for example ALMA band 7 and 8 (275-373 GHz and 385-500GHz) pushing even more the bandwidth requirement in a compact same spacing (cartridge). We report on a novel Schottky frequency tripler working on a very broad frequency range. Its configuration combines the advantage of antiparallel pair of diodes for the confinement of the second harmonic signal, thin substrate transmission lines for uniform impedance matching, as well as varistor mode operating leveraged by the presence of a DC bias. Efficiency of 5 % over 300 GHz up to 520 GHz and an output power going from 0.5 mW to 1 mW provided within a single chip only offer the possibility to feed up to 8 pixels Superconductor-Insulator-Superconductor (SIS) mixers.

10:30 **A High Harmonic Terahertz Frequency Multiplier Based On Plasmonic Grating** **Fr-A2-1a-2**

Juan-Feng Zhu; Chao-Hai Du; Lu-Yao Bao; Zi-Chao Gao; Shi Pan; Pun-Kun Liu
Peking University, China
In this paper, a THz frequency multiplier model is proposed. A 0.5 THz radiation source can be achieved based on the electron beam synthesizing with the 10th harmonic of electron beam bunches. It has greatly increased the operating harmonic order of electron beam bunches and enhanced the radiation frequency consequently. It may promisingly be applied to develop a high-efficient THz source.

10:45 **The Enhanced Third Harmonic Superradiation Of Smith Purcell Terahertz Radiation Source** **Fr-A2-1a-3**

Zhenhua Wu; Pengfei Hu; Min Hu; Yueheng Cao; Xiaoqiuyan Zhang; Sen Gong; Tao Zhao; Shenggang Liu
University of Electronic Science and Technology of China, China
We propose a new mechanism to enhance the third harmonic of super Smith-Purcell radiation. In this paper, the specific designed grating structure enhances the power of the third harmonic by suppressing the second harmonic. Therefore, the higher frequency radiation signal (25 mW, 326 GHz) is generated by the lower energetic electron beam (9 keV) passing through the grating with larger size (0.4 mm), compared with normal superradiation. Accordingly, this mechanism is expected to achieve more efficient compact and tunable terahertz radiation sources with higher frequency.

11:00 **A Imaging System Based On Two Bands RF Mixer And Output Multiplier In One Stage At 340GHz And 170GHz** **Fr-A2-1a-4**

Jiang Jun[1]; He Yue[1]; An Jianfei[1]; Miao Li[1]; Tian Yaoling[1]; Chen Peng[1]; Hao Hailong[2]
[1]Microsystem and Terahertz Research Center, CAEP, China; [2]Institute of Electronic Engineering, CAEP, China
This paper introduces a design of a novel FMCW imaging system, working at bands of 170GHz and 340GHz at the same time. This FMCW imaging system can be used in zero-IF and super-heterodyne system. This method can reduce the half of local

oscillator source of the system. There are two key components in the transmitter and receiver, including two bands output multiplier and two bands RF mixer. The last stage multiplier in transmitter includes quadrupler at 340GHz and doubler at 170GHz. The last stage in receiver includes sub- and 4th- harmonic mixer. For experimental verification, there are four DUT modules: 170GHz and 340GHz two bands output passive network, 4-Octave CSMRs low pass filter (LPF), multiplier and mixer module. Output passive network results are S11<-10dB at 150GHz-185GHz and S11<-10dB at 306-355 GHz, and two ports isolation is better than 30dB. The transmitter peak power is more than 1 mw@340 GHz and 6mW@170 GHz. The receiver conversion loss is around -15dB and the bandwidth is more than 30 GHz@170 GHz and 80 GHz@340 GHz.

11:15 **(Withdrawn)** **Fr-A2-1a-5**

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11:30 **YBaCuO Hot Electron Bolometric Mixer: Evaluation Of Performance Requirements For Standoff THz Passive Detection** **Fr-A2-1a-6**

Romain Ladret[1]; Alain Kreisler[2]; Annick Degardin[3]
[1]CentraleSupelec, France; [2]CentraleSupelec - GeePs, France; [3]Sorbonne Universite - GeePs, France

Introduction. Hot electron bolometers (HEBs) using superconducting high-TC YBaCuO material have been suggested more than a quarter of a century ago. However, the development of YBaCuO HEBs has been delayed due to various causes of YBaCuO film chemical degradation, with the consequence of premature aging of the ultrathin films required by HEB action. These technological efforts were in fact comforted by early performance predictions using the point bolometer approach, further confirmed by the 1-D hot spot model. This model was then improved to include the HEB constriction behavior at THz frequencies. After outlining this latter model achievements, we consider the potential performance that can be expected from an YBaCuO HEB THz heterodyne system for standoff detection.

YBaCuO HEB Hot Spot Model Results. The HEB characteristics were predicted from the hot spot model, which considers the variation along the constriction length L of both the YBaCuO electron $T_e(x)$ and phonon $T_p(x)$ temperatures. Moreover, two main hypotheses were included in a more achieved version of this model: i) the THz current delivered by the antenna is assumed to be constant along the constriction, hence a non-uniform absorption of the local oscillator (LO) power; ii) the YBaCuO superconducting transition THz dependence is introduced, which also allows to take into account the impedance matching coefficient between the constriction and the antenna.Finally, the mixer performance was deduced in terms of double sideband noise temperature T_{DSB} and conversion gain G. Optimized results are given for a "medium size constriction", of length x width = 400 nm x 400 nm, and thickness = 35 nm. These dimensions can be achieved with our current technological process. Optimal values range from T_{DSB} = 1800 K (G = -9 dB) at 0.5 THz with 7.5 microwatt local oscillator power, to T_{DSB} = 1100 K (G = -6.5 dB) at 4 THz with 13.5 microwatt local oscillator power.

Evaluating Standoff Detection Perormance. We have checked the feasibility of standoff target detection operating in the passive mode with a YBaCuO HEB THz mixer. We have considered a simplified schematic, including losses of various origin (focusing lens, cryostat window, local oscillator injection, atmospheric absorption and other obstacles). Four situations were considered, with detector to target distance ranging from 1 m to 10 m and various humidity conditions. For instance, detection at 5 m can be readily achieved in moderate humidity with 1 K / 3 cm resolutions. Detection at 10 m with high humidity is more challenging.

Acknowledgment. This work was supported in part by the French National Research Agency (ANR) under grant # 2011-BS03-008.

11:45 **[Keynote] Excitation-Wavelength Dependent Terahertz Wave Polarization Control In Laser-Induced Filament** **Fr-A2-1a-7**

Liangliang Zhang[1]; Cunlin Zhang[1]; Xiaomei Yu[2]; Ming Liu[3]; Yuejin Zhao[3]; Xi-Cheng Zhang[4]

[1]Capital Normal University, China; [2]Peking University, China; [3]Beijing Institute of Technology, China; [4]University of Rochester, United States
We examine the terahertz (THz) emission from air filament driven by two-color lasers with relatively longer wavelengths than 800 nm. The THz energy dependence on the input laser energy increases more rapidly with a longer laser wavelength, and the scaling laws of THz energy as a function of fundamental wavelength vary for different optical powers, which is theoretically validated by considering the optical wavelength-dependent ionization rate. Furthermore, the THz polarization undergoes a continuous rotation as a function of the laser wavelength, since the relative phase and polarization of the two pulses are adjusted through changing the excitation wavelength in the frequency doubling crystal. Our results contribute to the understanding of THz wave generation in a femtosecond laser filament and suggest a practical way to control the polarization of terahertz pulses for potential applications.

10:15 - 12:15 **Fr-A2-R2 MM and sub-MM wave systems II** **Reception Hall**

Session Type: Oral

10:15 **[Keynote] Integrated Microwave-Photonics (iMWP) For Mobile Terahertz Systems** **Fr-A2-R2-1**

Andreas Stöhr
University Duisburg-Essen, Germany
This keynote talk will highlight the generic advantages integrated photonics offers for compact and mobile THz systems, especially for high spectral efficient THz communi¬ca¬tions as well as for THz imaging and spectros¬copy systems. The talk will also focus on some technological challenges involved in integrating THz photonics and electronics. At first, the state of the art in high output power millimeter-wave and terahertz 1.55 µm InP photodiodes (PDs) including waveguide pin-PDs, UTC-PDs, MUTC-PD, and TTR-PDs will be reviewed. Next, novel techniques for interconnecting and packaging high-frequency THz range photodiodes will be presented. This includes novel planar laminate based THz transitions for interconnecting PDs to rectangular waveguides. Also, compact lens-assisted quasi-optical THz transmitter with integrated planar log-periodic toothed antenna and THz PD arrays for optical beam steering will be reported. Finally, key advantages integrated photonics offers for compact THz systems will be discussed by means of developed THz systems. This includes remote THz LO generation, THz communications and THz spectroscopy.

10:45 **[Keynote] ITER Heating And Current Drive Systems** **Fr-A2-R2-2**

Mark Henderson
ITER Organization, France
The ITER device is to demonstrate a burning plasma with a net energy gain of a factor of 10 relative to the power injected into the plasma. Such conditions require heating a plasma to roughly 150 million ˚C, which is achieved by injecting 73MW of heating power from three systems (neutral beam, radio frequency and microwave frequency heating systems). In addition, the three systems are optimized to support the control of plasma instabilities, current and temperature profiles. This paper aims at describing the functional requirements, design and current status of these heating systems with particular attention given to the 20MW microwave system operating at 170GHz.

11:15 **Optimizing And Experimental Investigation Of A Ka-band Relativistic Backward Wave Oscillator Operating At TM02 Mode** **Fr-A2-R2-3**

Dongyang Wang; Yan Teng; Shuang Li; Yanchao Shi; Yibing Cao; Guangshuai Zhang; Xiaoling Wu; Jun Sun
northwest institute of nuclear technology, China
In this paper, a ka-band RBWO operating at TM02 mode is optimized for consideration of stability in practical situation. The numbers of front and post cascaded resonators are both reduced with the acceptable drop of conversion efficiency from 41% to 34%. The optimized RBWO is 50 mm shorter than the previous one with ouput power basically unchanged in simulation. Finally We obtained 363 MW output power in the experiment, and the operating frequency, radiation pattern, as well the regulation of output power versus diode voltage are all corresponding with the theoretical calculate or PIC simulation.

11:30 **The Multi-Frequency ECRH System At ASDEX Upgrade - Current Status And Plans -** **Fr-A2-R2-4**

Dietmar Wagner[1]; Joerg Stober[1]; Michael Kircher[1]; Fritz Leuterer[1]; Francesco Monaco[1]; Max Münich[1]; Martin Schubert[1]; Hartmut Zohm[1]; gerd Gantenbein[2]; John Jelonnek[2]; Manfred Thumm[2]; Andreas Meier[2]; Theo Scherer[2]; Dirk Strauss[2]; Walter Kasparek[3]; Carsten Lechte[3]; Burkhard Plaum[3]; Alexander Zach[3]; Alexander Litvak[4]; Gregory Denisov[4]; Alexey Chirkov[4]; Vladimir Malygin[4]; Leonid Popov[5]; Vadim Nichiporenko[5]; Vadim Myasnikov[5]; Evgeny Tai[5]; Elena Solyanova[5]
[1]Max-Planck-Insitut fuer Plasmaphysik, Germany; [2]Karlsruhe Institute of Technology, Germany; [3]IGVP Stuttgart, Germany; [4]Institute of Applied Physics, RAS, Nizhny Novgorod, Russian Federation; [5]GYCOM Ltd., Russian Federation
Last year, two more two-frequency 1 MW gyrotrons have been installed and put into operation at ASDEX Upgrade. In total 6 gyrotrons were in operation in the last experimental campaign. This year, two more gyrotrons will be installed which will bring the upgraded ECRH system to its completion. The system upgrade also includes technological advances in subsystems and loads as well as new concepts for passive protection of in-vessel components against ECRH stray radiation.

11:45 **Electron Bernstein Wave Detection By Sub-Tera-Hz Scattering In The QUEST** **Fr-A2-R2-5**

Shin Kubo[1]; Hiroshi Idei[2]; Teruo Saito[3]; Yoshinori Tatematsu[3]; Moe Iizawa[4]
[1]National Institute for Fusion Science, Japan; [2]RIAM, Kyushu University, Japan; [3]FIR Center, University of Fukui, Japan; [4]Department of Advanced Energy, Nagoya University, Japan
A collective scattering method using the sub-THz gyrotron radiation is planned to apply to the direct detection of the electron Bernstein wave in the QUEST where the electron Bernstein wave plays one of the main heating/current drive roles in sustaining steady state spherical tokamak configuration.

12:00 **Frequency Dependence Of Atmospheric Millimeter Wave Breakdown Plasma** **Fr-A2-R2-6**

Yasuhisa Oda[1]; Masayuki Takahashi[2]; Kuniyoshi Tabata[3]; Naofumi Ohnishi[2]; Kimiya Komurasaki[3]; Keishi Sakamoto[1]
[1]National Institute of Quantum and Radiological Science and Technology, Japan; [2]Tohoku University, Japan; [3]the university of Tokyo, Japan
The propagation velocity of developing breakdown plasma head generated on the straight beam was measured for 203 GHz / 170 GHz / 137 GHz using a multi-frequency gyrotron. As a result, the propagation velocity has small dependence on frequency.

10:15 - 12:00 **Fr-A2-4 Ultrafast Measurements II** **Room 432**
Session Type: Oral

10:15 **[Keynote] Ultrafast Dynamics And Control In High-temperature Superconductors** **Fr-A2-4-1**

Richard Averitt
UC San Diego, United States
We have investigated nonequilibrium superconductivity in c-axis oriented crystals of of La2-xBaxCuO4. We utilize the c-axis electromagnetic response to monitor the superconductivity following short pulse excitation. We observe a long-lived state upon photo-induced collapse of the stripe-ordered phase. The spectroscopic signatures are consistent with an inhomogeneous response containing photo-induced regions of enhanced condensate density.

10:45 **[Keynote] Coherent And Incoherent Dynamics Of Charge-transfer Excitons** **Fr-A2-4-2**

Philipp-Henrik Richter[1]; Markus Stein[1]; Christian Lammers[1]; Christian Fuchs[1]; Wolfgang Stolz[1]; Martin Koch[1]; Osmo Vänskä[1]; Maria J. Weseloh[1]; Mackillo Kira[2]; Stephan W. Koch[1]
[1]Philipps-Universität Marburg, Germany; [2]University of Michigan, United States
We investigate the formation, decay and coherence properties of charge-transfer excitons (CTX) in a type-II quantum well sample. A distinct CTX resonance in the linear absorption spectrum allows the realization of resonant and off-resonant optical excitation conditions. By use of four-wave-mixing and optical pump-THz probe spectroscopy, we observe the charge transfer process and extract time constants for the coherent as well as the incoherent dynamics. Our experimental investigations include a direct comparison to regular type-I excitons, revealing pronounced disparities in their temporal evolution. Furthermore, they are corroborated by results from a predictive microscopic theory.

11:15 **Field Correlation Measurements Of Photon Modes With Sub-unity Photon Occupation Per Mode Inside A Fabry-Perot Cavity** **Fr-A2-4-3**

Ileana-Cristina Benea-Chelmus; Francesca Fabiana Settembrini; Giacomo Scalari; Jérôme Faist
Quantum Optoelectronics Group/ ETH Zuerich, Switzerland

The non-destructive nature of electro-optic sampling is exploited to study the first order coherence function of modesoscillating inside a cold Fabry Perot cavity with sub-unity photon occupation number per mode, where the vacuum fieldcontribution is similar to the thermal contribution. For this purpose, a fast electro-optic correlation setup has beenimplemented inside a cryogenic environment to suppress the thermal background. The Fabry-Perot cavity is constituted by thedetection crystal itself.

11:30 **Terahertz Nano-Streaking: Resolving Nearfields And Plasmon Propagation** **Fr-A2-4-4**

Georg Herink
Universität Bayreuth, Germany

We present the principles and recent applications of THz streaking spectroscopy at metallic nanostructures. The combination of strong THz near-fields with nonlinear photoemission enables novel schemes of femtosecond time-resolved detection at the nanoscale. Near-field THz-waveforms are sampled via nonlinear photoemission. We discuss the electron dynamics in strong THz-near fields with implications on the shaping of ultrashort electron pulses in the temporal and spectral domains, and on THz-induced field emission. Particularly, we present a recent application of streaking spectroscopy to clock the propagation and plasmonic nano-focusing of surface plasmon-polaritons (SPP) with sub-10 fs temporal resolution.

11:45 **Responsibility Of Plasma Current For The Generation Of The Highest Frequency Part Of Ultrabroadband Coherent Infrared Pulses With 200-THz Bandwidth** **Fr-A2-4-5**

Eiichi Matsubara[1]; Masaya Nagai[2]; Masaaki Ashida[2]
[1]Osaka Dental University, Japan; [2]Osaka University, Japan

We reveal that plasma current is essential not only for the generation low frequency part but also for that of highest frequency part of 150-200 THz by both experiment and simulation, examining the dependence of the generation efficiency on the pump fluence and thickness of nonlinear crystals. The contribution of four wave mixing is relatively minor in the frequency range.

12:15 - 12:45 **Closing Remarks** **Shirotori Hall**

Session Type: Others