Monday, August 24, 2015

08:45 - 09:15 **Welcome and Opening Remarks** — **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

09:15 - 10:45 **Plenary Session P1-P2** — **Lecture Theatre 1**

Chairpersons: Xuechu Shen;

09:15 **Reflections On The Early Days Of THz Spectroscopy** **P1**

Y. R. Shen

Early struggles in the development of THz spectroscopy are reviewed. The field, covering an important spectral region for material characterization, suffered badly from poor light sources and detectors in the old days, but blossomed rapidly after the arrival of femtosecond lasers. It provides another example how advances of laser technology revolutionize a field.

10:00 **Graphene Opto-electronics And Plasmonics For Infrared Frequencies** **P2**

Frank Koppens

Here, we present novel aspects of infrared photocurrent and plasmonics in graphene, with a focus on understanding the physical mechanisms of plasmon damping and infrared photovoltage creation [Badioli et al. 2014]. Both far-field and near-field microscopy as well as near-field and far-field photocurrent mapping are used to study the nanoscale interactions between infrared light, hot carriers and plasmon excitations. We report record-high optical field confinement while maintaing relatively high plasmon quality factors (>30)[Woessner et al. 2014].

11:15 - 12:45 **M1A - 05 - Spectroscopy and Material Properties I** — **Lecture Theatre 2**

Chairpersons: Jan Balzer;

11:15 **Wafer-scale Characterization Of Carrier Dynamics In Graphene** **M1A-1**

Jonas C D. Buron; Dirch H. Petersen; Peter Bøggild; Peter Uhd Jepsen

The electronic properties of single-layer graphene, such as surface conductance, carrier concentration, scattering time and mobility, can be characterized in a noncontact manner by THz time-domain spectroscopy. Standard spectroscopic imaging reveals the AC conductance over large areas with a few hundred μm resolution, and spectroscopic imaging on back-gated graphene allows for extraction of both the carrier concentration and the mobility. We find that spatial variations of the conductance of single-layer CVD-grown graphene are predominantly due to variations in mobility rather than in carrier concentration.

11:45 **Relativistic Doppler Frequency Up-conversion And Probing The Initial Relaxation Of A Non-Equilibrium Electron-Hole Plasma In Silicon** **M1A-2**

Fanqi Meng; Mark D. Thomson; Bo E. Sernelius; Hartmut G. Roskos

We demonstrate experimentally the relativistic Doppler frequency up-conversion of the THz pulses from the counter-propagating ionized plasma front in silicon. The observed frequency up-conversion can be well modeled by the 1D FDTD simulations if significant short scattering time (well below 10 fs) in the plasma is assumed. To further elucidate the scattering rate in the electro-hole plasma, we performed pump probe experiment employing ultra-broadband (150 THz) THz pulse. The results show the scattering time decreases from ~200 fs down to ~20 fs when the carrier density increases up to 10^19cm^-3, and then saturates for higher densities. Such scattering time dependence on plasma carrier density can be very well fitted by the Drude model for thermalized electron-holes, and the saturation behavior is attributed to electron-hole phase-space restriction as the plasma becomes degenerate. The resultant much shorter scattering time measured with non-thermalized plasma is in good accordance with the Doppler experiment, which demonstrates Doppler geometry an effective method for probing non-equilibrium plasma dynamics.

12:00 **Magneto Plasma Oscillations In N-InSb With FEL At Terahertz Radiations Revisited** **M1A-3**

Papori Gogoi; Dmytro Kamenskyi; Denis Arslanov; Hans Engelkamp; Jan Kees Maan; Britta Redlich; A. F. G. Van Der Meer

We have investigated the magneto transmission of the electron plasma in heavily doped InSb up to 33T, which shows field induced transparency modulated by quantum oscillations at helium temperature. Transmission was measured in the far infrared using a recently developed setup coupling terahertz radiation from FEL to a 33T magnet via a waveguide. The onset of the field-induced transparency and the period of the frequency-dependent transmission oscillations match with our calculations based on a classical magneto-plasma including multiple reflections and the Faraday effect. The additional features on transmission are correlated to the measured DC conductivity. Minima in conductivity caused by singularities in the density of states lead to maxima in the transmission. In the extreme quantum limit (above 20T) increase in conductivity with field causes damping of the transmission amplitude which is in complete contrast to semi classical results.

12:15 **IR-THz-MMW-LF Spectroscopy Of H2O Molecule Confined In Nano-Cages Of Crystal Lattice: Low-Energy Dynamics and Incipient Antiferroelectric Behavior** **M1A-4**

Victor Torgashev; Boris Gorshunov; Maxim Savinov; Christelle Kadlec; Filip Kadlec; Volodymyr Skoromets; Elena Zhukova; Victor Thomas; Dmitry Fursenko; Evgeniy Pestrjakov; Vladimir Uskov; Gil'man Shakurov; Reinhard Kremer; Anatoliy Prokhorov; Martin Dressel

Broadband (1 Hz to 10^14 Hz) dielectric response of water-containing beryl single crystals is measured at temperatures from 300 K down to 5 K, using a set of spectrometers: monochromatic frequency-domain spectrometer based on backward-wave oscillators, time-domain and Fourier spectrometers. The response determined exclusively by water molecules that are localized within nanosized crystalline cages is extracted, with the phonon contributions excluded. Infrared resonances caused by translational and librational movements of individual H2O molecules, as well as the intramolecular H2O vibrational modes are identified. Soft-mode behavior at THz frequencies is discovered that indicates incipient antiferroelectric behavior due to interacting dipole moments of water molecules.

12:30 **Terahertz Probing Of Surface Electron States In Topological Crystalline Insulators Pb1-xSnxSe** **M1A-5**

Svetlana Egorova; Sergey Ganichev; Vladimir Chernichkin; Lada Yashina; Evgeny Skipetrov; Ludmila Ryabova; Dmitry Khokhlov; Sergey Danilov

We suggest a method for detection of highly conductive surface electron states including topological ones. The method is based on measurements of the photoelectromagnetic effect using terahertz laser pulses. In contrast to conventional transport measurements, the method is not sensitive to the bulk conductivity. The method is demonstrated on an example of topological crystalline insulators Pb1-xSnxSe. It is shown that highly conductive surface electron states are present in Pb1-xSnxSe both in

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the inverse and direct electron energy spectrum.

11:15 - 12:45	**M1B - 14 - High-Field THz Wave Generation and Nonlinear THz Physics - 20 - Quantum Cascade Lasers - 21 - Gyro-Oscillators and Amplifiers** **Chairpersons: Alexander Shkurinov;**	**Lecture Theatre 3**

11:15 **Simultaneous Generation Of X-ray And Terahertz Radiation Produced By Intense Femtosecond Laser Pulses From Atomic Cluster Plasma** **M1B-1**

Alexander Shkurinov; Alexey Balakin; Alexander Borodin; Marat Dzhidzhoev; Maxim Evdokomov; Mikhaïl Esaulkov; Vyacheslav Gordienko; Peter Solyankin

The present paper analyses the main mechanisms and properties of terahertz radiation generated by intense femtosecond laser pulses from gas and nanosize gas clusters. The possibilities of simultaneous generation terahertz and X-ray radiations are discussed and demonstrated experimentally. It was shown that optimal conditions for effective generation of terahertz and X-ray radiation are different. That makes possible to control the magnitudes of terahertz and X-ray signals simultaneously generated from gas nano-cluster jet. Controlling could be provided by means: by varying of time delay between laser pulse and cluster jet formation moment, or by varying of chirp parameter of laser pulses.

11:45 **Terahertz-Induced Crystallisation Of Amorphous Systems** **M1B-2**

Juraj Sibik; Nicholas Tan; Denis Arslanov; Wim Van Der Zande; Britta Redlich; Axel Zeitler

We performed initial experimental studies on inducing crystallisation in amorphous organic compounds with intense terahertz radiation generated by the free electron laser FLARE of the FELIX Laboratory. By performing careful experiments we minimized the role of thermal heating and show that there is a different behaviour between THz-induced and thermal-induced crystallisation.

12:00 **Development Of THz Range CW Gyrotrons At IAP RAS** **M1B-3**

Mikhail Glyavin; Alexey Chirkov; Gregory Denisov; German Golybyatnikov; Andrey Fokin; Andrey Kuftin; Vladislav Kholoptsev; Alexey Luchinin; Vladimir Manuilov; Vladimir Malygin; Mikhail Morozkin; Mikhail Proyavin; Anton Sedov; Evgeny Sokolov; Elena Soluyanova; Evgeny Tai; Aleksander Tsvetkov; Vladimir Zapevalov

The CW/263 GHz gyrotron is developed at IAP RAS for future application as microwave power source in DNP/NMR spectrometers. The new experimental facility with computerized control was built to test this and subsequent gyrotrons. The maximum power up to 1 kW in 15 kV/0.4A operation regime has been obtained. The power about 10W, which looks enough for spectroscopy, was realized in low current 14 kV / 0.02A regime. The possibility of frequency tuning with variation of coolant temperature about 4 MHz / 1 degree was demonstrated. The spectrum width of the gyrotron is about 10^-6. Next tubes with frequencies 527 GHz and 790 GHz are under development.

12:15 **Threshold Conditions Of Quasicontinuous Terahertz Optical Discharge In Gases** **M1B-4**

Vitaly Kubarev; Oleg Shevchenko; Yaroslav Getmanov; Pavel Koshlakov

Threshold conditions of quasicontinuous terahertz optical discharge in five atmospheric gases were measured exactly by the Novosibirsk terahertz free-electron laser (THz NovoFEL) at wavelength of 130 μm (2.3 THz). Comparison of our breakdown data with the data in other experiments and calculations based on a classical theory of microwave electron heating was made. Accuracy of our experiment (± 20%) was much better than one of previous experiments in terahertz range.

12:30 **Waveguide-integrated Terahertz-frequency Quantum Cascade Lasers For Detection Of Trace-gas Species** **M1B-5**

Rui Dong; Alexander Valavanis; Edmund Linfield; Paul Dean; Li Chen; Lianhe Li; Iman Kundu; Yingjun Han; Alexander Davies; Jingxuan Zhu; Brian Ellison; Luke Bushnell; Matthew Oldfield

Abstract--We demonstrate high-performance THz QCLs lasing at 2.2, 2.53, 3.5 and 4.7 THz, which target absorption lines of water, methane, hydroxyl and atomic oxygen respectively. Reliable single-mode targeting of gas species is obtained through the use of a photonic lattice design. A highly reproducible micro-machined waveguide block yields narrow beam-divergence and enables future integration of a complete THz heterodyne system including local-oscillator, mixer, and feed-horn.

11:15 - 12:45	**M1C - 16 - MMW systems, Transmission Lines and Antennas I** **Chairpersons: Nuria Llombart-Juan;**	**Lecture Theatre 4**

11:15 **On-chip Terahertz Spectroscopy Of Liquid Mixtures** **M1C-1**

Matthew Swithenbank; Christopher Russell; Andrew Burnett; Lianhe Li; A. Giles Davies; John Cunningham; Edmund Linfield; Christopher Wood

We demonstrate 'through-substrate' sensing of fluids for application in the terahertz spectroscopy of biological materials. This technique employs planar Goubau lines with integrated photoconductive material, formed on a flexible, thin polyimide substrate, and bonded to a microfluidic channel. Few-picosecond pulses are used to probe liquid samples confined within the channel, over a total interaction length of 4 mm, overcoming water-absorption limitations of free-space terahertz transmission measurements.

11:45 **Development And Test Of A Millimeter-wave MW-power Bolometric Load For CW Gyrotrons And High-power Transmission Lines** **M1C-2**

Alex Bruschi; William Bin; Koji Takahashi; Fabio Dell'Era; Ryosuke Ikeda; Daniele Minelli; Antonio Nardone; Yasuhisa Oda; Keishi Sakamoto; Alessandro Simonetto; Nicolò Spinicchia

The development of high-power dummy loads with calorimetric capabilities started in IFP with short pulse loads and continued with the design of a 2MW CW load in the frame of EGYC Consortium activities on the development of the European Gyrotron for ITER, coordinated by F4E. The loads are characterized by a spherical shape, with the cavity internal surface coated by a ceramic absorber. Special care has been devoted to the design of the power distribution on the surface and on the selection of the coating thickness. For the CW version, the cooling channels cover completely the external surface, for a fast heat removal. A prototype load with partial coating of the internal surface has been tested successfully in pulses up to 300 sec. at the 170 GHz JAEA ITER transmission line test bed, proving the capability of a full-coated version at power levels exceeding 1 MW. Load design and test results are discussed.

12:00 **Design Of Planar Antennas For The Superconducting Terahertz Detector** **M1C-3**

Mei Yu; WeiWei Xu; DeYue An; MingYi Zhang; YingChao Xu; JIAN CHEN; PEIHENG WU

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

The heart of the integrated antenna and detector is the matching network between them. In this paper, four type antennas for matching the small impedances of high temperature superconducting terahertz detectors at 650GHz are proposed. And the antenna arrays are designed to harvest more energy from the space. The resonant property and the coupling efficiency are measured by the terahertz time-domain spectroscopy (THz - TDS) system. And the coupling efficiency could be improved by the using of high temperature superconducting YBa2Cu2Ox (YBCO) Josephson junction detector by these antennas.

12:15 **Study Of Radiative Losses Of Terahertz Surface Plasmons On Plane Metal-dielectric Interfaces** **M1C-4**

Vasily Gerasimov; Boris Knyazev; Alexey Nikitin; Alexey Lemzyakov

Radiative losses of terahertz surface plasmons (SPs) on plane metal-dielectric interfaces have been studied. Experiments performed with "gold - zinc sulfate - air" plane structures at a 130 μm wavelength have shown that a thin-film dielectric coating of the metal of about λ/500 thickness could double the SP propagation length. In addition, an optimal dielectric layer thickness corresponding to the minimum total SPs energy loss has been found. Experiments with two sets of samples of different quality of preparation combined with atomic force microscopy surface characterization demonstrated the influence of surface structure (roughness, grain, layer thickness uniformity) on the propagation length and optimal dielectric layer thickness.

11:15 - 12:45 **M1D - 08 - Sources, Detectors, and Receivers I** **Lecture Theatre 6**

Chairpersons: Christopher Matheisen;

11:15 **Room-temperature, High-gain, Broad-spectrum InAs Nanowire Infrared Photodetectors** **M1D-1**

Weida Hu; Peng Wang; Pingping Chen; Xiaoshuang Chen; Wei Lu

In this paper, we review our recent progress on low dimensional room-temperature, high-gain, and broad-spectrum photodetectors based on InAs nanowires. Several novel infrared photodetectors based on InAs NWs are fabricated showing a high photo-gain at room temperature. It shows that majority carriers contributing one-dimensional photocurrents in core shell-like InAs photodetectors. This new phenomenon and related properties will pave a way to enable novel high-sensitive broad-spectrum room-temperature detection. These interesting nanoscale infrared photodetectors may provide potential applications in photonics, optoelectronics, and their integrated systems.

11:45 **Sum-frequency-generation Based Terahertz Detection Using A Periodically Poled Lithium Niobate** **M1D-2**

Kouji Nawata; Takashi Notake; Hideki Ishizuki; Yuma Takida; Yu Tokizane; Takunori Taira; Hiroaki Minamide; Shinn'ichiro Hayashi; Zhengli Han

Optical frequency up-conversion based on sum frequency generation is a promising technique for efficient single-photon detection because of low optical noise and high quantum efficiency of commercially available detectors. Single-photon detection in the near infrared and visible range has been demonstrated. In frequency translation, signal photons (at angular frequency ωs) interact with a strong pump (ωp) to produce converted photons (ωc), where ωc = ωp + ωs for up-conversion. Much noise photons caused by spontaneous Raman scattering and spontaneous parametric down-conversion due to strong pump light have the frequency less than that of the pump light. Therefore, sum frequency generation has strong advantage for low noise photon detection. In the recent decade, terahertz (THz) technologies have demonstrated single-photon detection with ultra-low noise equivalent power (NEP) operating in cryogenically cooling temperature. The THz single-photon detectors have opened up a new field such as photon-counting THz imaging and sub wavelength high-resolution passive THz microscopy. A THz single-photon detector operating at room temperature is a strong tool for assisting the above THz applications. In this report, we demonstrated up-conversion detection based on sum frequency generation to terahertz-wave region using a periodically poled lithium niobate (PPMgLN). One of the most suitable nonlinear crystals for wavelength conversion from terahertz (THz) to near infrared (NIR) is the lithium niobate crystal thanks to its large figure of merits. We have investigated sensitive THz detection based on parametric down-conversion process using a bulk and a PPMgLN crystal. Sum frequency generation is another way for sensitive THz detection and a promising technique as a single-photon detector in THz frequency region operating at room temperature.

12:00 **Electro-optic Sampling Of Terahertz Pulses Using BaTiO3 In Non-collinear Cherenkov Phase-matching Scheme** **M1D-3**

Shinpei Ozawa; Taka-aki Hori; Syougo Azuma; Stefan Funkner; Gudrun Niehues; Kohji Yamamoto; Takashi Furuya; Hideaki Kitahara; Gabriel Banciu; Liviu Nedelcu; Elmer Estacio; Michael Bakunov; Masahiko Tani

In this paper we report electro-optic (EO) sampling of THz pulses using ferroelectric crystal in the non-collinear Cherenkov phase-matching scheme, where an effective velocity matching is achieved in an EO crystal with a large refractive index in the THz frequency region. We demonstrate efficient THz EO sampling using LiNbO3 and BaTiO3 crystals in the Cherenkov-phase-matching scheme. It is shown that the efficiency of EO sampling with BaTiO3 is smaller than that with LiNbO3, even though the EO coefficient (r33) of BaTiO3 is three times higher than that of LiNbO3. The reason of the poor performance of BaTiO3 is attributed to the strong absorption in the THz frequency region.

12:15 **Compact Submillimeter-wave Multi-pixel Local Oscillator Sources** **M1D-4**

Imran Mehdi; Jose Siles; Choonsup Lee; Robert Lin

Successful implementation of single-pixel tunable frequency-multiplied sources for the 1-2 THz regime was an enabling feature for the HIFI instrument onboard the Herschel Space Observatory. Single pixel passive, as well as active systems, start to hit fundamental limits when used in a scanning or imaging mode. The next generation of heterodyne instruments that have been proposed or are under consideration will relay on array receivers to increase science return but will still require broadband performance. However, extending the approach towards a large pixel systems based on the current state of Submm-wave components is not practical or even feasible. We present a novel approach that utilizes silicon micro-machining along with 3-D interconnect technology to fabricate complete Submm-wave radiometers on a stack of semiconductor wafers. The individual semiconductor wafers in the stack allow one to optimize and select the most appropriate technology thus enhancing system-level performance. The basic concept along with preliminary results and designs from 100 to 600 GHz will be presented. This technique allows one to package GaAs Schottky diodes, InP based power amplifier MMICs, and novel micro-lens based antennas all in a stack of thin wafers enabling a low-mass super-compact radiometer. The talk will focus on presenting some of the challenges and opportunities in developing this technology.

12:30 **Fully Integrated Vertical Nanocontact Photomixer For Continuous-wave Terahertz Generation** **M1D-5**

Shihab Al-Daffaie; Oktay Yilmazoglu; Franko Küppers; Hans Hartnagel

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

A new type of a fully integrated vertical nanocontact THz photomixer was fabricated on LTG-GaAs / n+GaAs / SI-GaAs wafer with a single silver nanowire of Ø60 nm. The new vertical structure provides simple fabrication steps and better performance in terms of stability and antenna integration. The THz output power itself can be increased due to high photocurrent of 7.5mA and small device capacitance of 0.6 fF.

11:15 - 12:45 **M1E - 21 - Gyro-Oscillators and Amplifiers I** **Lecture Theatre 7**

Chairpersons: Tani Masahiko;

11:15 **Theoretical And Experimental Investigations On The Coaxial Gyrotron With Two Electron Beams** **M1E-1**

Shenggang Liu; Diwei Liu; Yang Yan; Sheng Yu; Wenjie Fu

Theoretical and experimental investigations on the coaxial gyrotron with two electron beams has been carried out. The output power is measured with a calorimeter. The operating frequencies are measured with a detector and a frequency mixer simultaneously. The experimental results agree well with the theoretical predictions. The quasi-optical mode convertor for dual-frequency operation coaxial gyrotron with two electron beams to separate the output power with two different frequencies efficiently is designed.

11:45 **Evaluation Of Experimentally Measured Non-stationary Oscillations In Gyrotrons Using Adequate Simulation Methods** **M1E-2**

Falk Braunmueller; Stefano Alberti; Trach-Minh Tran; Jérémy Genoud; Quentin Vuillemin; Jean-Philippe Hogge; Minh Quang Tran

In order to properly simulate cases in which gyrotrons exhibit fast temporally varying oscillations, such as non-stationary oscillations or possible dynamic After-Cavity Interaction (ACI), an adequate model for the beam-wave interaction has to be used. We will show that the commonly used assumption of considering a constant wave-field envelope during the electron transit time has to be abandoned. The appropriate model (reduced 1D Particle-In-Cell (PIC) model) is briefly presented and the implications of using an inadequate model are illustrated. For the case of a 150W/260GHz gyrotron, non-stationary simulations with the new model will be compared to experiment and used in order to investigate the underlying mechanism of these oscillations.

12:00 **Discrete Frequency Hopping In Long-Pulse High-Power Gyrotrons** **M1E-3**

Andreas Schlaich; Stefan Illy; Gerd Gantenbein; Manfred Thumm; John Jelonnek

Careful investigation of the RF oscillation frequency generated by MW class long-pulse 140 GHz gyrotrons for the Wendelstein 7-X (W7-X) stellarartor found discrete frequency hopping in steps of 5-10 MHz during the initial frequency down-tuning as well as in long-pulse "quasi" steady-state operation. The classical explanation for this behavior, such as electron beam acceleration voltage ripple and the classical long-line effect of the load, are reviewed, and are found not to match to the experimental observations. As alternative hypotheses we propose a long-line effect involving multiple internal reflections, or small discrete changes in the effective cavity radius, caused by discontinuous thermo-mechanical expansion.

12:15 **Design And Testing Of A 900 KW, 140 GHz Gyrotron** **M1E-4**

Stephen Cauffman; Monica Blank; Philipp Borchard; Kevin Felch

A 140 GHz gyrotron capable of producing output powers up to 900 kW for 1000-second pulses has been developed at CPI. Factory testing demonstrated 1000-second operation at the CW current limit of the test facility, at which the output power was about 500 kW, as well as 900 kW operation for short pulses. The gyrotron was then shipped to Hefei, China, and installed as part of the electron cyclotron heating and current drive system for the EAST tokamak. As of July, 2015, commissioning of the gyrotron at the EAST site has begun, with the goal of demonstrating operation at full parameters (900 kW for 1000-second pulses).

12:30 **Broadband THz Gyrotron Based On A Pulse Magnet** **M1E-5**

Pu-Kun Liu; Li Luo; Chao-Hai Du

This paper presents the recent development of a 0.33 THz pulse gyrotron, operating on the fundamental harmonic co-rotating mode. It employs a novel pre-bunched interaction circuit. The pulse magnet generates a time varying magnetic field to tune the radiation frequency via backward wave interaction. The optimized system is capable of generating radiation power about 1 kW ~ 2 kW during 330 GHz ~ 340 GHz. The compact pulse gyrotron is promising in scientific research and industrial applications. THz radiation generated by gyrotron is applied to drive the dynamic-nuclear-polarization (DNP) enhanced NMR, which would greatly increase the high-field NMR sensitivity and bring revolution to the biomedical and material research. Until now, the gyrotron is the best available high-power THz source to drive DNP-NMR system. Furthermore, gyrotron with broadband capability is especially attractive for a series of advanced applications.In order to improve the tunable frequency bandwidth, the THz gyrotron reported in this paper selects a backward-wave interaction circuit to replace the traditional open cavity circuit. The system design is shown in Fig. 1(a). The system consists of a compact pulse magnet, a single-anode MIG, a broadband interaction circuit, and an internal mode convertor. The output power radiates through a broadband Brewster window. The overall size of the pulse gyrotron system is very compact, as small as 25 cm X 25 cm X 42cm. Fig. 1 (b) shows the magnet profile and the single-anode electron gun. The electron beam is accelerated by the voltage of 20 kV and current of 0.5 A. When the highest magnetic field changes between 12.3 Tesla ~ 13.3 Tesla, without any assistant magnet coils in the gun region, the pitch factor of the electron beam varies between 1.6 ~ 1.2, and the axial velocity spread varies between 3.5% ~ 2.0%. Generally speaking, the electron optical system guided by the pulse magnetic field maintains a concise configuration and the electron beam parameters are very suitable for broadband tunable gyrotron application.

14:15 - 15:45 **M2A - 09 - Imaging and Remote Sensing I** **Lecture Theatre 2**

Chairpersons: Kwai Man Luk;

14:15 **Recent Development Of Small Pixel Uncooled Focal Plane Arrays At IRay** **M2A-1**

Peng Wang; Hongchen Wang

Small pixel microbolometer technology has shown dramatic improvements in uncooled infrared focal plane arrays in recent years. The uncooled microbolometer makers have transitioned through smaller pitches about every six years while maintaining a noise equivalent temperature difference (NETD) of 20-50mK. IRay commercialized 25μm pixel pitch 640×512 and 384×288 uncooled infrared focal plane arrays (IRFPAs) and 20μm pixel pitch 640×512 and 384×288 IRFPAs in the past five years.

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Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Vanadium oxide (VOx) microbolometers incorporated in these products is depicted in this paper. A 17μm pixel pitch 640×512 uncooled IRFPA with NETD of less than 35mK is also presented. The detectors are designed to enhance its manufacturability, life time, and its reliability under shock and vibration to meet security applications and Driver's Viewer Enhancer (DVE) requirements.

14:45 **Terahertz Single Frequency Adaptive Holography With Large Depth Of Focus** **M2A-2**

Chao Li; Guangyou Fang

THz imaging has potential applications in various domains, such as nondestructive materials detection and security inspection. In single frequency THz holography, the 2D images are reconstructed with a fixed restoration range distance [1], which means the targets are assumed to be located in a plane and with a known and fixed distance. For practical applications, targets usually have surfaces with variant range distances, and the conventional single frequency holography no longer works due to its narrow depth of focus. In this paper, an adaptive focusing method based on the minimum entropy concept was proposed to realize THz single frequency holography with large depth of focus.

15:00 **THz Photoconductive Antenna Array Based Near Field Imaging** **M2A-3**

Mingguang Tuo; Jitao Zhang; Min Liang; Weiren Ng; Michael Gehm; Hao Xin

In this work, a 2 × 2 photoconductive antenna (PCA) array is used in a THz near field imaging setup as THz emitters while the sample is placed close to the antenna array (the antenna-sample distance is about 10 μm). A microlens array is used to couple and focus femto-second laser pulse onto each antenna. The response of a sample of gold pattern on quartz is measured. A FDTD model combined with HFSS simulation is used to predict the time domain current and near field scanning result. Good agreement between simulation and experiment is obtained.

15:15 **A 320GHz Low Drive Level Sub-harmonic Mixer Based On Quantum Barrier Junctions** **M2A-4**

Mussa Elsaadi; David Steenson; Ian Robertson; Viktor Doychinov

A sub-harmonically pumped (n=4) down conversion mixer, employing single quantum barrier junction in place of a Schottky pair, is designed and simulated using the symbolically defined device capability in ADS and transmission line optimisation using HFSS prior to fabrication. The performance in terms of conversion loss and LO power requirements are estimated and compared with state-of-the-art Schottky diode mixers. The intent was to explore a low drive level mixer with high conversion efficiency (minimum conversion loss) for potential use at sub-millimetre wave frequencies, where the device parasitic's, such as junction capacitance and series resistance have a marked effect on performance and where LO pump powers are often weak. The performance is explored via a design operating at 320GHz and showing a signal side band (SSB) conversion loss with 5.7dB, with only -9.5dBm (≈0.1mW) of LO power. The conversion loss is maintained below 10dB, even when using -8dBm to -11dBm of LO drive level, and the eventual aim of the work is to realize a similar design with an operating frequency of 640GHz for meteorological studies.

15:30 **High Resolution Terahertz Volume Inspection Using A Rectangular Dielectric Rod Antenna In Transceiver Configuration** **M2A-5**

Bessem Baccouche; Neda Baktash; Johannes Clemens; Anna Natale; Joachim Jonuscheit; Fabian Friederich

Ultra wide-band frequency-modulated continuous-wave imaging systems operating in the lower terahertz regime have proven to be highly desirable for non-destructive testing applications. However, either quasi-optical configurations or the characteristics of typically used antennas as well as temperature- dependent nonlinear frequency sweeps restrict the achievable spatial resolution and reliability of these systems. In this contribution we report on the implementation of a dielectric rectangular rod antenna and a software-assisted feedback control loop to overcome these limitations.

14:15 - 15:45 **M2B - 25 - Ultrafast Measurements I** **Lecture Theatre 3**

Chairpersons: Jianming Yuan;

14:15 **Terahertz Technology Into Attosecond Science** **M2B-1**

Zengxiu Zhao; Jianmin Yuan

Although differing in frequency by more than 6 orders of magnitudes, the attoseond burst and THz emission from two-color laser pulses are found both related to the sub-cycle electron dynamics and can be coherently controlled on the equal footing. Through synchronization, the generation of terahertz waves has been clocked in attosecond precision from the intrinsic chirp of high harmonics in our previous work. In this talk we will further discuss how they are correlated for aligned molecules. Then we will show that by manipulating the polarization of the two-color laser pulses, the polarized THz waves can be used as a sensitive indicator of the tunneling time-delay, a fundamental yet debatable concept in attosecond physics. Finally we conclude that blending attosecond physics with THz technology could advance both fields and yield unprecedented understanding of other ultrafast processes.

14:45 **Understanding Charge Carrier Dynamics In Solar Cell Materials Using Time Resolved Terahertz Spectroscopy** **M2B-2**

Villy Sundström; Carlito Ponseca

The need for developing highly efficient solar cell devices have never been so pressing until recently when the urgency of using renewable energy sources becomes more evident. There are several promising technologies being explored by many groups with the sole purpose of optimizing harvesting sunlight and converting it to useful electricity. These include, but not limited to, dye- and quantum dot-sensitized, bulk heterojunction organic, inorganic nanowires, and very recently perovskite-based solar cells. In this talk, charge carrier dynamics of an assortment of solar cell technologies probed using time-resolved terahertz spectroscopy will be presented. Electron injection, mobility, charge carrier lifetime and recombination dynamics will be discussed

15:15 **Single Shot Measurement of THz pulses based on Pulse Front Tilting by reflective grating** **M2B-3**

Jiang Li; Zhaohui Zhai; Sencheng Zhong; Kun Meng; Lianghui Du; Qiao Liu; Liguo Zhu; Qixian Peng; Zeren Li

A femtosecond pulse with tilted intensity front generated by a reflective grating were used as the probe beam for the single shot measurement of THz pulses with high frequency resolution and low distortion. The time window is up to 20 ps and spectrum range covers 0.1-2.5 THz. The result agrees well with the traditional electrical-optic sampling method.

15:30 **Simple And Distortion Free Optical Sampling Of THz Pulses Near Zero Optical Transmission Point** **M2B-4**

Marion Cornet; Jérôme Degert; Emmanuel Abraham; Eric Freysz

A simple and distortion free method to sample THz pulse in zinc-blende crystal is proposed and experimentally demonstrated in <110> cut ZnTe. A comparison of its performances with other techniques is given.

08:45 - 09:15 **Welcome and Opening Remarks** — **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

14:15 - 15:45 **M2C - 14 - High-Field THz Wave Generation and Nonlinear THz Physics I** — **Lecture Theatre 4**

Chairpersons: Gian Piero Gallarano;

14:15 **Evolved Injection Seeded THz-wave Spectrometer For Mail Inspection** **M2C-1**

Kodo Kawase; Ryo Yamazaki; Kazuki Imayama; Kosuke Murate

In 2003, we demonstrated a non-destructive terahertz spectroscopic imaging of illicit drugs hidden in envelopes using a widely tunable THz-wave parametric source, though its dynamic range at that time was less than four orders. Recently, we have realized ten orders of dynamic range with an evolved injection seeded THz-wave spectrometer. Now we can detect drugs under much thicker obstacles than before. In this report, we introduce related topics; 1) Enhanced tuning range up to 4.7 THz, 2) >90dB dynamic range THz detection using near infrared detector, 3) Comparison between is-TPG spectrometer and TDS, and 4) THz-wave amplifier.

14:45 **Tunable Nonlinear Optical Response Of Silicene In Terahertz Regime** **M2C-2**

Yee Sin Ang; Matthew Sanderson; Chao Zhang

The nonlinear optical response of silicene in terahertz (THz) regime is theoretically studied. Since the intrinsic spin-orbit coupling gap of silicene is in the order of 1 THz, the optical response in few THz frequency regime is strongly enhanced by linear and nonlinear conductivity peaks. Furthermore, these conductivity peaks are gate-tunable. The frequency-tripling nonlinear optical current can be significantly larger than the single-frequency current under a moderate electric field strength of 1000 V/cm. This suggests that tunable strong THz frequencytripling effect can be achieved in silicene.

15:00 **THz Pulses Up To Millijoule From Organic Crystal Pumped By A Cr:Fosterite Laser** **M2C-3**

Carlo Vicario; A. V. Ovchinnikov; Mostafa Shalaby; S. I. Ashitkov; Christoph P. Hauri

We present a table-top THz source based on organic crystal emitting single-cycle transients at frequencies of 0.1-5 THz with electric and magnetic fields at the focus larger than 40 MV/cm and 14 Tesla. The source is realized by optical rectification in recently developed 4 cm^2 partitioned DSTMS pumped by 30 mJ Cr:Mg2SiO4 (Cr:F) laser, for details see. With respect to optical parametric amplifier used in the past to drive the organic crystal, the Cr:F laser offers one order larger energy and which turns into THz pulse energy as large as 900 μJ and energy conversion efficiency of 3 %.

15:15 **Efficient Generation Of Terahertz Radiation At 800 Nm Wavelength** **M2C-4**

Xiaojun Wu; Sergio Carbajo; Koustuban Ravi; Wenqian Huang; Shaobo Fang; Frederike Ahr; Giovanni Cirmi; Giulio Rossi; Oliver Mücke; Franz Kärtner

Highly efficient generation of strong-field terahertz (THz) pulses by using very short laser pulses ~30 fs has some challenges due to chromatic aberrations. Here, we demonstrate an optical-to-THz conversion efficiency of 0.2% using a 3 mJ pump pulse energy. This result paves the way for strong-field applications of THz radiation. Commercial Ti:sapphire laser systems delivering more than 20 mJ output pulse energy at the central wavelength of 800 nm with 150 fs pulse width is appropriate for table-top, compact terahertz (THz) sources [1]. The expected maximum THz output pulse energy can be scaled up to ~100 μJ, when employing optical rectification using tilted-pulse-fronts (TPF) and cryogenic cooling to mitigate THz absorption in the lithium niobate crystal. We have already demonstrated 0.2% optical-to-THz energy efficiency by using 150 fs Ti:sapphire laser pulses. In order to further scale up the THz output energy from the μJ to mJ-level, customized Ti:sapphire systems delivering J-level output pulse energy are promising. However, this kind of laser system has an extremely broadband infrared spectrum. When these ultrashort laser pulses (30 fs) are used for THz generation with the conventional TPF technique, there are several limitations [2]: (i) Effective interaction length for efficient THz generation will be shorter than longer pulses (150 fs). (ii) The diffracted optical beam from the grating will be expanded to an unmanageably large size due to the large bandwidth. (iii) Different spectral components will be imaged into different spatial volumes in the crystal. We systematically investigate different imaging schemes including one concave mirror (f=-100-mm), two concave mirrors (f1=-200 mm, f2=-100 mm) and one bi-convex lens (f=60 mm) for THz generation using TPF in lithium niobate driven by 30 fs Ti:sapphire laser pulses. The best results of 6 μJ THz output energy, 0.2% optical-to-THz conversion efficiency with 20 MV/m electric field in lithium niobate at room temperature pumped at 3 mJ is achieved from the simplest scheme with one bi-convex lens as the imaging element, shown in Fig. 1 (a). As exhibited in Fig. 1 (b) and (c), the single-cycle THz pulse holds a peak frequency at 0.32 THz. The maintenance of 0.2% optical-to-THz efficiency from 150 fs to 30 fs is helpful for scaling up THz output energy from μJ to mJ-level when employing J-level ultrashort Ti:sapphiure laser pulses. Future work will be focused on cryogenic cooling of the generation crystal, improving out-coupling of the THz pulse at the interface of lithium niobate and air, newly designing the generation lithium niobate crystals, trying contact-grating method to make a linear generation geometry, and finally scaling up the output THz energy by impinging the generation crystal with J-level laser pulses for THz generation.

15:30 **THz Induced Nonlinear Absorption In ZnTe** **M2C-5**

Pernille Klarskov; Peter Uhd Jepsen

Terahertz (THz) systems are widely used for studies of lowest vibrational modes in crystalline materials. At the same time, the possibility of generating THz field strengths on the order of MV/cm with table-top THz systems has enabled nonlinear studies of intermolecular vibrational modes as well as carrier dynamics. ZnTe is an example of a semiconductor, which is often used both for coherent generation and detection of THz pulses due to its high second-order nonlinearities. ZnTe has a number of low-frequency phonon modes below the fundamental TO phonon mode at 5.4 THz, particularly the two bands around 1.6 and 3.7 THz originating from difference frequency modes from longitudinal and transverse optical and acoustic phonons (LO, TO, LA and TA). Here, the absorption spectrum of these phonon modes is investigated when the incident field strength is increased to several MV/cm using a DSTMS THz source and air-biased coherent detection in order to cover the desired bandwidth from 1 to 4 THz.

14:15 - 15:45 **M2D - 12 - Devices, Components, and Systems I** — **Lecture Theatre 6**

Chairpersons: Edmund Linfield;

14:15 **Millimeter And Sub-terahertz Wave Generation With An On-chip Colliding Pulse Mode-Locked Laser Diode.** **M2D-1**

Carlos Gordón; Robinson Guzmán; Xaveer Leijtens; Guillermo Carpintero

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

We report the generation of millimeter and sub-terahertz waves with an on-chip colliding pulse mode-locked laser diode (OCCP-MLLD) by using two different approaches. The first approach is the pulsed source method based on an OCCP-MLLD structure that allows on-chip integration using multimode interference reflectors (MIRs). The OCCP-MLLD is capable of generating a carrier at 70 GHz due to the colliding pulse mode locking regime. The second approach is the optical heterodyning method using an on-chip colliding pulse mode-locked laser with an arrayed waveguide grating optical filter (OCCP-AWG). The OCCP-AWG provides a carrier at 90 GHz by filtering two optical modes.

14:45 **Ultra-broadband Terahertz Perfect Absorber** **M2D-2**

Xiaofei Zang; Cheng Shi; Yan Peng; Yiming Zhu

We propose three kinds of ultra-broadband terahertz (THz) perfect absorbers by fabricating gratings on heavily boron-doped silicon substrate. By optimizing the doping density, the absorption bandwidths are 1 THz, 1.5 THz, and 2.0 THz, respectively, with absorbance above 95%. The fundamental principles are mainly attributed to the antireflection effects, the grating diffractions and the air gap-mode resonance.

15:00 **3D-printed Dielectric Helical THz Waveguides** **M2D-3**

Dominik Vogt; Rainer Leonhardt

We report on a 3D-printed helical waveguide to increase the bandwidth of a low-loss dielectric tube Terahertz (THz) waveguide. The helical design prevents the multiple reflections in the tube cladding hence avoiding the pronounced resonance pattern in the attenuation spectrum of a dielectric tube waveguide. Both THz time-domain spectroscopy (THz-TDS) measurements and finite-difference time-domain (FDTD) simulations consistently confirm the extended bandwidth of the dielectric helical waveguide.

15:15 **Wideband Sensitive THz Core For Application Integration** **M2D-4**

Luc Mercier; Mathieu Demers; Marc Terroux; Yan Desroches; Bruno Fisette; Francis Généreux; Denis Dufour; Patrick Beaupré; Linda Marchese; Christine Alain; Patrice Topart; Alain Bergeron

A new compact THz camera core is introduced. The high sensitivity broadband FPA is combined to a very low noise level electronics. With its high acceptance angle the FPA can be used with new fast optical elements making it an ideal tool for prototyping applications.

15:30 **Terahertz Radiations From Triple Junction Solar Cells Excited By Wavelength-Tunable Laser Pulses** **M2D-5**

Toshihito Umegaki; Shota Hamauchi; Yuji Sakai; Akira Ito; Hidetoshi Nakanishi; Iwao Kawayama; Hironaru Murakami; Masayoshi Tonouchi

We observed waveforms and images of THz radiations from a triple-junction-solar-cell (TJSC) with InGaP-GaAs-Ge layered structure excited by wavelength-tunable laser pulses, and wavelength-dependent THz signals and images could be observed. The results indicate that characteristics of an each layer in TJSC can be extracted with this system.

14:15 - 15:45 **M2E - 11 - Metamaterial Structures and Applications I** **Lecture Theatre 7**

Chairpersons: Tiejun Cui;

14:15 **A Flexible And Conformal THz Coding Metamaterial** **M2E-1**

Weiwei Liu; Biaobing Jin; Tiejun Cui; Peiheng Wu

Control of terahertz (THz, 1 THz=10^12 Hz) wave is still a big challenge in the THz community. We present here a flexible coding metamaterial, which is composed of "0" and "1"elements, i.e., 1-bit coding case, to shape the reflection and scattering of THz wave. The far-field patterns can be varied by adjusting the digital sequence. We also demonstrate a low-reflection-and--scattering metamaterial, which show a reflectivity less than -10 dB in a wide THz range. Since this metamaterial is made of flexible substrate, it can be conformal to the object, which indicates a widespread application.

14:45 **Electromagnetic Wave Funneling Through Lambda /10,000,000 Nanogaps For Microwave Regime** **M2E-2**

Kwanghee Lee; Jeeyoon Jeong; Jiyeah Rhie; Youngmi Bahk; Daisik Kim

We observe microwave funneling through few nanometer-wide gap arrays. Nanogaps having rectangular ring shaped geometries are fabricated by atomic layer lithography technique. Microwave transmittance in 10~40 GHz range is measured by vector network analyzer (VNA) connected with pairs of rectangular waveguides supporting TE10 mode. The peak transmittance of 2 nm width gap is about 45% and it corresponds to the electric field enhancement factor of over 10,000. Terahertz transmittance is also measured by time domain spectroscopy to further verify the funneling phenomena in microwave regime.

15:00 **Switchable Terahertz Metamaterials: Using The Insulator-Metal Transition Of Vanadium Dioxide To Activate Metamaterial Properties** **M2E-3**

Fei Yan; Edward Parrott; Georges Humbert; Aurelian Crunteanu; Emma Pickwell-MacPherson

Terahertz (THz) metamaterials have recently attracted much interest due to their ability to tune propagation properties using sub-wavelength structures. In this paper we demonstrate the first metamaterial device developed by patterning a vanadium dioxide (VO2) wire-grid structure onto a c-sapphire substrate. Temperature and polarization dependent THz time-domain spectroscopy transmission measurements are taken for 10/1 μm and 10/2 μm (period/width) wire-grid gratings to evaluate the device performance as a function of the metamaterial parameters. The normalized amplitude transmission of the 90° oriented wave remains ~100% for both VO2 wire-grid gratings when the temperature increases from 60 to 80 °C. In contrast, the amplitude transmission of the 0° oriented wave decreases from ~100% to ~74% and ~37% for the 10/1 μm and 10/2 μm wire-grid grating, respectively. These VO2 wire-grids with micrometer scale period and width are to our knowledge the first metamaterials developed using only VO2 and have potential applications in active THz polarization modulators through optimization of the metamaterial parameters.

15:15 **Switchable Terahertz Metamaterials In Resonance Amplitude** **M2E-4**

Xiaoqiang Su; Quan Xu; Chunmei Ouyang; Jiaguang Han; Weili Zhang

Recently,the concept of artificially engineered materials,known as metamaterials, has provided access to an even broader range of novel functionalities. In particular, active control of meta-atoms induced resonances attracts much interest in realistic applications, such as sensing, ultrafast switching and slow light propagation, and various active schemes have been exploited to manipulate the properties of electromagnetic waves in metamaterial-based devices. Here, we experimentally and theoretically demonstrate three types of active metamaterials in Terahertz regime, two of which can be optically manipulated through integrating photosensitive silicon islands into the metamaterial building blocks and the third with high-doped silicon ingredient

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

can be electrically controlled. The unit cell of the first meta-device is comprised of two pairs of identical and gap opposite-directed U-shape split-ring resonators (SRRs), symmetrically placed on both sides of a central metallic bar resonator, in which the silicon islands connect the arms of the opposite U-shape SRRs. Attributed to the modification in damping rate in one of the resonance modes under optical excitation, the broadband transparency transmission window resulted from the mode coupling is dynamically modulated. The second active metamaterial sample with coaxial rectangle microstructures is also presented. Under optical excitation, multi-transmission-peak effect is dynamically switched. By carefully designing the position of silicon islands in the metamaterial unit cell, one or more transmission peaks can be dynamically modulated in amplitude. The unit cell of the third metamaterial consists of eight C-shaped split-ring hole resonators with identical resonance amplitude and gradual phase change, fabricated on a doped semiconductor substrate. The metamaterial arrays and the substrate together effectively form a Schottky diode, enabling the modulation of the terahertz transmission through controlling the external voltage. The schemes suggested here are promising to construct active terahertz devices and to realize on-to-off switching response of the terahertz radiation at room temperature.

15:30 **Terahertz Response Of Spherical TiO2 Microresonators Embedded In A Dielectric Layer** **M2E-5**

Michal Sindler; Christelle Kadlec; Hynek Němec; Filip Dominec; Petr Kuzel; Catherine Elissalde; Patrick Mounaix; Seu U-Chan Chung

Resonant frequency of TiO2 microparticles is controlled by their permittivity and dimensions, whereas it is almost independent on the filling fraction or on the permittivity of the surrounding dielectric medium. Paraffin and polyethylene were found to be suitable media for accommodating TiO2 microspheres, enabling their use as a durable metamaterial based on Mie resonance.

16:15 - 17:45 **M3A - 27 - Metrology I** **Lecture Theatre 2**

Chairpersons: Seongsin Margaret Kim;

16:15 **Improved Algorithm For Material Characterization By Terahertz Reflection Imaging** **M3A-1**

Shuting Fan; Edward Parrott; Benjamin Ung; Emma Pickwell-MacPherson

We propose a new algorithm to improve the accuracy of sample characterization when the sample is measured on the imaging window of a terahertz reflection imaging system. Most existing approaches assume that the imaging window is homogeneous, but we have noticed that there are small variations in thickness across such windows and that these can significantly affect the accuracy of standard approaches to extract the sample properties, particularly the absorption coefficient. Our algorithm accounts for both thickness variation across the imaging window as well as fluctuations in the incident pulse and mechanical jitter. Furthermore, our algorithm removes the need to measure the reference at every point that the sample is measured and thus reduces the imaging time.

16:45 **Design Of A WR-6 Thermoelectric Conversion Power Sensor** **M3A-2**

Chao Ma; Xiaohai Cui

In this paper, the thermoelectric conversion power sensor, which is the key part in the WR-6 (110 GHz -- 170 GHz) rectangular waveguide microcalorimeter, was designed and evaluated. The ANSYS simulation software was used to evaluate the quantitative relation between the THz power and DC power for the power sensor.

17:00 **Measurement And Simulation Of Heat Transfer Into A Human Skin Phantom** **M3A-3**

Oriano Bottauscio; Djamel Allal; Michele Borsero; Thorsten Schrader; Alireza Kazemipour; Luca Zilberti; Thomas Kleine-Ostmann; Michael Charles; Mario Chiampi

Reliable in-vitro millimeter and sub-millimeter wave exposure investigations need well characterized radiation sources, accurate phantom models and calibrated SAR/temperature-rising probes. A practical setup is presented for studies regarding the human skin exposure at frequencies above 30 GHz. A standard-gain horn antenna is used to provide a Gaussian beam and known field-intensity on the sample, together with an infrared camera to monitor the temperature variations. The measurement results, including uncertainty, are presented and compared with parametric numerical simulations of the temperature distribution in the gel phantom.

17:15 **A Comparison Of Terahertz Power Measurements At Sub-microwatt Levels** **M3A-4**

Hitoshi Iida; Moto Kinoshita; Kuniaki Amemiya; Yozo Shimada

In this paper, we compare absolute power measurements obtained at 1 THz using a newly proposed terahertz (THz) calorimeter and a commercial power meter. The experimental measurement was performed at a sub-microwatt level using a photomixer as the THz source. Using the calorimeter, we obtained highly sensitive measurement results with good accuracy at room temperature of 23°C, and there was good agreement with the result from the commercial power meter.

17:30 **Beam Profile Measurement Of THz Pulses In A TDS System** **M3A-5**

Yang Zeng; Andre Sarker Andy; Theo Kreouzis; Xiaodong Chen; Robert Donnan

Understanding the beam profile of a THz pulse in a TDS system is of great significance to high spatial resolution measurement and detection. The spatial distribution of the THz pulse is generally measured with a THz camera based on a bolometer array. However, by this method, only the amplitude of the THz beam is measured; phase information is lost. In this paper, a new method of THz beam profile measurement in TDS system is introduced.By measuring the THz beam field within a THz-TDS system, phase information is preserved. Beam parameters are calculated and compared with simulations results. Low frequency components are found out to be distributed more dispersed around the focal. High order modes of THz wave are also observed in the measurement. This work is of great significance for power calibration, high accuracy detection and high spatial resolution measurement with TDS technique.

16:15 - 17:45 **M3B - 03 - Applications in Security and Defense - 09 - Imaging and Remote Sensing** **Lecture Theatre 3**

Chairpersons: Rene Beigang;

16:15 **Can The Sub-THz Image Of Skin Be The New Fingerprint? Visions In Biometrics** **M3B-1**

Yuri Feldman; Paul Ben Ishai; Haim Goldberger; Alexander Puzenko; Ilya Gutman

The sub-THz reflectance of the Human palm was imaged while the person was subjected to varying degrees of stress. The pattern of individual pixel intensity and their correlation to stress matched the actual physical distribution of sweat pores on the hand surface. This fact is put forward as a possible novel biometric avenue.

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

16:45 **The Design, Construction And Measurement Of A Quasi-optical Multiplexer And Antenna For Space-borne Atmospheric Measurements From 56 To 425 GHz** **M3B-2**

Richard Wylde; Peter Ade; Stuart Froud; Stephen Hanham; Amber Hornsby; Lifei Jiang; William Otter; Kevin Pike; Carole Tucker; Adam Woodcraft; Zhenchao Xie; Hongxin Xu

We have developed a low-loss quasi-optical multiplexer (QOM) for future space-based meteorological radiometry covering nearly a decade of frequencies - from 54 GHz to 425 GHz. We have shown that very low loss can be combined with high channel co-alignment in a compact package, suitable for surviving the launch environment. The QOM uses shallow angle low-loss dichroic plates (DCP's) allowing polarization diversity and ultra-Gaussian horn feeds to minimize both component size and standing waves. The losses in the multiplexer were measured using a novel double path S11 VNA technique, and beam co-alignment was verified by scanning with a wideband detector.

17:00 **Towards Mm-wave Camera Assisted Human Stress Gauging** **M3B-3**

Evgeny Shumaker; Dan Corcos; Paul Ben Ishai; Ilya Gutman; Yuri Feldman; Alexander Puzenko; Danny Elad

Recent publications show strong correlation between the sub-THz reflection coefficient of a human skin and various stress related ECG parameters. The main hypothesis explaining the phenomenon is based on the coiled nature of human sweat ducts. The way to the development of disruptive commercial applications exploiting this phenomena, traverses through multi-pixel imaging of the human skin tissue (in the sub-THz range). Towards that goal, a fully integrated and packaged SiGe based total-power single pixel receiver (operating in the W-band) has been employed for human stress gauging in both reflectometric and radiometric modes. Initial (and quite encouraging) results are brought forth in this article.

17:15 **3-D THz Tomography With An InP HBT Signal Source And A SiGe HBT Imaging Receiver Operating Near 300 GHz** **M3B-4**

Daekeun Yoon; Jongwon Yun; Jungsoo Kim; Kiryong Song; Mehmet Kaynak; Bernd Tillack; Jae-Sung Rieh

In this work, 3-D THz tomography was demonstrated with an InP HBT signal source and a SiGe HBT imaging receiver. The signal source employs a common-base differential pair for an LC cross-coupled topology. It shows an output power of 5.3 dBm at 305.8 GHz. The receiver, which serves as an imaging detector in this work, is composed of a fundamental mixer, a local oscillator, an IF detector, and an on-chip antenna. It exhibits a responsivity of 322 kV/W and NEP of 3.9 pW/Hz^1/2 at 300 GHz. A set of sinograms was acquired with an imaging setup employing the fabricated source and detector, and 3-D tomographic images were reconstructed based on the inverse filtered backprojection algorithm from the acquired sinograms.

17:30 **Vector Characterization Of A Focused Terahertz Beam** **M3B-5**

Xinke Wang; Sen Wang; Yan Zhang

Vectorial properties of a focused terahertz (THz) beam are measured by using a THz digital holographic imaging system. The THz transverse and longitudinal polarization components around the focal point are obtained utilizing the detection crystals with different crystalline orientations. This imaging technique provides an effective method for presenting the vector diffraction process of the THz wave.

16:15 - 17:45 **M3C - 05 - Spectroscopy and Material Properties II** **Lecture Theatre 4**

Chairpersons: Charles Schmuttenmaer;

16:15 **Using Time-Resolved THz Spectroscopy To Study Carrier Dynamics And Solar Energy Conversion In Nanostructured Materials** **M3C-1**

Charles Schmuttenmaer

Terahertz (THz) spectroscopy has emerged over the last two decades as a versatile probe of a large variety of materials and processes. Because the transient THz electric field rather than its power is measured, frequency-dependent material properties such as absorption coefficient, refractive index, and complex conductivity in the far-infrared region of the electromagnetic spectrum are determined in a very straightforward manner. Optical-pump THz-probe studies characterize the photo-induced response of a material with sub-picosecond temporal resolution. One of the most important applications of time-resolved THz spectroscopy (TRTS) has been to probe transient photoconductivity and carrier dynamics in a variety of nanomaterials of interest in renewable energy research.

16:45 **Active Terahertz Modulations Based On Graphene-silicon Hybrid Structures** **M3C-2**

Quan Li; Xueqian Zhang; Zhen Tian; Ranjan Singh; Liangliang Du; Jianqiang Gu; Chunmei Ouyang; Jiaguang Han; Weili Zhang

We have experimentally demonstrated a graphene-silicon hybrid film that behaves as an efficient "diode" for the terahertz waves under simultaneous CW photoexcitation and DC bias voltage. The "terahertz diode" achieves a large modulation depth of up to 83% at a small negative gate bias voltage of -4 V. The active tuning behavior of the graphene-silicon hybrid film would enable promising applications in terahertz technology, such as communications, plasmonic engineering and graphene-based metamaterials.

17:00 **Modified Elastomeric Polymers For Loss Reduction In The Terahertz Range** **M3C-3**

Daniel Headland; Peter Thurgood; Daniel Stavrevski; Withawat Withayachumnankul; Derek Abbott; Madhu Bhaskaran; Sharath Sriram

A method of reducing the dielectric loss of polydimethylsiloxane (PDMS) in the terahertz range with dopants is presented. Samples of PDMS are doped with varied concentrations of polytetrafluoroethylene (PTFE) micro-particles, and characterized with terahertz time domain spectroscopy (THz-TDS) in order to extract their material properties. It is found that controlled doping can significantly reduce dielectric loss in PDMS at terahertz frequencies, and for the sample with highest dopant concentration, a 15.3% average reduction in loss tangent is demonstrated over a range from 0.3 to 1 THz. Measured material properties are compared with the Lichtenecker logarithmic mixture formula, and approximate agreement is attained.

17:15 **Photon-Assisted Tunneling Through Single Molecules Induced By Terahertz Radiation Enhanced In The Sub-nm Gap Electrodes** **M3C-4**

Kenji Yoshida; Kenji Shibata; Kazuhiko Hirakawa

Electron transport through single molecules is attracting considerable attention owing to their potentiality of utilizing a variety of molecular functions for electronics. So far, most of the works on the single molecule transport has been performed on their static properties and very little has been done on their dynamical transport. Typical energy scales in the single molecule transport lie mostly in the terahertz (THz) frequency range and interactions between THz fields and single molecules may well result in intriguing transport phenomena. Here, we report on electron transport in single C60 molecule transistors (SMTs) under

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

the illumination of monochromatic THz radiation at 2.5 THz with an intensity of a few tens mW. We have fabricated a sample structure that can focus the THz radiation onto a single molecule trapped in the nanogap electrodes. Under the THz radiation, the SMTs exhibit satellite conductance lines that arise from the photon-assisted tunneling (PAT). From the power dependence of the PAT conductance, we have found that the THz electric field induced across the nanogap electrodes exceeds 100 kV/cm, which is enhanced from its value in the free space by a factor of ~10^5.

17:30 **Spin And Lattice Excitations Of Multiferroic (Ba0.2Sr0.8)3Co2Fe24O41 In The THz Range** **M3C-5**

Filip Kadlec; Christelle Kadlec; Josef Bursík; Jakub Vít; Veronica Goian; Jan Prokleska; Martin Kempa; Fedir Borodavka; Stanislav Kamba

The materials with the Z-type hexaferrite structure belong to the rare examples of roomtemperature magneto-electric multiferroics which are expected to have a great technological importance in future electronic applications. The advantage of Z-type hexaferrites is a high resistivity, low permittivity and loss tangent at room temperature. At the same time, they exhibit a transverse conically ordered magnetic state up to ca. 400 K and, most of them, a uniaxial magnetic anisotropy parallel to the c axis. Their particular feature is the absence of ferroelectric polarization at zero magnetization. However, a polar state with space group P63mmc can be magnetically induced via the inverse Dzyaloshinski-Moriya interaction; it arises at very weak intensities of the magnetic field and persists up to ca. 1.5 T. The dynamical magnetic properties of Z-type hexaferrites are still largely unknown; they present a great interest both from the fundamental point of view and with respect to potential applications in memories and magnonics.

We have studied samples of (Ba0.2Sr0.8)3Co2Fe24O41 ceramics using time-domain THz transmittance and Fourier- transform infrared reflectivity spectroscopies. Further, we carried out measurements of their magnetic susceptibility, magnetization and magneto-electric effect. The measurements were performed at temperatures from 5 to 900 K. For THz measurements, a magnetic field of up to 7 T was applied in the Faraday geometry (wavevector parallel to the magnetic field).

At zero field, we observe a pronounced resonance near 1 THz. Upon applying magnetic field, the maximum shifts towards lower frequencies, it broadens and disappears below H = 1.5 T. At this value of H, we observe also an increase by 0.04 in the refractive index value at 2 THz. This is a clear sign of a coupling between a spin excitation and a phonon, which proves that this resonance is due to an electromagnon. As the magnetic field is further increased, another narrow resonance appears in the low-frequency part of the spectrum. At H = 7 T, its absorption peaks near 0.22 THz, a value which is temperature-independent within 5--250 K. This is probably a ferromagnetic resonance, whose frequency remarkably hardens with magnetic field.

16:15 - 17:45 **M3D - 08 - Sources, Detectors, and Receivers II** **Lecture Theatre 6**

Chairpersons: Jian Chen;

16:15 **Picosecond Impulse Radiating Arrays In Silicon** **M3D-1**

Aydin Babakhani; Mahdi Assefzadeh

In this work, two digital-to-impulse radiating chips are reported that produce and radiate electromagnetic impulses with duration of less than 10psec and repetition frequency of 10GHz. These chips are based on fully electronic methods; no laser is used. The first chip uses a single-ended slot-bowtie antenna with a current switch to radiate impulses with record pulse-width of 8psec and EIRP of 13dBm. The radiation of this chip is coupled to air through a silicon lens attached to the backside of the substrate. The second chip uses a differential slotbowtie antenna with an active feed to radiate impulses with record pulse-width of 9psec and EIRP of 10dBm. Both chips are fabricated in a 130nm SiGe BiCMOS process technology.

16:45 **Optimization Of GaAsSb/InAlAs/InGaAs Tunnel Diodes For Millimeter-Wave Detection** **M3D-2**

Mikhail Patrashin; Norihiko Sekine; Akifumi Kasamatsu; Issei Watanabe; Iwao Hosako; Tsuyoshi Takahashi; Masaru Sato; Yasuhiro Nakasha; Naoki Hara

We evaluated optimal voltage sensitivity (SV) and noise equivalent power (NEP) of GaAsSb/InAlAs/InGaAs tunnel diode detectors in 220-330 GHz band at room temperature. The NEP values have strong dependence on the diode mesa size. With increasing the device area from 0.8×0.8μm^2 to 1.4×1.4μm^2, the estimated minimum NEP improved from 200pW/Hz^1/2 to 80pW/Hz^1/2.

17:00 **Ultrabroadband THz Emission With Controlled Wave-frony From LTG GaAs Large Area Interdigitated Photoconductive Antenna** **M3D-3**

Matthieu Baillergeau; Thomas Nirrengarten; Kenneth Maussang; Anaïs Acquaviva; Jose Palomo; Sukhdeep Dhillon; Jerome Tignon; Juliette Mangeney

We demonstrate THz pulses emitted by LTG GaAs large area interdigitated photoconductive antennas with frequency components from 0.3 to 20 THz. The THz radiation is characterized with a 20-μm thick ZnTe crystal and the dynamic range reaches 60 dB. Under an original optical excitation scheme, the emitted THz pulses show frequency-independent spherical wave front, which provides focusing of the THz beam close to the diffraction limit.

17:15 **Unidirectional Cherenkov Radiation For Improved Terahertz Generation In The Si-Prism-Coupled LiNbO3 Layer** **M3D-4**

Michael Bakunov; Eugene Mashkovich; Elena Svinkina

We show that a Cherenkov emission of terahertz waves from a femtosecond optical pulse propagating in a LiNbO3 crystal can be strongly spatially asymmetric with respect to the direction of the optical pulse propagation. We propose using this phenomenon to improve the spectral characteristics of one of the most efficient optical-to-terahertz converters: a thin LiNbO3 layer attached to a Si-prism outcoupler.

17:30 **Novel Relativistic Plasma Excitations In A Gated Two-dimensional Electron System** **M3D-5**

Ivan Andreev; Pavel Gusikhin; Viacheslav Muravev; Igor Kukushkin

A new mode is discovered in microwave response of a two-dimensional electron system (2DES) covered by a conducting top gate in the relativistic regime for which the 2D conductivity $\sigma_{2D} > c/2\pi$. This mode shows a very unusual frequency and amplitude dependence on the magnetic field, conductivity, gate geometry, and separation from the 2DES, and survives for temperatures up to 300 K, allowing for new room-temperature microwave and terahertz applications.

16:15 - 17:45 **M3E - 11 - Metamaterial Structures and Applications II** **Lecture Theatre 7**

Chairpersons: Hou-Tong Chen;

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

16:15 **High-sensitive Terahertz Biosensor From A Thin Metamaterial** **M3E-1**
Biaobing Jin; Lanju Liang; Caihong Zhang; Yayi Hou; Jian Chen; Pei-Heng Wu
we demonstrate a high-sensitive and multi-frequency THz measurement on the biomolecules based on a flexible metamaterial. The sensitivity of our proposed biosensor is finally achieved to be around 0.132 GHz/nm that is much higher than other reported results. The tumor molecules are coated on the metamaterial, and a very large frequency shift is observed, which implies its application in disease detection.

16:45 **Terahertz Metamaterials Application In Sensing Bacteria And Fungi** **M3E-2**
Yeong Hwan Ahn; Sae June Park
We fabricated THz metamaterial sensors for sensitive, on-site detection of microorganisms such as fungi and bacteria. Strong field localization and enhancement in a gap area enables us to detect the microorganisms with high sensitivity, in aqueous and ambient conditions. The resonant frequency shift is investigated as a function of the dielectric constant and shape of the microorganisms. To optimize microbial sensors, the sensitivity has been studied with respect to substrate dielectric constant and geometrical parameters of the gap structures.

17:00 **Quadrature & Frequency Diverse Terahertz Imaging With Metamaterials** **M3E-3**
Willie Padilla; Claire Watts; John Montoya; Christian Nadell; Sanjay Krishna
The terahertz (THz) portion of the electromagnetic spectrum is a notoriously difficult regime in which to perform imaging. Assembly of focal plane arrays are possible, but the lack of pixel sensitivity requires active illumination with a high power source, or long imaging times to increase signal to noise via averaging. Often raster scan imaging is performed where an object is simply moved through the object plane and an image is built up from the measurements. Terahertz spectrometers, such as time domain spectrometers, realize high signal to noise, thus raster scan acquisition produces high fidelity images. However, the imaging process is inherently serial, thus leading to long acquisition times. A more critical limitation is that image resolution is set by the beam aperture size. There is thus a fundamental trade-off between image resolution and photon throughput, i.e. signal to noise. We propose and demonstrate an alternative approach to imaging, using an all-electronic metamaterial spatial light modulator (SLM). The SLM is placed in a conjugate image plane and is used to multiplex the image. The multiplexed image is sent to a single pixel detector and a value is recorded. The SLM is dynamically reconfigured and detector values are recorded for each configuration of the mask. In single pixel imaging, the number of values recorded is equal to the desired resolution of the image, and we use a number of different types of matrices from which encoding masks are derived, including: Hadamard, S-matrix and random.

17:15 **Effect Of Electron Momentum Relaxation Time On The Terahertz Plasmonic Properties Of Graphene Structures** **M3E-4**
Hugo Condori; Berardi Sensale-Rodriguez
In this work we describe the effect of the electron momentum relaxation time on the terahertz properties of periodically-patterned graphene plasmonic structures; more specifically, its effect on the quality of the characteristic plasmonic resonances. From analytical theory as well as numerical simulations, it is observed that the electron momentum relaxation time heavily affects the quality factor of these resonances. In general, for a given electron concentration level, the larger the electron momentum relaxation time the larger the quality factor at resonance.

17:30 **Experimental Demonstration Of Metamaterial Flat Lens In F<dash>Band** **M3E-5**
Daisuke Kitayama; Ho-Jin Song; Makoto Yaita; Akihiko Hirata
Recently, gradient refractive index lenses, in which the spatial profile of the refractive index is varied instead of precisely controlling surface topography to reshape the wavefront of the incident waves, have been reported for various frequency regions. These lenses have significant potential advantages in that they can be made flat and easily integrated with electric devices or plane antennas, particularly in millimeter and terahertz-wave applications. In this report, we experimentally demonstrate a metamaterial flat lens based on split-ring resonators (SRRs) at 120 GHz, designed on the basis of the gradient index optics theory. The gap of the SRRs used as the unit cells of the lens was varied to obtain the desired reflective index at specific place in the lens. Measurements of a far-field radiation pattern of an open-ended waveguide antenna with and without the metamaterial flat lens experimentally verified an improvement of beam directivity in antenna gain by approximately 11 dB.

17:45 - 19:15 **MS - Poster Session 1** **YIA Lobby**

Chairpersons: Peter Siegel;

Efficiency Enhancement Of Coaxial Device With Two Charged-Particle Beams By Controlling Its Limiting Currents **MS-1**
Tetyana Yatsenko; Kostyantyn Ilyenko
Efficiency enhancement of electron devices with two concentric magnetically-confined annular charged-particle beams with the help of non-zero bias voltage applied to the inner conductor of a coaxial drift-tube is studied. The inner conductor bias voltage not greater than ±50 kV is capable of controlling the limiting currents of two electron beams on the level up to 15 %.

DC Space-Charge Field Representation In Kisunko-Vainshtein Waveguide Excitation Theory **MS-2**
Kostyantyn Ilyenko; Anatoliy Opanasenko
We obtain representations for static electric and magnetic fields induced by charged-particle current in a regular simply connected ideally conducting waveguide in the form of solutions to equations of the Kisunko-Vainshtein waveguide excitation theory. Using generic expressions for evanescent (and propagating) waveguide modes, an equivalence of the developed expressions with Green's function representations of these fields is demonstrated as well as a correspondence between equations of excitation for non-static part of the potential electric field in the standard and Sovetov's variants of the Kisunko-Vainshtein theory and the present approach is established.

Theoretical Study Of Terahertz Generation From Atoms And Aligned Molecules Driven By Two-color Laser Fields **MS-5**
Wenbo Chen; Yindong Huang; Chao Meng; Jinlei Liu; Zhaoyan Zhou; Dongwen Zhang; Jianmin Yuan; Zengxiu Zhao
We study the generation of terahertz (THz) radiation from atoms and molecules driven by an ultrashort fundamental laser and its second harmonic field by solving time-dependent Schrödinger equation. The simulations show that the initial wave-packet and its subsequent acceleration in the laser field, and rescattering with long-range Coulomb potential play key roles on THz generation. We also present the dependence of the optimal phase delay and yield of terahertz radiation on the laser intensity, wavelength, duration, the ratio of two-color laser components, and against the molecular alignment.

We first examine in details how the THz yields depend on various of parameters of the two-color laser pulses, especially the optimal phase-delay (OPD) and optimal THz yield that maximizes (optimize) the THz yields (OTY). When the atomic potential

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

is the long-range Coulomb potential, for either 1D, 2D or 3D calculations, the optimal phase follows the same trend that varys from 0.9π to 0.6π as increasing laser intensity. The intensity dependence of the OPD indicates that different ionization mechanism are involved. As the laser intensity increases, the ionization mechanisms varies from multi-photon ionization to tunneling ionization and over-the-barrier ionization. The dominated mechanisms of THz generation are from four-wave-mixing, rescattering currents of soft-recollision between ionized electron with atomic core, to photocurrent model without Coulomb potential, respectively. The dependence on the intensity ratio of both the OPD and OTY are consistent with laser-assisted soft-collision model, and the OTYs are scaled as power of the intensity ratio, which is consistent with the experiment. As the laser wavelength increases, the OPDs obtained from TDSE shift from 0.8π to 0.6π. This variation might be rationalized that the wave packet is more diffused during each cycle for the longer wavelength, and the soft-recollision with atomic nuclear plays less rule. However, the discrepancy of OTY's wavelength scaling between numerical and experimental data needs further investigation in the future.

Next, we focus on THz and HHG generation dependence on both molecular alignment angle and molecular potential. The total OTYs, dominated by parallel component to laser polarization, take maximum at 0° and minimum at 90° respectivley, which closely assembles the angular dependence of the ionization probability and has been confirmed by experiment. The maximum variation of OPDs is found less than 0.1π. Although this variation, converting into a time delay of 67 attoseconds, is small, it indeed indicates that the molecular potential plays a role in the generation of THz waves. Furthermore, it clearly demonstrates that THz yields can be used to gauge the harmonic yield to gain the two-center interference information of HHG. The phase-delay dependence of THz generation can be used to probe the modulation of harmonics as well.

Broadband Porous-Core Bandgap Terahertz Fiber Based On Kagome Lattice Of Air Holes **MS-6**

Xiao Rao; Jintao Fan; Yanfeng Li

We propose a novel bandgap fiber for the transmission of terahertz (THz) radiation based on a Kagome lattice of air holes. The fiber core comprises a triangular lattice of air holes having the same or a smaller size than the cladding air holes. Numerical simulation of a 19-cell fiber is carried out using finite element method. Proper design of the fiber parameters allows the transmission of broadband THz radiation in the 1.0~2.3 THz range.

Experimental Proof-of-Principle Demonstration Of Sub-MM Clinotron-Multiplier **MS-7**

Kostyantyn Ilyenko; Mihail Milcho; Viktor Zavertanny; Anatoly Tishchenko

We demonstrate experimentally a possibility of triple frequency multiplication in a simple CW clinotron (a BWO with inclined beam) oscillator. In the proof-of-principle experiment the device generated λb ≈ 2.8 mm (107 GHz) in the buncher section while in the catcher section 10 mW at λc ≈ 0.935 mm (321 GHz) were measured. The principal ability of a clinotron-type oscillator to pre-bunch a layer of the electron beam capable of production of terahertz radiation in the short-wavelength part of sub-millimetre waveband is shown.

Sub-THz/THz Amplification In A Semiconductor Superlattice **MS-8**

Alexander Hramov; Vladimir Makarov; Alexey Koronovskii; Kirill Alekseev; Vladimir Maximenko; Nikita Frolov; Mark Greenaway; Mark Fromhold; Olga Moskalenko; Alexander Balanov

We examine the feasibility of amplification of the electromagnetic signal in semiconductor superlattice (SL) by moving charge domains, which are generated in SL by applied DC bias. We show that an external resonator connected to the SL significantly broadens the frequency range of amplified signals to the higher harmonics of domain transient frequency. These promising results open the way to use SLs as efficient sub-THz/THz amplifiers

Design And Efficient Coupling Of TE01 Mode In Small-core THz Bragg Fiber **MS-9**

Hsin Yu Yao; Jhih Yao Jiang; YI Sheng Cheng; Zih Yu Chen; Tsun Hsu Chang; Tsing Hua Her

We report a design of small-core, multiple-layer Bragg waveguide for guiding the terahertz (THz) signal using TE01 mode, which is composed of alternating high-index dielectric (HDPE) and low-index dielectric (air). The propagation loss is less than 0.1 dB per centimeter ranging from 0.95 THz to 1.20 THz, which is better than that of the traditional metallic tube. Furthermore, a novel scheme is proposed to excite and extract the TE01 mode in the Bragg fiber by employing Y-type mode converters. Based on this scheme, for the first time, one can generate the Bragg TE01 mode and further apply such wave-guiding system in THz communication or beam-wave interaction for THz generation.

Broadband Multilayer Antireflection Coating In THz Region **MS-10**

Hsin Yu Yao; Zih Yu Chen; Tsun Hsu Chang

A new approach to design and realize a broadband multilayer anti-reflection coating is proposed in this study. The binominal multi-section transformer is employed to determine the refractive index of each matching layer, while those layers can be realized by doping different fraction of silicon-nano-powders (for relatively-high-index layers) or air bubbles (for relatively-low-index layers) into the HDPE polymers. Based on this method, a broadband THz anti-reflection coating for silicon is designed, which works from 0.20 THz to 0.90 THz (127% bandwidth) in which the total THz transmission can be higher than 97% and the corresponding reflectance is less than 1% for both TE and TM polarizations at any incident angle less than 50o .

Design, Fabrication, And Measurement Of Terahertz Mode Converter **MS-11**

Jhih Yao Jiang; Bor Yuan Shew; Yi Sheng Cheng; Tsun Hsu Chang

.In this report, two mode converters are designed and fabricated to extract TE41 and TE01 modes for the generations of 0.4 THz and 1 THz signal by high-harmonic interaction with gyrating electron beam, respectively. The purities of the desired modes in these two converters are both higher than 90% with remarkably broad bandwidth (380 GHz to 420 GHz for TE41 mode and 910GHz to 995 GHz for TE01 mode). Since the geometrical aspect ratios of the designed mode converters are both larger than 5, it is too difficult to realize them by the traditional machining processes and UV lithography. We therefore employed X-ray lithography to fabricate these designs, which will be characterized by THz time-domain spectroscopy.

Schottky Diode 4th-Harmonic Mixer Characterization At 440 GHz **MS-12**

Ramon Gonzalo; Itziar Maestrojuan; Iñigo Ederra

This paper presents the measurements of a 4th-harmonic Schottky diode mixer working at sub-millimeter frequencies, in particular at an RF frequency of 440 GHz. Measured DSB noise temperature of 7900 K and conversion loss of 14 dB have been obtained. This configuration offers an alternative solution which simplifies the LO signal generation. It can find an application in imaging systems, where arrays of detectors need to be simultaneously fed by the same LO.

A Comparison Method For THz Measurements Using VNA And TDS **MS-13**

Mira Naftaly; Nick Ridler; John Molloy; Nosherwan Shoaib; Daniel Stokes

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

A method is described for direct comparison of dielectric measurements obtained by a vector network analyzer and a time domain spectrometer. The method employs a material that can be inserted into a waveguide for VNA measurements or contained in a cell for TDS measurements.

Terahertz Spectroscopic Study Of Ion Effects On Protein Hydration **MS-14**

Toshiaki Hattori; Katsuyoshi Aoki; Kentaro Shiraki

Effects of salts on the dynamical properties of hydration water of protein in aqueous solutions are studied using high-precision terahertz spectroscopy. Effects of ions on properties of proteins have been studied very well, and it has been known that the ability of ions to precipitate proteins and also their effects on the protein stability are ordered in the Hofmeister series. We obtained the amount of hydration water around protein molecules by measuring the terahertz absorption spectra of aqueous solution of a protein (hen egg white lysozyme) with various concentrations of anions: SO42-, H2PO4-, Cl-, NO3-, and SCN-. From the experimental results, we have found that kosmotropic anions (water-structure makers) in the Hofmeister series are found to decrease hydration water, and chaotropic anions (water-structure breakers) increase it. This result is consistent with the theoretical model presented by K. D. Collins, where effects of anions to the hydrogen-bonding network of water is considered. Present results show that influence of anions on hydration is the main factor that determines the stability of proteins in aqueous solutions.

Strong Optical Phonon Mode Of Natural Seraphinite Probed By Terahertz Time-domain Spectroscopy **MS-15**

Daehoon Han; Heejae Jeong; Yunheung Song; Jai Seok Ahn; Jaewook Ahn

The natural seraphinite has the optical phonon modes in the frequency range from 0.1 to 2 THz. The observed absorption modes at 0.8, 1.2, and 0.96 THz are understood as infrared active phonon modes of Au(z) and Bu(x, y) symmetries, respectively. The 0.96 THz mode is, in particular, strong and narrow comparable to the reported 0.53 THz mode in α-lactose monohydrate. Experiments carried out by THz time-domain spectroscopy shows a good agreement with theoretical analysis based on the phonon-polarition dispersion relation.

Multi-Frequency Design Of A 2 MW Coaxial-Cavity Gyrotron For DEMO **MS-16**

Joachim Franck; Konstantinos Avramidis; Ioannis Pagonakis; Stefan Illy; Gerd Gantenbein; Manfred Thumm; John Jelonnek

The Karlsruhe Institute of Technology (KIT) is working on a possible physical design of 2 MW coaxial-cavity gyrotrons for future fusion applications, initially considering a first demonstration fusion power plant (DEMO). One focus of the investigations is how successfully such gyrotrons can be operated at significantly different frequencies. The gyrotron design as presented here is optimized for operation at one very high order main cavity mode around 237.5 GHz, with secondary modes at 170.0 GHz and 203.8 GHz. The considered technical design restrictions as well as simulation results are presented.

Study Of Paraffin-embedded Brain Glioma Using Terahertz Spectroscopy **MS-17**

Zeren Li; Kun Meng; Jiang Li; Sencheng Zhong; Lianghui Du; Qiao Liu; Zhaohui Zhai; Tunan Chen; Liguo Zhu; Hua Feng; Jianheng Zhao

we measured the refractive indices, absorption coefficients and complex dielectric constants of paraffin-embedded brain glioma and normal brain tissues using terahertz time-domain spectroscopy system (THz-TDS). The results show distinct differences of aforementioned THz properties between brain glioma and normal tissues. The suitable THz frequency for varies imaging methods (intensity, coherent or pulsed imaging) for paraffin-embedded brain glioma are analyzed.

Terahertz Dielectric Properties Of MgO-TiO2-ZnO Based Ceramics **MS-18**

Shuang Wang; Jianqiang Gu; Jiaguang Han; Weili Zhan

We investigated terahertz dielectric properties of MgO-TiO2-ZnO based ceramics using a THz-TDS system. Doped with Ca2+, the decrease in tetragonality (c/a) of pervoskite structure and porisity lead to an increase in refractive index, meanwhile, power absorption is enhanced due to the CaTiO3 phase and small grains microstructure, which result in an increase in both the real and imaginary parts of dielectric constant.

A 2 × 2 3D Printed Micro-lens Array For THz Applications **MS-19**

Dalu Guo; Jinchao Mou; Haidong Qiao; Weidong Hu; Xin Lv

This paper presented a 2×2 3D printed micro-lens array, which is used for THz focal plane array imaging applications. Firstly, the quasi-optical receiver unit is designed, which consists of a planar antenna chip and lens based on 3D printing technology. Then a prototype of 2×2 lens array are designed and optimized with the coupling effect taken into account. The radiation pattern are calculated and the micro-lens array are fabricated. All the measurements are in progress.

Optical Resonator Optimization Of CAEP THz-FEL **MS-20**

Yuhuan Dou; Xiaojian Shu; Xingfan Yang; Ming Li; Yong Xu; Zhou Xu

The optical resonator of CAEP THz-FEL is optimized to ensure wavelength tunable in a wide range and high power operation. The FEL power strongly depends on the performance of the optical resonator including output efficiency, gain and round-trip loss. The optical resonator consists of metal-coated reflect mirror, the center-hole output mirror, waveguide. The influence of waveguide and Rayleigh length on the quality of optical cavity is evaluated by the 3D-OSIFEL code. The waveguide size, mirror curvature radius, and output coupling hole radius is optimized to different frequencies between 1 THz to 3 THz.

Soft Mode Behavior In Lead Germanate Studied By Terahertz Time-Domain Spectroscopy **MS-21**

Alexander Mamrashev; Nazar Nikolaev; Valery Antsygin; Oleg Potaturkin

We study temperature dependence of terahertz dielectric properties of ferroelectric lead germanate crystal. Observed soft mode behavior directly indicates transition from displacement to order-disorder type of ferroelectric in the vicinity of phase transition point.

Magneto-photoluminescent Structure Of HgCdTe **MS-22**

Liang Zhu; Zhen Qi; Xiren Chen; Lu Chen; Liangqing Zhu; Fangxing Zha; Jun Shao

Photoluminesence(PL) and magneto-optics are classical routines to characterize electronic structures of semiconductors. We incorporated magnetic field with infrared (IR) PL based on a Fourier transform infrared spectrometer, such that thermal background disturbance is well eliminated and signal-to-noise ratio significantly improved. By resolving closely-spaced PL components in Hg$_{1-x}$Cd$_{x}$Te at various magnetic induction intensities, effective masses, shallow level types and energetic positions are deduced. It's demonstrated that magneto-PL is powerful in resolving IR-PL structure, and able to provide accurate parameters like effective masses and ionization energies of band-edge levels, along with the impurity types.

High-Speed Broadband Frequency Sweep Of Continuous-Wave Terahertz Radiation **MS-24**

Dae Su Yee; Ji Sang Yahng; Choon Su Park; Hwi Don Lee; Chang Seok Kim

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

We present a new technical implementation of a high-speed broadband frequency sweep of continuous-wave terahertz (THz) radiation. THz frequency sweeping with a kHz sweep rate and a THz sweep range is implemented using THz photomixing in which an optical beat source consists of a wavelength-swept laser and a distributed feedback laser diode. During the frequency sweep, frequency-domain THz interferograms are measured using the coherent homodyne detection employing signal averaging for noise reduction, which can give time-of-flight information via fast Fourier transform. Multiple reflections in a Si wafer and the thickness of the wafer are measured to demonstrate the potential of this method for fast THz tomography and thickness measurement.

Generation Of Cherenkov Superradiant Pulses With Correlated Phases Defined By Sharp Edges Of High-Current Electron Bunches **MS-25**

Irina Zotova; Naum Ginzburg; Anton Golovanov; Michael Yalandin; Vladislav Rostov

Recently coherent summation of several SR pulses generated in parallel channels has been demonstrated in X- and Ka wavelength bands. This possibility is caused by picosecond stability of explosive emission from a cold cathode and strong correlation of phase of the SR pulses with respect to the leading edge of the electron bunch. In fact stimulated SR emission is initiated by spontaneous mission from bunch leading edges. In report we describe results of recent experiments and develop a theoretical model which covers both spontaneous and stimulated Cherenkov emission.

Identification Of Fabric Fibers And Their Blending Ratio By Terahertz Spectroscopy **MS-27**

Toru Kurabayashi; Takuya Inoue; Haruka Iguchi; Shinichi Yodokawa; Takeshi Ando; Satoru Kosaka

Absorption spectra of cellulosic fibers in THz region show discriminative absorptions which are derived from crystallized cellulose, when we prepare the samples by cutting at a length of about 0.1-0.2 mm. The blending ratio of two different kinds of fibers has been examined by using this method, and the spectra were analyzed by an analysis of principal component as a multiple classification analysis after the first derivation of the spectra. The result means the blending ratio can be identified with considerable accuracy at a few percent of reliability.

PULSE OROTRON WITH DOUBLE - ROW PERIODIC STRUCTURE OF 150...400 GHz FREQUENCY RANGE **MS-28**

Evgenee Myasin; Il'yn Andrey

The experimental results of the generation study of the orotron with double - row periodic structure in frequency tuning region of 150...400 GHz and their discussion will be represented. On the bases of the obtaining results, conclusion about outlook of the advancement upwards on frequency will be made.

High Frequency Metal-Insulator-Metal (MIM) Diodes For Thermal Radiation Harvesting **MS-29**

David Etor; Linzi Dodd; Claudio Balocco; David Wood

The fabrication of low-cost metal-insulator-metal (MIM) diodes using a self-assembled monolayer as the insulating layer is presented. DC and AC analysis show that the diodes have excellent non-linear current voltage characteristics compared to those typically reported, with a zero-bias curvature coefficient ranging from 0.5 to 5.4 per volt, voltage responsivity of 1.9 kV/W at a frequency of 1 GHz. The process developed for fabricating these diodes is simple, cost effective, and can potentially be used in the roll-to-roll manufacturing of MIM diodes. Reliability tests performed on the fabricated OTS diodes shows that the OTS layer of the diodes remains unaffected by high temperature up to approximately 450 °C which is significant in thermal energy harvesting applications, where the diode may be exposed to high temperatures.

Detecting Terahertz Signatures Using Guided Under-determined Source Signal Separation **MS-30**

Luis Rivera; Guilherme DeSouza

Terahertz technology has seen many advances over the past decades. Special interest for the use of this technology is directed to the detection of illegal drugs, explosives and other hazardous materials. These materials exhibit characteristic signatures at terahertz wavelengths which may be used to identify them. In this paper we present a method for detecting the presence of chemicals and other materials using their terahertz signatures and a technique for signature recognition called Guided Under-determined Source Signal Separation (GUSSS). The method was tested using a public THz database, achieving high true positive and true negative percentages.

Long-wave Mid-IR Source Based On GaSe1-xSx **MS-31**

Zhiming Huang

For the first time pure and Al-doped solid solution GaSe1-xSx or heavily S-doped crystals were used in design of the tunable narrow-bandwidth long-wave mid-IR source. Solid solution compositions were within not well established optimal limits of from x=0.09 to x=0.133 to get best optical quality (α<0.1 cm^-1). Al concentrations were selected within optimal doping limits of 0.01-0.05 for pure GaSe crystals and larger that, relatively, optimizes optical quality and maximizes hardness at still suitable optical quality for application. Studied samples were manufactured by exfoliation from the as-grown boules. For the first time to the best of our knowledge additive effect from double-element doping was clearly observed. The GaSe0.888S0.112 (2.5 mass. %) doped with 0.05 at. % of Al was of the best optical quality. Optical quality of GaSe0.888S0.112 doped with 0.75 at. % of Al was still estimated as optical grade by naked eye. It feels as a material of a "metal-grade" hardness. Tunable long-wave (from 13 μm to 20 μm) narrow-bandwidth source was designed by down-conversion of tunable narrow-bandwidth ((λ=0.9835 -1.0103 μm, $\Delta\nu$=0.075 cm^-1) KTP OPO idler waves and residual pump Nd:YAG emission (1.064 μm, $\Delta\nu$=0.003 cm^-1). The GaSe0.888S0.112 (2.5 mass. %) crystal shown about 1.5 times higher down-conversion efficiency to that for GaSe crystal at identical experimental conditions. Doping with 0.05 at. % Al increases efficiency for 15 or 20% but at pre-damage pump intensity the advantage rises up to 6 times. Further increase is possible by using high quality pump beam and optical set-up optimization. Designed monochromatic source can be used as a spectroscopic tool or as a seed source in design of long-wave scaled-up power laser system with extended operation range.

Terahertz Conductivity Across The Insulator-metal Transition Of Epitaxial Praseodymium Nickel Oxide Thin Films **MS-33**

Eswara Phanindra Vallabhaneni; Sarmistha Das; santhosh kumar kadakuntla; piyush agarwal; Rakesh Rana; Dhanvir Singh Rana

Terahertz time domain spectroscopy is a powerful tool to explore the low energy charge dynamics of the strongly correlated materials like perovskite Nickelates. Nickelates shows wide variety of unusual electronic and magnetic properties like charge, spin ordering and epitaxial strain controlled insulator-metal transitions etc. perovskite nickelates belongs to correlated class of transition metal oxide systems, whose insulator-metal (I-M) transition can be engineered using strain, hydro-static pressure, chemical doping, etc. Among these, the Praseodymium Nickel Oxide (PNO) is a fascinating system that exhibits simultaneous I-M transition and Neel ordering exactly at ~ 130 K. The understanding of the low energy charge dynamics of perovskite Nickelates is intriguing and has challenged present day physicist and is still strongly debatable. Recently, it was shown that the

charge ordered state can be stabilized in the tensile strained epitaxial PNO thin films. To explore the insulating ground state Terahertz (THz) - time domain spectroscopy (TDS) measurements were carried out in order to get the understanding of low temperature insulating phase of PNO thin films across the I-M transition. THz-TDS measurements were carried out in transmission mode on epitaxially grown PNO thin film deposited on LSAT (110) substrate by pulsed laser deposition technique. The low energy charge dynamics in the energy range of 0.8 - 7 meV were probed by THz-TDS and the complex dielectric constant and optical conductivity were obtained for the PNO films by solving the Fresnel's equations. We observe a Drude like behavior for the PNO film across the I-M transition.We obtained convincing fits for the terahertz conductivity spectra and deduced values of the parameters after fitting for scattering rate as 13.3 meV, 15.1 meV and 21.4 meV and plasma frequency as 399.5 meV, 405.2 meV and 444.4 meV various temperatures. From these parameters we find that in the insulating state the values of Γd is nearly half than that above the I-M transition indicating a robust insulating state for PNO film having lesser scattering of the Drude carriers. However, it is interesting to note that the inset depicts the temperature dependence of the THz conductivity for the PNO films, where we find two I-M transitions at 130 K (reminiscent as of the bulk PNO) and a re-entrant I-M transition around 25 K. This is surprising and may be attributed to the competing coexisting antiferromagnetic phases having collinear and non-collinear spin configurations. We have observed intriguing I-M transitions in the epitaxial PNO thin-films and have studied the low energy dynamics using THz spectroscopy highlighting the rich physics governing this correlated class of system having unusual complex magnetic ground state.

Differentially-Driven Circularly-Polarized Planar Aperture Antenna For Millimeter-Wave Application **MS-34**

Dia'aaldin Bisharat; Shaowei Liao; Quan Xue

This paper presents a novel differentially-driven planar aperture antenna for circularly-polarized (CP) radiation. The proposed antenna is simple in structure and is constructed on only a single layer laminate using standard printed-circuit-board (PCB) technology. Circular polarization is realized by rotationally-symmetric windmill-shaped aperture-strip formation with travelling wave distribution. An opening-cavity that is formed by metalized vias is adopted to offer favorable unidirectional radiation and higher gain. Simulation results of a prototype working at V-band show a 3-dB axial ratio (AR) bandwidth of 17.4% (56.8--67.5 GHz), which is within its -10-dB impedance bandwidth. Meanwhile, the left-handed CP (LHCP) gain is stable throughout the operating bandwidth with a peak gain of 14.2 dBi. The proposed antenna is a promising candidate for millimeter-wave (mmWave) bands due to its merits of wideband, high gain, simple structure, low cost, and easy integration with differential circuits.

Controlling Terahertz Conductivity In SWNT/Polymer Composite **MS-35**

Debanjan Polley; Anjan Barman; Rajib Kumar Mitra

Terahertz (THz) conductivity of single walled carbon nanotube (SWNT)/poly-vinyl alcohol (PVA) composites has been studied in the frequency window of 0.3-2.0 THz. SWNT/ PVA composite films with a constant thickness of 300 ± 20 μm are grown by dispersing required amount of SWNT in PVA solution via a slow drying process at room temperature under ambient condition. THz time domain spectroscopic measurements have been performed in transmission geometry at room temperature under N2 atmosphere and THz conductivity spectra have been extracted from the time domain data. Bare PVA film has an uncharacteristic refractive index and increasing absorption coefficient; therefore it does not considerably affect the characteristic of THz conductivity of SWNT. It is found that conductivity of these samples can be efficiently tuned by changing the length of the SWNTs and also the SWNT weight fraction inside the polymer matrix. For the highest weight fraction at a frequency of 1.0 THz, longer SWNT sample (average length ~ 15 μm) showed ~ 90% increased conductivity than its shorter counterpart (average length ~ 2 μm) of same diameter (1-2 nm). Shielding effectiveness of the samples has also been engineered by simply changing the effective length of SWNT inclusion in the polymer matrix showing a very intimate relation between the shielding effectiveness and conductivity of a composite material. A modified Universal Dielectric Response (UDR) model given by the following formula $\sigma_{real}(\omega) = \sigma_{(D.C.)} + A\omega^s$, where $\sigma_{(D.C.)}$ is the dc plateau observed in the low frequency regime, A is a parameter which depends on the temperature, s is the frequency exponent which in turn depends upon the conductive properties of the sample and the temperature, is applied to analyze the conductivity spectra of the samples. Hopping or tunnelling type of conduction of carriers is described by a sub-linear frequency dependence ($0 < s < 1$) and in case of $1 < s < 2$, motion of carriers get disturbed by columbic traps and there movement is limited only in the local environment.

Low Frequency Modes Of Biomolecules In The Hydrated States **MS-36**

Ohki Kambara; Norihisa Hiromoto

Hydration process of few organic molecules is examined in the low-frequency region under 100 cm^-1. THz spectra of both hydrated states and anhydrous states in the solid crystal samples are measured by a self-build THz-TDS instrument and their vibrational modes are analyzed by periodic boundary condition implemented DFT calculation. By comparing with single molecule calculation, peak assignment of their peaks was performed and the effects of each water molecules which bind to the anhydrous molecules are discussed.

Effects Of Relative Humidity On Thermistor Mount Measurements **MS-37**

Wenze Yuan; Xiaohai Cui; Yong Li; Ma Chao

Thermistor mounts are served as transfer standards which are calibrated in microcalorimeter. A correlation between the effective efficiency of thermistor mount and the relative humidity of the laboratory has been observed. The difference of effective efficiency measurement in 20% and 50% humidity level can be about 9 times the k=1 uncertainty. The effects of humidity on thermistor mounts can result in the changes of effective efficiency. While the humidity impacts on other microwave device in microcalorimeter is not the main reason of these changes.

Gbps THz External Modulator Based On High Electron Mobility Transistors-metamaterials **MS-38**

Shen Qiao; Yaxin Zhang; Shenggang Liu

Utilizing THz wave to transmit data for communication and imaging places high demands in phase and amplitude modulation. In this paper we combined a metamaterial array with HEMT structure to form an ultrafast electronic grid-controlled THz modulator. By controlling the carrier concentration of 2DEG, a resonant mode conversion between two different dipolar resonances has been realized. In the real-time dynamic test, this THz modulator achieved 1 GHz modulation speed with 85% modulation depth and 1.26 rad phase shift. It could provide an alternate way to achieve effective and ultra-fast active devices in THz wireless communication system.

Excellent Photonic-assisted Measurement System For High Order Mode Pattern Scan In Reactive Near Field **MS-39**

Ingeun Lee; Mun Seok Choe; Dong-Joon Lee; EunMi Choi

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

We present experimental results of TE6,2 mode electric field pattern results utilizing a photonic-assisted W-band measurement system and a vector network analyzer (VNA) system in the reactive near field region. We introduce the photonic-assisted W-band measurement system and demonstrate that it provides extremely precise probing capability compared to the VNA system, especially when a higher order mode pattern is scanned in the extreme near field region.

Design Of A Millimeter-Wave Absorber Composed Of Resistive Films Printed On A Flexible PET Substrate **MS-40**

Sang Lam; Kim Lau

A low-cost design of millimeter-wave absorbing sheets is investigated. The absorber is composed of a perforated resistive film on a flexible polyethylene terephthalate (PET) substrate which is backed by a resistive ground plane. Broadband (60 GHz to 120 GHz) and wide-angle (up to 80°) absorption (> 50%) is achieved for a design with a square lattice of circular holes (diameter d = 5.5 mm and lattice period a = 7.5 mm) in the perforated resistive film of thickness tR = 100 μm and conductivity σ = 80 S/m.

Suppression Of High Gain GaAs Photoconductive Semiconductor Switch At High Electric Field **MS-41**

Ming Xu; Wei Shi; Xiaoqing He; Zhijing Yan; Hong Liu

GaAs photoconductive semiconductor switch is being used in a variety of applications, for the advantageous properties of low jitter, high speed operation and simple structure. As we known, GaAs PCSS can operate in two important modes, i.e., linear and high gain mode. When the bias electric field and energy of trigger laser is above a certain threshold value, the important feature of high gain mode can produce as many as 10^3-10^5 electron-hole (e-h) pairs per absorbed photon, compared to linear PCSS, in which only one e-h pair is generated in per absorbed photon. Up to now, however, the utility of GaAs for THz emission depends on the operation of linear mode. There is no report that one uses GaAs PCSS operating with high gain mode as THz emitter. In order to use the GaAs with high gain mechanism as intensive THz emitter, it should allow to form the photoconduction with the feature of high gain mode and radiate the intensive THz emission. A concept that attempts to bring the carriers' high gain mechanism in high electric field to the linear mode of GaAs is proposed in this paper. We utilize the infrared activation and inhibition of high field domains to interrupt the development of filament current with two excitation beams of same wavelength at 1064 nm. The infrared activation and inhibition of high field domains is achieved and the good hold-off characteristics is obtained with 32 kV. Experiments were performed based on SI GaAs which is grown by the Liquid Encapsulated Czochralski (LEC) technique. The Au/Ge/Ni electrode forms ohmic contact by using a standard mixture of Ni/Au-Ge/Au for the metallization at 450 celsius degree. The electrode dimensions were 6×3 mm^2 with a 500-nm-deep ledge has been etched with reactive ion etching and 800 nm thickness Si3N4 insulator layer is coated on the material. The Nd:YAG nanosecond laser operated with 15 ns full width at half maximum laser pulse, at wavelength of 1064 nm. The trigger laser pulses were reflected by a piece of quartz to make sure the intensity of laser is appropriate. This method actually results in two dependent trigger laser spot in the SI-GaAs sample due to the reflection of the upper and bottom surface of quartz, and the relative timing between the two laser pulses is about 100ps based on the thickness of quartz. Results show the characteristics of switching controlled by those dependent infrared lasers based on the samples with the 12 mm electrode gap. In our experiment, the bias voltage starts from 6.4kV and the maximum bias voltage can be up to 32 kV with 0.9 kA current switching. When the bias voltage is increased to 34 kV, breakdown of PCSS occurs due to surface flashover. Although the electric field and trigger laser energy meet the critical condition to occur high gain mode, somewhat surprising but interesting results appear repeatedly during the whole experiments, that there are no remarkable waveforms with characters of "lock-on".

Characterization Of An Optically Generated 3THz Continuous Wave Using A Phase-locked QCL And A HEB Mixer **MS-42**

Motohiro Kumagai; Yoshihisa Irimajiri; Isao Morohashi; Akira Kawakami; Shigeo Nagano; Yuko Hanado; Iwao Hosako

We characterized a 3THz continuous wave generated by photomixing two optical modes of a broadband optical frequency comb. This optically generated THz wave and the output beam of a 3THz quantum cascade laser phase-locked to a THz reference were coupled onto a hot electron bolometer mixer operated at 4K and the beat signal was precisely evaluated. This direct comparison at 3THz reveals that the optically generated 3THz wave has fractional frequency instability of 4×10^-15 at 100sec averaging time and the power spectral density of -10 dBc/Hz at 1Hz Fourier frequency.

Direct Detection Of THz Pulse Position And Amplitude **MS-43**

Stefan Katletz; Harald Pühringer; Michael Pfleger

We present a novel measurement method to continuously measure the temporal position and amplitude of a terahertz (THz) pulse in a typical time-domain setup. Currently we have achieved a sampling time of 50 Hz and a resolution of less than 10 μm. The method is therefore very well suited for online measurements in production processes to monitor the thickness and inhomogeneities in the composition of non-conducting materials.

Study Of A Pseudospark-sourced G-band EIO **MS-44**

Yong Yin; Bin Wang; Wenlong He; Liang Zhang; Huabi Yin; Adrian Cross

Numerical study of a G-band Extended Interaction Oscillator (EIO) based on a pseudospark-sourced electron beam is presented. Preliminary results show a new way to generate several hundred watts of pulse power in millimeter and even terahertz frequency range in a compact and affordable way.

Far-Infrared Spectroscopy Of Quantum Spin Chain PbCuSO4(OH)2 **MS-45**

Andrew Squires; Evan Constable; Kirrily Rule; Roger Lewis

This work presents far-infrared transmission spectroscopy on single crystal PbCuSO4(OH)2 using synchrotron radiation. The study covers the spectral region 150--400 cm^-1 with electric field polarisation parallel to either the a or b crystal directions. The results reveal a number of anisotropic absorption features tentatively attributed to phonon modes.

QAM-32/0.588 THz Communication Using Electronic Schottky Transceivers **MS-46**

Guillaume Ducournau; Pascal Szriftgiser; Denis Bacquet; Emilien Peytavit; Mohammed Zaknoune; Rédha Kassi; Jean-Francois Lampin

We report on THz communication system using vectorial modulations schemes above 500 GHz. Using schottky-based electronic technologies at 588 GHz, potentialities of high-level multi-carrier modulation schemes for wireless links are analyzed. The wireless link is composed of an emitter with sub-harmonic mixer for up-conversion from 294 to 588 GHz and carrier modulation. A pumped zero-bias detector is used at reception. Mono-carrier signaling is realized using for up to 32-symbol modulation scheme and multi-carrier THz transmission is also achieved using several modulation schemes in parallel

Mode Conversion And Resonant Absorption Of Electromagnetic Waves In Inhomogeneous Chiral Media **MS-47**

Kihong Kim; Seulong Kim

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

The mode conversion and the resonant absorption of electromagnetic waves occurring in inhomogeneous chiral media are studied theoretically. The resonant absorption is found to occur when the inhomogeneous medium contains a region where the effective refractive index vanishes.

Close-space Sublimation Growth And Characterization Of ZnTe Epitaxial Thick Film **MS-48**

Jiawei Li; Gang qiang Zha; Yadong Xu; Shouzhi Xi; Yingrui Li; Rui Yang; Wanqi Jie

ZnTe epitaxial film with thickness of 200μm was grown on the GaAs substrate by close-space sublimation（CSS）. The surface topography of ZnTe film was analyzed by SEM, and the evolution of growth pit was observed, which revealed the mechanism of epitaxial growth. The structure was analyzed by X-ray radiation diffraction (XRD) θ-2θ scan and rotary Φ-scan, and the results suggested that the ZnTe thick film is epitaxial film. The crystalline quality of ZnTe thick film was characterized by X-ray rocking curve and Raman spectrum, and the results suggested that ZnTe epitaxial film obtained by CSS could be as a replacement of ZnTe single crystal, especially for thinner and larger requirement.

Silk Foam Terahertz Waveguides **MS-49**

Hichem Guerboukha; Guofeng Yan; Olga Skorobogata; Hang Qu; Maksim Skorobogatiy

Silk foam-based terahertz waveguides are fabricated using lyophilisation and casting techniques. This work is motivated by the lack of biocompatible waveguides for low-loss guidance of THz for applications in remote sensing in biomedical and agro-alimentary industries.

Terafluidics Devices: Perspectives And Problems **MS-50**

Sergey Pasechnik; Dina Shmeliova

The new approach to an elaboration of liquid crystals (LC) tuned THz devices, based on usage of shear flows, is proposed. Flows are considered as more universal tool for LC orientation in the comparison with the action of properly treated surfaces. In particular, they can be used for an orientation of both thin and thick (of order 1mm) LC layers. High sensitivity of LC to the flows makes possible to elaborate LC devices of new types -- terafluidics.

High Performance Solar Selective Absorbers Constructed By Multilayers **MS-51**

Shaowei Wang; Feiliang Chen; Xiaoshuang Chen; Liming Yu; Wei Lu; S.C. Shen

High-performance solar absorbers need to have high solar absorptivity and low infrared thermal emissivity at the same time. They are core part for architecture integratable solar thermal technologies such as solar water heaters and solar thermoelectric generators. In this work, we presented a kind of solar absorber with TiNxOy-based multilayers. Its solar absorbance can be as high as 97.5% and infrared thermal emissivity as low as is 4.3% with total thickness less than 300 nm. The solar absorbance can maintain above 90% for a broad incident angle to 65°.

Compact Transmission Line Design In A Multi-Metallization Nano-CMOS Process For Millimeter-Wave Integrated Circuits **MS-52**

Sang Lam; Mansun Chan

A compact transmission line design based on the conventional microwave stripline is presented for implementation of millimeter-wave CMOS integrated circuits. In a 65-nm process, the design gives a low insertion loss of 2.2 dB/mm at 60 GHz as determined by 3D electromagnetic (EM) simulations. A 50-Ω characteristic impedance is achieved resulting in a reflection coefficient of about -27 dB up to 80 GHz. The transmission line structure occupies minimal space of less than 17 μm in width and it accommodates active devices beneath it unaffected by any possible EM interference.

A Metal Mesh Flat Prism For MM-wave Applications **MS-53**

Paul Moseley; Giorgio Savini; Giampaolo Pisano; Peter Ade; Elena Saenz; Jin Zhang

By using the previously unwanted dispersive properties of metal mesh artificial dielectrics, we propose a novel design for a flat prism. This is a device that steers an incident plane wave by a given angle based on its frequency. This is achieved by using existing graded index theory and further understanding of the dispersion effects in metal mesh grids. Such a device would act as an alternative to diffraction gratings and operate over the frequency range of 100-200 GHz.

Preliminary Design Of Powerful Gyrotrons For IGNITOR And DEMO **MS-54**

Vladimir Zapevalov; Alexey Chirkov; Gregory Denisov; Andrey Kuftin; Alexander Litvak; Mark Moiseev; Nikolay Zavolsky

Design development of continuous-wave 240 GHz gyrotron and 300 GHz gyrotrons with output power about 200-1000 kW for fusion research at advanced plasmas with intense magnetic field is presented. Main goal of such gyrotrons is application for EC complexes of IGNITOR and DEMO tokamaks. This paper includes task motivation and existing technical basis, results of calculation, design, technical requirements and pre-prototype experimental tests for main subsystems of gyrotron.

Effect Of Non-ideal Beam Splitters In THz Electro-optic Detectors **MS-55**

John Mabon; Roger Lewis

We extend a mathematical study to multiple THz electro-optic detectors to determine the detector with the lowest noise floor. We do this by using "real world" optics where polarisers and beam splitters have non-ideal properties. We find that certain detectors are not sensitive to non-ideal beam splitters while other detectors are.

Plasmonic Detection Of Wide Band Modulated THz Radiations In GaAs Technology **MS-56**

Shamsun Nahar; Mona M. Hella; Stephane Blin; Annick Penarier; Philippe Nouvel; Wojciech Knap; Dominique Coquillat

A fully integrated THz detection system consisting of an on chip dipole antenna, a plasmonic detector and a wide band amplifier in 130 nm AlGaAs/InGaAs pHEMT technology is reported. The fabricated chip achieves an absolute responsivity of 3 V/W, while maintaining a 50 dB signal to noise ratio (SNR) over a modulation bandwidth of 8.5 GHz at ~ 0.3 THz.

Low Loss Silicon Waveguides For The Terahertz Spectral Region **MS-57**

Bart Kuyken; Antoine Pagies; Mathias Vanwolleghem; Dmitri Yarekha; Jean-Francois Lampin; Gunther Roelkens

Chip scale terahertz dielectric waveguides, consisting out of high resistivity silicon as a core material have been fabricated. The waveguide loss is measured to be ~1dB/cm at both 1 THz and 2.5 THz.

High-Efficiency Planar Schottky Diode Based Submillimeter-Wave Frequency Multipliers Optimized For High-Power Operation **MS-58**

Jose V. Siles; Erich Schlecht; Robert Lin; Choonsup Lee; Imran Mehdi

We report on a new series of millimeter and submillimeter-wave frequency multipliers specifically optimized for very high-power operation in order to meet the requirements of next generation terahertz instruments for Astrophysics, Planetary science, Earth science and radar imaging applications. New frequency multiplier chips have been designed and fabricated in the 100 GHz to 1 THz range focusing on higher power operation. Initial tests have shown efficiencies of around 30% for a single-chip 105-120 GHz tripler, and 25% for a single-chip 170-200 GHz doubler, when pumped with 500 mW. These results

Monday, August 24, 2015

08:45 - 09:15	**Welcome and Opening Remarks**	**Lecture Theatre 1**
	Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;	

correspond to a factor of 2-3 improvement with regards to previous designs at these frequencies. Similar improvements are expected for the new designs at higher frequencies.

Design And Fabrication Of Beam Transmission System For Terahertz Extended Interaction Oscillator **MS-60**
Wenxin Liu; Zhaochuan Zhang; Chao Zhao; Xin Guo; Ke Li
The extended interaction oscillator (EIO) is considered to be a novel type of high power Terahertz (THz) source, which has a promising application prospects in Radar, medical imaging, etc. Up to now, CPI and other institutes have developed this type of EIO. The investigation on the J-band (220GHz-325GHz) EIO at the Institute of Electronics, Chinese Academy of Sciences (IECAS) is being developed. The electric and structural designs for the J-band EIO have been accomplished, in which many technical problems are continued to be resolved. The design of electron optical system for EIO is finished and the permanent magnetic uniform field is adopted. This paper presents mainly the design of electron optical system for the J-band EIO in detail.

Terahertz Generation From Electric-Optic Side-Chain Polymer Films **MS-61**
Takahiro Kaji; Toshiki Yamada; Yukihiro Tominari; Isao Aoki; Rieko Ueda; Shukichi Tanaka; Akira Otomo
We investigated terahertz (THz) emission properties of the electric-optic (EO) side-chain polymer films. We evaluated the THz electric field intensity from the EO polymer film by comparing the results with that of a ZnTe crystal. We also characterized the material properties of the EO polymer with respect to the THz generation.

Theory And Simulation Of A Terahertz Single Grating Rectangular Waveguide Back-ward Wave Oscillator **MS-64**
Wenqiu Xie; Zi-Cheng Wang; Jirun Luo; Ding Zhao
A three dimensional (3-D) nonlinear analysis of the beam-wave interaction in the single-grating rectangular waveguide (SGRW) sheet-beam Back-ward Wave Oscillator (BWO) is presented, in which space-charge effects and conductivity losses are considered. The results are compared with those obtained by CST-PS code PIC simulations.

Tuesday, August 25, 2015

08:45 - 09:00	**Morning Announcements**	**Lecture Theatre 1**
09:00 - 10:30	**Plenary Session P3-P4**	**Lecture Theatre 1**
	Chairpersons: George Neil;	
09:00	**Anti-Hermitian Optics And Parity-time Lasers**	**P3**
	Xiang Zhang	
09:45	**Terahertz Quantum Cascade Lasers -- The Past, Present, And Potential Future**	**P4**
	Edmund Linfield; A Giles Davies; Paul Dean	
	Since their first demonstration in 2002, the development of terahertz frequency quantum cascade lasers has been extremely rapid. We overview some of the advances that have taken place and which have made the terahertz quantum cascade laser such a ubiquitous source. We also consider potential future directions for terahertz quantum cascade laser technology, including its use in satellite-borne instrumentation for future Earth observation and planetary science missions.	
11:00 - 12:30	**T1A - 09 - Imaging and Remote Sensing II**	**Lecture Theatre 2**
	Chairpersons: Zhiming Huang;	
11:00	**Probing Thermal Evanescent Waves On Dielectric Surfaces**	**T1A-1**
	Yusuke Kajihara; Takafumi Yokoyama; Kuan-Ting Lin; Sunmi Kim	
	Our passive near-field microscope probes thermal evanescent waves. With the microscope, we study dielectric samples since they have surface phonon resonances very close to our detection wavelength. GaAs, SiC, and AlN show reasonable signals due to thermal phonons, whereas GaN show very unique characteristics. In this report, we show and discuss the results.	
11:30	**A 0.6-1.2 THz Monolithic Imaging Array**	**T1A-2**
	Dan Corcos; Noam Kaminski; Danny Elad; Thomas Morf; Winnie Tatiana Silatsa Saha; Ute Drechsler; Lukas Kull; André Bischof; Yingyun Zha	
	A 19x8 pixel array with a read-out integrated circuit was designed and fabricated in a micro-machined SOI-CMOS process. The pixels are antenna-coupled MOSFET bolometers operating at room temperature in a wide 0.6-1.2 THz band. The read-out circuit features column multiplexed differential amplifiers, offset calibration capability and chopper stabilization. The post-processed pixels showed a responsivity of the order of 61 kV/W. Their typical measured noise voltage spectral density (VSD) is 2.1 μV/Hz^1/2 at 1 Hz with 1/f spectrum. The read-out circuit has a low input referred noise of 5 μV RMS, which is about half the RMS pixel noise, and it drops to 1 μV if signal chopping is applied. The column amplifiers includes a 5 bit DAC for coarse offset cancellation. The measured DAC range is 5 mV (168 μV/LSB), which is sufficient for cancelling the variance of the amplifier's offset voltage. In this talk we will present the performance of the read-out circuit building blocks, as well as characterization results of the pixels.	
11:45	**Preliminary Results Of Narrowband Doppler Radar Imaging Using Real Data In The 0.5 THz Frequency Band**	**T1A-3**
	Pawel Dzwonkowski; Witold Dyszynski; Piotr Samczynski; Krzysztof Kulpa; Anna Kurowska	
	In this paper preliminary results of radar imaging measurements using a narrowband signal in the low terahertz band are presented. Measurement system architecture as well as the narrowband imaging technique are also discussed. Verification of the theoretical method of acquiring images by the use of narrowband signal through its application to real radar data is presented. Additionally, the results obtained are compared with the results acquired using the Inverse Synthetic Aperture Radar (ISAR) technique utilizing a bandlimited signal.	
12:00	**Characterization Of A THz SLM And Its Application For Improved High Resolution THz Imaging**	**T1A-4**
	Jan Hieronymus; Sven Augustin; Heinz-Wilhelm Hübers	

08:45 - 09:15 **Welcome and Opening Remarks** — **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Spatial light modulators (SLM) can be used for many applications, including imaging and beam steering. With the emergence of THz SLMs being able to control thousands of pixels, the aforementioned applications become feasible for the THz region. The degree of control that can be exerted with a SLM and in turn its usefulness directly depends on the light pattern it creates. The resulting light patterns can be quite different from the intended light patterns, due to systematic and random non-uniformities, especially for large THz wavelengths. Here we present results on the performance of a Germanium based THz SLM. These results enable the efficient application of Compressed Sensing techniques in THz SLM imaging settings.

12:15 **High-Power Terahertz Non-Diffractive Bessel Beams With Angular Orbital Momentum: Generation And Application** — **T1A-5**

Boris Knyazev; Yulia Choporova; Mikhail Mitkov; Vladimir Pavelyev; Boris Volodkin

Using radiation of the Novosibirsk free electron laser (NovoFEL) and silicon binary phase plates with spiral Fresnel zone patterns, we generated for the first time non-diffracting terahertz Bessel beams with angular orbital momentum ("vortex beams") and topological charges l= 1, 2. The amplitude and phase characteristics of the beams at a wavelength of 141 μm were thoroughly investigated and showed excellent agreement with numerical modelling based on scalar diffraction theory. We have demonstrated self-reconstruction of the beams passing non-uniform media. We studied the peculiarity of vortex beam diffraction on different apertures, generated surface plasmon polaritons by the end-fire coupling technique, and discovered unusual features in the mechanism of coupling of the vortex beams.

11:00 - 12:30 **T1B - 20 - Quantum Cascade Lasers I** — **Lecture Theatre 3**

Chairpersons: Edmund Linfield;

11:00 **Terahertz Pulse Generation From Quantum Cascade Lasers** — **T1B-1**

Feihu Wang; Kenneth Maussang; Souad Moumdji; Raffaele Colombelli; Joshua Freeman; Iman Kundu; Lianhi Li; Edmund Linfield; Giles Davies; Juliette Mangeney; Jerome Tignon; Sukhdeep Dhillon

We demonstrate the generation of 11ps terahertz pulses from metal-metal (MM) quantum cascade lasers (QCLs) at 77K via active mode-locking. Contrary to popular belief that a long gain recovery time is required, we demonstrate that the dominant factor necessary for active pulse generation is in fact the synchronization between the propagating electronic microwave modulation and the generated THz pulses in the QCL. This allows the THz pulse to propagate in phase with the microwave modulation along the gain medium, permitting pulse generation.

11:30 **Self-Mixing Imaging Using A Terahertz Quantum Cascade Amplifier** — **T1B-2**

Robert Wallis; Yuan Ren; David Jessop; Riccardo Degl'Innocenti; Adam Klimont; Harvey Beere; David Ritchie

We demonstrate a terahertz imaging system utilizing self-mixing in a 2.9 THz quantum cascade amplifier, through the use of an anti-reflection coated silicon lens to completely suppress lasing action. The fully exploited optical gain of the quantum cascade amplifier allows induced voltage perturbations to be spatially mapped with a signal to noise ratio of up to 55 dB and an acquisition rate of up to 20,000 pixels per second.

11:45 **Metal-Metal Terahertz Quantum Cascade Laser With Hybrid Mode Section** — **T1B-3**

Paul Dean; Hanond Nong; Tobias Fobbe; A. Giles Davies; Reshma A. Mohandas; Nathan Jukam; Sergej Markmann; Lianhe Li; Rüdiger Schott; Andreas D. Wieck; Shovon Pal; Edmund H. Linfield; Negar Hekmat

A hybrid mode section at an out-coupling facet of a metal-metal terahertz quantum cascade laser (QCL) is fabricated by removing sub-wavelengths portions of the top metal. This allows the mode to penetrate into the air which improves the out-coupling performance. Further improvements are obtained if the length of the hybrid section satisfies the criteria for constructive interference. The addition of the hybrid section is shown to increase the emitted power by over a factor of 2.

12:00 **Observation Of Time-resolved Gain Dynamics In A Terahertz Quantum Cascade Laser** — **T1B-4**

Sergej Markmann; Hanond Nong; Shovon Pal; Negar Hekmat; Reshma A. Mohandas; Paul Dean; Lianhe Li; Edmund H. Linfield; A. Giles Davies; Andreas D. Wieck; Nathan Jukam

The dynamic response of a terahertz quantum cascade laser is probed as a function of time. The gain of the THz QCL is saturated by injection seeding the laser with an initial THz seed pulse. The time-resolved gain of the injection seeded laser is then probed with a second THz pulse.

12:15 **Phase Locking Of A 2.5 THz Quantum Cascade Laser To A Microwave Reference Using THz Schottky Mixer** — **T1B-5**

Berhanu Bulcha; Jeffrey Hesler; DongAlex Valavanis; Vladimir Drakinskiy; Jan Stake; Dong Rui; Jingxuan Zhu; Paul Dean; Lianhe Li; Giles Davies; Edmund Linfield; Nicolas Barker

The frequency of a 2.5 THz QCL are stabilized to sub-hertz accuracy by phase-locking to a stable 100 MHz microwave reference, using a 2.3--3.2 THz room temperature Schottky diode based harmonic mixer. The down-converted phase locked beat note is stable over a long term test.

11:00 - 12:30 **T1C - 25 - Ultrafast Measurements II** — **Lecture Theatre 4**

Chairpersons: Jean Leotin;

11:00 **Electrical Detection Of THz Ramsey Interference For Orbital Transitions In Silicon Donor Impurities** — **T1C-1**

Ben Murdin

Shallow donor impurities in silicon, once frozen out at low temperature, share many properties in common with free hydrogen atoms. They have orbital transitions at THz frequencies, such as the 1s to 2p for Si:P at 9.25 THz. We investigated the time-domain dynamics using short, intense pulses from a free electron laser. Recently we have demonstrated coherent control of superpositions of orbital states, important for applications in quantum information science and technology. I shall describe here the electrical detection of such superpositions, following a variety of THz pulse sequences.

11:30 **Photoconductive Terahertz Receivers Utilizing Single Semiconductor Nanowires** — **T1C-2**

Lan Fu; Fan Wang; Michael Johnston; Hannah Joyce; Qiang Gao; Jessica Boland; Patrick Parkinson; Hoe Tan; Nian Jiang; Chennupati Jagadish; Kun Peng; Ya-Nan Guo

We have demonstrated phase sensitive detectors of coherent terahertz radiation that use single nanowires as active elements. The single GaAs/AlGaAs nanowires acted as sensitive photoconductive elements within a gold antenna structure on quartz. The detectors were also implemented in a terahertz time domain spectroscopy (THz-TDS) system. Our devices show great promise as near-field terahertz sensors or as components for on-chip terahertz micro-spectrometers.

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

12:00 **Picosecond VIS-FIR Photoconductive Germanium Detector** **T1C-3**

Sergey Pavlov; Nils Deßmann; Andreas Pohl; Nikolay Abrosimov; Stephan Winnerl; Jacob Otto; Roman Zhukavin; Dmitry Shengurov; Veniamin Tsyplenkov; Konstantin Kovalevsky; Valery Shastin; Heinz-Wilhelm Hübers

A broad-band fast germanium detector based on unipolar and bipolar photoconductivity has been demonstrated. Typical response times are about 200 ps. Such short times are realized by using heavily doped and highly compensated germanium crystals.

12:15 **Detection Of Individual Terahertz Pulses At 80 MHz Repetition Rate** **T1C-4**

Florian Rettich; Nico Vieweg; Oleg Cojocari; Anselm Deninger

We present a novel technique to detect individual terahertz pulses at a repetition rate of 80 MHz. Our setup combines a femtosecond fiber laser, an InGaAs-based terahertz emitter, a zero-bias Schottky detector, and a high-speed data acquisition unit. The detected pulses consist of two lobes with half-widths of 1-2 ns, which is much shorter than the inverse repetition rate of the laser. The system lends itself for high-speed terahertz transmission measurements, e.g. to study wetting dynamics in real time.

11:00 - 12:30 **T1D - 08 - Sources, Detectors, and Receivers III** **Lecture Theatre 6**

Chairpersons: Rupert Huber;

11:00 **Plasmonics Enabled Advances In Photoconductive Terahertz Radiation Sources** **T1D-1**

Mona Jarrahi

We present an overview of recent advances in photoconductive terahertz sources that utilize plasmonic nanostructures to significantly enhance optical-to-terahertz power conversion efficiency by enhancing light-matter interaction at nanoscale. We show that the impact of the plasmonic nanostructures on enhancing the optical-to-terahertz conversion efficiency of photoconductive terahertz sources is universal and can be employed in various types of photoconductive source designs under various operational settings.

11:30 **YBaCuO HEB Hot-spot Model With Non-uniform RF Power Absorption: THz Mixing Frequency-dependent Performance** **T1D-2**

Romain Ladret; Annick Dégardin; Alain Kreisler

Introduction and Background. During the past decade, superconducting hot electron bolometers (HEB) have been the object of unceasing progress, especially for low-TC devices. Efforts on high-TC YBaCuO HEBs have been more limited, however, with few published results because ultrathin film YBaCuO technology has proven difficult due to chemical reactivity and aging effects. Besides, early predictions were encouraging, with noise temperature TN ~ 1000 K DSB at PLO = 11 µW local oscillator (LO) power for an YBaCuO constriction of length L = width w = 100 nm and thickness θ = 10 nm. This model was based on the "0-D" point bolometer approach that describes the system in terms of thermal reservoirs only, namely the (hot) electrons at temperature Te and the phonons at temperature Tp < Te. Furthermore, the "1-D" hot spot model that includes the spatial dependence along the superconducting constriction as Te(x), was implemented for low-TC HEBs. Our initial motivation was to extend this model to YBaCuO, while taking the high-TC specificities into account. Our main objective here is to introduce the THz frequency dependence to predict the HEB mixer noise temperature and conversion gain.

Model implementation. We have dropped the usual hypothesis that considers the LO power to be uniformly absorbed over the HEB constriction length L. We have substituted to it the major assumption that the THz current is now constant along the constriction, hence a non-uniform LO power absorption. The local electron temperature Te(x) was obtained by solving the coupled electron and phonon thermal reservoir equations, which could be used to determine the local YBaCuO complex resistivity (from the superconducting impedance transition), hence the locally dissipated LO power. A modified two-fluid model description allowed deriving the mid-transition temperature shift (about -1% per THz) and transition broadening (about +20% per THz). Another outcome of the model was to obtain the constriction global THz impedance, hence the ability to introduce the power matching coefficient to the antenna.

Results. The device simulations provided first the DC current-voltage plots under LO pumping, which were in line with available experimental results (both low-TC and high-TC HEBs), and so confirmed the non-uniform LO power assumption. Secondly, we considered the mixer TN (DSB) and conversion gain G. DC current vs. voltage maps allowed to exhibit the conditions for optimal LO pumping power. For a typical medium size constriction of L = w = 400 nm and θ = 35 nm, and at the optimal LO power of 9 µW, TN (G) ranged from 1900 K (-10 dB) below 100 GHz, through 2700 K (-13 db) at 1 THz, to 4150 K (-15 dB) at 2.5 THz, in agreement with published data.

Acknowledgment. This work is being supported by the French National Research Agency (ANR) under grant # 2011-BS03-008-01.

11:45 **Wideband SIS Receiver Development For The Submillimeter Array** **T1D-3**

Cheuk-yu Edward Tong; Lingzhen Zeng; Paul Grimes; Raymond Blundell

Millimeter and submillimeter receivers benefit from a large instantaneous operating bandwidth, B. If the receiver is used for the remote sensing of the temperature of a distant object, the radiometer equation states that the resultant uncertainty in the observation varies inversely as the square root of B. In the case of spectroscopy, a wider bandwidth allows multiple spectral lines to be observed simultaneously. In this paper, we report on the development of wideband receivers for the Submillimeter Array, a radio interferometer on Mauna Kea, Hawaii. Like most observatories for millimeter and submillimeter wavelengths, we employ state-of-the-art receivers based on the superconductor-insulator-superconductor (SIS) mixer. In order to increase the instantaneous bandwidth of the SIS mixer, we have employed series connected SIS junction array with low output capacitance at the intermediate frequency (IF). As the output bandwidth increases, the mixer also becomes more prone to saturation effects. The use of a series junction array increases the dynamic range of the mixer and thereby facilitates the wideband operation. We have also developed a wideband cryogenic isolator, which operates over 2 octaves of frequency range. This isolator provides a wideband match between the SIS mixer and the low noise amplifier, which follows it. Receivers for the Submillimeter Array are now operating with an IF of 4 -- 14 GHz. Recently, we have further pushed the frontier of wideband SIS mixing. We have demonstrated a low noise receiver operating at 270 GHz, which delivers an IF output between 4 and 18 GHz. The details of the design and performance will be described in this paper.

12:00 **Plasmonic Enhanced Optical Coupling Effect On The Quantum Well Infrared Photodetector** **T1D-4**

Youliang Jing; Zhifeng Li

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

In conclusion we demonstrate the design of a novel plasmonic coupling structure for quantum well infrared photodetectors by inserting gold disk arrays to the interface between Au reflection film and a finite-thick dielectric layer. The simulated electric field distribution shows that the resonant mode squeezes most of optical energy into the quantum well layer, leading to a 10.5-fold enhancement of the average of electric field in z direction in quantum well layer. We believe that this plasmonic structure opens a new way to improve performance of photoelectric devices.

12:15 **The Use Of Higher Harmonics For Sub-THz Generation In Relativistic Virtual Cathode Oscillator** **T1D-5**

Semen Kurkin; Artem Badarin; Alexey Koronovskii; Alexander Hramov

We study the microwave generation regimes with intense higher harmonics taking place in a high-power virtual cathode oscillator (vircator) consisting of a relativistic electron beam with a virtual cathode. It has been shown that the system under study demonstrates the tendency to the sufficient growth of the amplitudes of higher harmonics in the spectrum of current oscillations in the virtual cathode region with the increase of beam current. The obtained results allow us to consider relativistic vircators as promising high power mmw-to-THz sources.

11:00 - 12:30 **T1E - 21 - Gyro-Oscillators and Amplifiers II** **Lecture Theatre 7**

Chairpersons: Weili Zhang;

11:00 **Progress And Status Of The Gyrotron Development For The JT-60SA ECH/CD System** **T1E-1**

Takayuki Kobayashi; Masayuki Sawahata; Masayuki Terakado; Shinichi Hiranai; Ryosuke Ikeda; Yasuhisa Oda; Kenji Wada; Jun Hinata; Kenji Yokokura; Katsumichi Hoshino; Koji Takahashi; Akihiko Isayama; Shinichi Moriyama; Keishi Sakamoto

High-power, long-pulse operations of a gyrotron for JT-60SA (Super-Advanced) have been carried out at 110 GHz (1 MW/100 s) and 138 GHz (1 MW/100 s). These results fully satisfied the requirements of the electron cyclotron heating and current drive (ECH/CD) system in JT-60SA. It was experimentally shown that the higher power operation at each frequency is expected to be acceptable for this gyrotron from the viewpoint of heat load at the cavity resonator, collector, and stray radiation absorbers. An oscillation of 1 MW for 1 s at 82 GHz has been demonstrated as an additional frequency of the same gyrotron. Experiments toward 1.5 MW or higher at 110 GHz and 138GHz are ongoing.

11:30 **Feasibility Study Of TM Modes For Electron Cyclotron Maser** **T1E-2**

Tsun Hsu Chang; Wei Chen Huang; Wei Chen Chen

The transverse magnetic (TM) modes have long been considered as the unsuitable waveguide modes for the operation of the electron cyclotron maser (ECM). This study investigates the linear behavior of the TM modes and reveals for the first time that certain TM modes might be suitable for gyrotrons --- ECM based devices. In addition, non-linear but non-self-consistent model shows that for a fixed field profile the efficiency could be as high as that of the transverse electric (TE) modes. Such interesting findings deserve more theoretical and experimental studies, and might facilitate some applications.

11:45 **Generation Of Ultrashort Microwave Pulses In Gyro-TWT With Saturable Cyclotron Absorber In The Feedback Loop** **T1E-3**

Naum Ginzburg; Gregory Denisov; Mikhail Vilkov; Irina Zotova; Aleksander Sergeev

For gyro-TWT possibility of production of ultrashort microwave pulses with peak power strongly exceeding the power in stationary generation regime has been demonstrated. This effect can be achieved due to installation in feedback loop addition section with non-linear saturable absorber. In high power microwaves as such absorber an additional section may be used, where radiation interacts with initially rectilinear electron beam under cyclotron resonance condition.

12:00 **Project Of A Third Harmonic W-band Gyroamplifier** **T1E-4**

Sergey Mishakin; Sergey Samsonov; Gregory Denisov

In this paper we present design of a broadband third-harmonic operating gyro-amplifier with helically corrugated interaction circuit. An analysis of stability of the gyro-TWT with respect to parasitic wave-beam interactions has been performed and the range of parameters at which the gyro-TWT is zero-drive stable is found. According to 3D simulations, the amplifier yields a 6% amplification bandwidth with the maximum output power/gain of 80 kW / 25 dB for a 10-A, 70-kV electron beam

12:15 **Non-Autonomous Regimes In Gyrotrons With Low-Q Resonators** **T1E-5**

Irina Zotova; Naum Ginzburg; Mikhail Glyavin; Alexander Sergeev; Roman Rozental; Anrey Fokin

Based on the description of wave propagation by a parabolic equation the time-domain theory of non-autonomous operation of gyrotrons with low-Q resonators has been developed. The influence of external signal is taking into account by modification of boundary condition at resonator output. Developed model can be effectively used for simulations of frequency-locking of gyrotron by external signal in soft and hard operation modes, frequency pooling with reflection from remote load, synchronization of several coupling gyrotrons.

14:00 - 15:30 **T2A - 09 - Imaging and Remote Sensing III** **Lecture Theatre 2**

Chairpersons: Derek Abbott;

14:00 **Room-Temperature Remote Sensing: Far-Infrared Imaging Based On Thermopile Technology** **T2A-1**

Giacomo Mariani; Matthew Kenyon

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. For space mission, this work will focus on the current development of detectors able to tolerate the harsh radiation environment at Europa (Jupiter's Moon) to understand the Moon's geology and habitability, while providing vital reconnaissance for future landed missions.

14:30 **Externally Triggered Terahertz Imaging For Microbolometer Focal Plane Array** **T2A-2**

Naoki Oda; Takayuki Sudou; Takao Morimoto; Tsutomu Ishi; Syuichi Okubo; Goro Isoyama; Akinori Irizawa; Keigo Kawase; Ryukou Kato

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Both 640x480 and 320x240 terahertz (THz) imagers were developed whose sensitivity were improved in sub-THz region by a factor of 10. The imagers include functions such as external-trigger imaging, lock-in imaging, beam profiling and so forth. The function of the external-trigger imaging was verified, using the pulsed THz free electron laser developed by Osaka University.

14:45 **Immersion In Refractive Index Matching Liquid For 2D And 3D Terahertz Imaging** **T2A-3**

Jean Baptiste Perraud; Joyce Bou Sleiman; françois Simoens; Jean Paul Guillet; Patrick Mounaix

We investigate the possibility to limit refraction effect at interfaces between a sample and a liquid medium to improve resolution in 2D and 3D terahertz imaging. Indeed, an important part of the terahertz beam is reflected, diffracted and refracted at each interfaces because of refractive index mismatch. We propose to adapt the refractive index of medium around the sample replacing surrounding air by medium with an optimized refractive index and low absorption coefficient. This approach will be developed to recover good dimension for metrology and to improve reconstruction by tomography algorithm

15:00 **A Sparse Multistatic Imaging System For Terahertz Volume Inspection** **T2A-4**

Bessem Baccouche; Andreas Keil; Matthias Kahl; Peter Haring Bolívar; Torsten Löffler; Joachim Jonuscheit; Fabian Friederich

Frequency modulated terahertz imaging systems have shown a great potential for volume inspections in the industrial process and quality control. However, many system concepts lack the capability to encompass a large field of view with fast data acquisition speed, while providing significant depth information. Based on our recently outlined system design of a terahertz imaging solution for the industrial process control, we report on the realization of a stepped-frequency modulated sparse array with 12 emitters and 12 heterodyne receivers operating in the frequency range from 75 GHz to 110 GHz. The system is ready to perform imaging tasks and will in a final step be combined with a band-conveyor for fast terahertz image acquisition.

15:15 **Towards Root Phenotyping In Situ Using THz Imaging** **T2A-5**

Nick Smith; Luis Rivera; Nathan Burford; Tyler Bowman; Magda El-Shenawee; Guilherme DeSouza

Root growth and development are critical for plant survival and productivity. While systems have been developed to automate the process of extracting root traits using 2D and 3D imaging under controlled conditions, to date, no systems exist that can non-destructively and repeatedly provide high-quality information on roots of field-grown plants. At the same time, Terahertz (THz) imaging is becoming a valuable tool in many areas, including medicine, pharmacology, security, etc. and has the potential for non-destructive, repeated imaging of root systems growing in pot and eventually field conditions. In this paper, we present a framework for investigating root growth and function of plants by analyzing and classifying THz data. The proposed system can successfully identify organic materials from potting soil or sand using both THz transmitted and reflected signals.

14:00 - 15:30 **T2B - 17 - MMW and Sub-millimeter Wave Radar and Communications I** **Lecture Theatre 3**

Chairpersons: Shengcai Shi;

14:00 **Parallel-plate Leaky Waveguides In The Terahertz Range** **T2B-1**

Daniel Mittleman; Nicholas Karl; Robert McKinney; Rajind Mendis; Yasuaki Monnai

The idea of using radiation in the 0.1-1.0 terahertz (THz) range as carrier waves for free-space wireless communications has attracted growing interest in recent years, due to the promise of the large available bandwidth. Recent research has focused on system demonstrations, as well as the exploration of new components for modulation and beam steering. However, the multiplexing and demultiplexing of terahertz signals remains an unaddressed challenge, despite the importance of such capabilities for broadband networks. One promising approach involves the use of leaky-wave devices. Leaky-wave antennas have been used as directional antennas in the microwave and RF ranges since the 1940's. In a leaky-wave antenna, a traveling wave is guided along a waveguiding structure and radiates outward azimuthally from the propagation axis. Often, the guide is a rectangular waveguide, for which the travelling wave is a fast wave with a phase velocity greater than the vacuum speed of light. The guided wave leaks into free space through an opening (a slot) in one of the waveguide walls. Although this mechanism can also work in the THz range, direct scaling of a rectangular waveguide from microwave to THz is challenging due to the increasing metallic losses and fabrication tolerance. Here, we investigate the use of a metal parallel-plate waveguide (PPWG) as a practical implementation of a leaky-wave structure in the terahertz range.

14:30 **Data Transfer By Frequency Comb Method With High-power Pulsed Terahertz Source** **T2B-2**

Yaroslav Grachev; Xinrui Liu; Anton Tsypkin; Sergei Putilin; Victor Bespalov; Sergei Kozlov; Xi-Cheng Zhang

Frequency comb in terahertz spectrum with element bandwidth of 0.03 THz utilizing high-power pulsed source are obtained. Data encoding and transmission via terahertz frequency comb are demonstrated. Information encoded in frequency comb by Si plate filter transferred on 60 cm in spectrum of two terahertz pulses.

14:45 **Portable Low THz Imaging Radars For Automotive Applications** **T2B-3**

David Vizard; M Gashinova; Edward Hoare; Mikhail Cherniakov

Compact frequency extenders enable the current generation of portable network analysers to be used in the low THz bands of 150 - 300 GHz. The wide instantaneous bandwidth of these extenders support complex waveforms within systems intended for automotive radars and communication networks. Recent experimental results of such radars intended for atmospheric measurements and autonomous vehicle applications are described.

15:00 **Fundamental Field Evaluations Of Radio-over-Fiber Connected 96 GHz Millimeter-Wave Radar For Airport Surface Foreign Object Debris Detection** **T2B-4**

Shunichi Futatsumori; Kazuyuki Morioka; Akiko Kohmura; Kunio Okada; Naruto Yonemoto

Even if the debris on an airport surface is of small volume and light weight, these objects may cause damage to aircraft. For example, a thin metallic strip caused fatal damage to an aircraft. To detect these small debris, the foreign object debris (FOD) detection systems have been developed based on various technologies. The millimeter-wave radar systems are suitable devices for the FOD detection systems from its high-sensitivity, high-range resolution and weather robustness. We have been developing a FOD detection radar system utilizing W-band. The developed radar system has a radar signal generation unit and radar antenna units. To reduce the number of the high-cost complicated radar signal generator and processor, these units are connected by optical fibers based on Radio-over-Fiber (RoF) technology. In this paper, the field evaluation of the test bed millimeter-wave radar system using buried optical fibers at an actual airport is discussed. In addition, the generations and the transmission of the radar signal are described.

The developed FOD detection millimeter-wave radar utilizes the frequency band within 92 GHz and 100 GHz. The 16 GHz radar baseband signal, which is a sixth part of millimeter-wave radar signal, is generated at the signal generation unit inside the facility building. Then, the electric signal is converted to the optical signal. To improve the long distance RoF transmission

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

characteristics, the optical double sideband suppressed-carrier transmission technique is applied. By using the suppressed-carrier method, the dispersion characteristic of the optical fiber can be negligible. Then, the signal is transmitted to the radar antenna unit at the side of the runway. The buried 1,050 m single-mode fiber is used for the radar signal transmission. From the measured 1-dimensional radar range spectrum at field test, it is confirmed the 30 dBsm radar reflector is located on the runway, is observed 62 m away from the radar antenna. The field feasibility, which utilize the actual buried optical fiber at the airport, is experimentally confirmed by the measurement.
The fundamental characteristics of the RoF connected 96 GHz millimeter-wave radar system was evaluated at an actual airport. The millimeter-wave radar transmission signal was delivered to the antenna unit through the optical fibers more than 1,000 m in length. In addition, the reflection signal from the target located on the runway was confirmed by the field test.

15:15 **A 2×40 Gbps Wireless Communication System Using 0.14 THz Band Oritho-Mode Transducer** **T2B-5**
Changxing Lin; Bin Lu; Cheng Wang; Qiuyu Wu
Based on 16QAM modulation, a 2×40 Gbps wireless communication demonstration system using 0.14 THz band oritho-mode transducer (OMT) is presented in this paper. The OMT is used for polarization division multiplex (PDM) transmission of the 0.14 THz band wireless link. The measured isolation of the designed OMT is more than 30 dB at 0.14 THz band, while the insertion loss is less than 1 dB. With this OMT, the wireless link succeeds in data transmission of 2×40 Gbps data over 1.5m with bit error rate (BER) < 10^-6, SNR > 23 dB.

14:00 - 15:30 **T2C - 05 - Spectroscopy and Material Properties III** **Lecture Theatre 4**

Chairpersons: Juraj Sibik;

14:00 **Research Progresss On Multidimensional Space Joint-observation SAR** **T2C-1**
Wen Hong
With the application requirement and technology development, the necessity and tendency of Synthetic Aperture Radar (SAR) imaging within the framework of multidimensional space joint-observation, which are polarimetry, frequency, angle, time series and etc., evoke catholic interests in SAR imaging research nowadays. Recent research progress on the Multidimensional Space Joint-observation SAR (MSJosSAR) in the National Key Lab of Microwave Imaging Technology, Institute of Electronics, Chinese Academy of Sciences(MITL-IECAS) is reported in this talk, where the a sphere cluster cordinate system is defined as the modeling basis on the demand of information fusion for SAR multidimensional space joint-observation. Further more, the advantage of MSJosSAR is revealed by using Kronecker product decomposition for better understanding of target scattering mechanisms, with the hypothesis and basic framework on which the MSJosSAR signal processing relies on. Tentative studies on multi-layer material with PolinSAR technique, anisotropic scattering mechanisms with multi-directional observation (cuverture or circular SAR technique), and instantaneous time-variant target with array SAR technique are demonstrated as the initial verification of the above defined hypothesis and framework. Finally, the value of joint observation space numbers for typical SAR configurations is enumerated, followed by the perspective discussions on the future work for MSJosSAR study.

14:30 **Ultrabroadband Terahertz Characterization Of Highly Doped ZnO And ITO** **T2C-2**
Tianwu Wang; Peter Jepsen
The broadband complex conductivities of transparent conducting oxides (TCO), namely aluminum-doped zinc oxide (AZO), gallium-doped zinc oxide (GZO) and tin-doped indium oxide (ITO), were investigated by using THz-TDS from 0.5 to 18 THz. The complex conductivities were accurately calculated using a thin film extraction algorithm and analyzed in terms of the Drude conductivity model. We find that a phonon response must be included in the description of the broadband properties of AZO and GZO for an accurate extraction of the scattering time, which is strongly influenced by the zinc oxide phonon resonance tail even in the low frequency part of the spectrum.

14:45 **Investigation Of The Terahertz Vibrational Modes Of ZIF-8 And ZIF-90 With Terahertz Time-domain Spectroscopy** **T2C-3**
Nick Tan; Michael Ruggiero; Claudia Orellana; Tian Tian; Andrew Bond; Tim Korter; David Fairen-Jimenez; Axel Zeitler
The terahertz spectra of ZIF-8 and ZIF-90 were acquired with terahertz time-domain spectroscopy (THz-TDS). Ab initio quantum mechanical calculations yield in spectra that match well with the experimental results and indicate that swing motions in these ZIFs may lie within the terahertz region. Variable temperature THz-TDS measurements on ZIF-90 suggest that the technique is sensitive to host-guest interactions, which can be used to study them in the future.

15:00 **Time- And Frequency-resolved Electrodynamics Of Germanium Nanoantennas For Mid-infrared Plasmonics** **T2C-4**
Michele Ortolani; Valeria Giliberti; Marco P. Fischer; Christian Schmidt; Alfred Leitensdorfer; Daniele Brida; Leonetta Baldassarre; Antonio Samarelli; Kevin Gallacher; Douglas J. Paul; Jacopo Frigerio; Emilie Sakat; Giovanni Isella; Paolo Biagioni
We investigate the mid-infrared response of heavily doped germanium films and periodic arrays of nanoantennas by both continuous wave transmission/reflection spectroscopy and ultrafast pump-probe spectroscopy. We compare the data to finite-element modeling electromagnetic simulations of the subwavelength nanostructures. The plasma frequency of the doped or optically activated semiconductor extends in the 1000-2000 cm^-1 range thus enabling access to molecular fingerprints. By Fourier transform infrared spectroscopy (FTIR) both in reflection and transmission geometry we demonstrate two orders of magnitude field enhancement factors in n-Ge nanoantennas. We assess that free carrier losses due to charged donor impurities and optical phonon scattering are extremely relevant in limiting the field enhancement factors. We propose that ultrafast activation by interband optical pumping of electron-hole pairs in i-Ge is a viable path to overcome both limitations, as charged impurities are not present in i-Ge and electron-phonon scattering times are longer than both the time needed to establish plasma oscillations and the mid-IR pulse length employed to probe the transient electrodynamics. Moreover, ultrafast mid-IR pulses provide extremely high field intensities for nonlinear plasmonics.

15:15 **Charge Transport In Sb-doped SnO2 Nanoparticles Studied By THz Spectroscopy** **T2C-5**
Volodymyr Skoromets; Hynek Němec; Kristina Peters; Dina Fattakhova-Rohlfing; Petr Kuzel
Terahertz (THz) spectroscopy is a pertinent tool for investigations of charge transport in weakly conducting materials as it enables contactless and broadband phase-sensitive probing of material conductivity. We employ time-domain THz spectroscopy supplemented with appropriate theoretical models to get an insight into the charge transport mechanisms in pellets made of undoped and antimony-doped (up to 10 %) tin-oxide nanoparticles synthesized via solvothermal reaction in tert-butanol. We study in detail how annealing influences the charge transport within individual nanoparticles and between them. Since the samples are inhomogeneous our analysis of the measured spectra must involve two steps. In the first one, we developed a model

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

for the microscopic conductivity, i.e., a response to the local THz electric field. In the second step, we took into account depolarization fields which define the relation between the incident THz pulse and the local field. The measured effective permittivity exceeded 4.5 in all samples. Such a high value cannot be achieved in an ensemble of isolated spheres. Therefore we conclude that the investigated nanoparticles form a network with a high degree of dielectric percolation. Undoped samples show very weak hoping-type conductivity which also perfectly correlates with their very low dc conductivity. We suggest that there are impurities or imperfections in the undoped material which are responsible for the hopping conduction. THz conductivity spectra of the doped samples have the real part starting at small non-zero values at low frequencies and increasing towards higher frequencies. Such spectral behavior is a signature of charge localization either as a result of the charge confinement or as a manifestation of the depolarization fields. We find that the doped samples show a band-like conduction of charges inside the nanoparticles. We calculate the conductivity using Monte-Carlo method, which takes into account microscopic properties of the material including nanoparticle size, mean carrier scattering in the interior of the nanoparticle and efficiency of inter-nanoparticle transport. Our fitting function is based on this conductivity and it also accounts for the porosity of the pellets and the phonon mode in SnO2. Calcination of undoped samples does not noticeably change the THz response. However, calcination of the doped samples leads to dramatic changes in the THz response. Calcination at low temperatures (200°C) before pressing leads to a poor intra-nanoparticle conductivity and to a very limited inter-nanoparticles transport. Calcination at elevated temperatures (500°C) before pressing enhances the intrinsic conductivity of the nanoparticles and increases also the conductivity of the contact area between the nanoparticles, but the interface resistance still remains rather high which limits the dc conductivity.Calcination after pressing improves both the intra-nanoparticle and the dc conductivity.

14:00 - 15:30 **T2D - 08 - Sources, Detectors, and Receivers IV** **Lecture Theatre 6**

Chairpersons: Lawrence Lves;

14:00 **Room-T Detection Of THz Radiation In Van Der Waals Heterostructures** **T2D-1**
Marco Polini
In this talk I will discuss why van der Waals heterostructures comprising graphene and hexagonal boron nitride are an ideal platform to realize resonant detectors of THz radiation operating at room temperature.

14:45 **Nitrogen-ion-implanted GaAs Fabry-Pérot Cavity Photoconductor For THz Photonics** **T2D-3**
Emilien Peytavit; Maximilien Billet; Yann Desmet; Guillaume Ducournau; Dmitri Yarekha; Jean-François Lampin
Ultrafast photoconductors using GaAs implanted by low energy N+ ions (55 keV) are fabricated and characterized up to 320 GHz by means of a photomixing experiment. Around 90 µW of output power was obtained at 290 GHz with a 2-µm-diameter photoconductor based on GaAs implanted with a main dose of 1.2×10^12 cm^-2 and a subsequent annealing at 600°C.

15:00 **Symmetry Effects In Broadband, Room-Temperature Field Effect Transistor THz Detectors** **T2D-4**
Stefan Regensburger; Martin Mittendorff; Stephan Winnerl; Hong Lu; Arthur C. Gossard; Sascha Preu
Rectifying large area field-effect Transistors (LA-FETs) are excellently suited for high power pump-probe experiments. They offer the possibility of single-shot measurements, as well as the simultaneous measurement of optical NIR pulses and their respective temporal delay.
This paper studies the phase of the rectified signal of LA-FET detectors for low and high THz frequencies.

15:15 **Broadband Tunable Supra-THz Test Sources** **T2D-5**
Eric Bryerton; Jeffrey Hesler; Steven Retzloff
Two broadband tunable sources are presented covering 1100-1500 GHz and 1750-2200 GHz. Both sources utilize a common driver chain covering the full WR-4.3 (170-260 GHz) band with >10mW output power. The WM-164 source provides greater than 1µW average power from 1100-1500 GHz. The WM-130 source provides greater than 0.5µW output power from 1750-2200 GHz.

14:00 - 15:30 **T2E - 12 - Devices, Components, and Systems II** **Lecture Theatre 7**

Chairpersons: Richard Averitt;

14:00 **W-Band Gallium Nitride MMIC Amplifiers For Cloud Doppler Radar Arrays** **T2E-1**
Andy Fung; Lorene Samoska; Pekka Kangaslahti; Greg Sadowy; Andrew Brown; Shane O'Connor; Darin Gritters
We present an effort in developing W-band (75-110 GHz) gallium nitride (GaN) monolithic microwave integrated circuit (MMIC) amplifiers for radar arrays. Due to GaN's high electric field breakdown capability and good 2D electron gas mobility in heterostructure field effect transistors, GaN power amplifiers provide best performance for high output power, high efficiency and small MMIC form factor amplifiers at W-band frequencies. GaN low noise amplifiers can also provide large receiver input dynamic range, reduce receiver noise figure and can be more tolerant of input power leakage from the transmitter without the need of protective limiter circuitry. All these characteristics are crucial for high frequency arrays where design require small circuit spacings, high efficiency to reduce power consumption and heating, and the minimization of circuit components for manufacturability and reliability. We will discuss results of power, driver and low noise amplifiers that we have designed, fabricated and characterized for radar array applications.

14:30 **Design And Performance Of Micro-Rectenna Arrays For Thermal Energy Harvesting** **T2E-2**
Yi Pan; Mark Rosamond; Andrew McDonald; Thomas Partridge; Claudio Balocco; Edmund Linfield; David Wood; Doug Cartwright
We report on the design and performance of a micro-rectenna device for harvesting wasted thermal energy. As an individual rectenna exhibits low efficiency and output power, we designed and studied a focal plane array (FPA) on a single semiconductor chip. Our FPA could be used for more general energy-harvesting applications as well as for THz imaging.

14:45 **Frequency Up-shifter For THz Light Via Relativistic Doppler Reflection** **T2E-3**
Nanase Kohno; Ryuji Itakura; Masaaki Tsubouchi
We realize the relativistic Doppler reflection of THz light from a counter-propagating plasma mirror in silicon (Si) with a practically simple geometry, which allows us to easily apply the frequency up-shift to the THz optics. The average frequency of the reflected THz light is 1.4 times higher than that of the input THz light. In view of application, the important facts are that the frequency up-shift can be achieved by a low pump energy density (1.3 µJ mm^-2), and that shifted frequency is almost

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

constant in the pump energy range above this threshold.

15:00 **Frequency Filters And Planar Lenses For The Terahertz Band: Configurations With Low- And High-Aspect Microstructures** **T2E-4**

Sergei Kuznetsov; Mikhail Astafev; Alexander Gelfand; Alexandr Gentselev; Victor Bessmeltsev

We overview the results of experimental development of high-performance frequency filtering and beam focusing devices operating at subterahertz and terahertz frequencies. The quasi-optical band-pass and high-pass filters, as well as planar lenses implemented as subwavelength metallized microstructures with thickness both of the order and much smaller than the wavelength are described. The techniques for fabricating these low- and high-aspect structures using lithographic and laser micromachining technologies are considered.

16:00 - 17:30 **T3A - 07 - Spectroscopy of Gases,Liquids, and Solids I** **Lecture Theatre 2**

Chairpersons: Joo-Hiuk Son;

16:30 **Evolution Of GaSe1-xSx Phonon Absorption Peaks With S-doping Studied By THz-TDS** **T3A-2**

John Molloy; Mira Naftaly; Yury Andreev; Konstantin Kokh; Gregory Lanskii; Valery Svetlichnyi

A dense set of solid solution crystals GaSe1-xSx is examined using THz-TDS. Evolution of phonon absorption peaks with the increase of S content is shown to have complex transformation, which should be considered in the design of dispersion equations for THz applications.

16:45 **Combined Infrared And Terahertz Analysis Of Amorphous Sorbitol** **T3A-3**

Juraj Sibik; Timothy Korter; Axel Zeitler

The nature and formation of the glassy state still lack comprehensive understanding. In this work we present a careful terahertz, FTIR, far-infrared, low frequency Raman and computational analysis using density functional theory on the inter-molecular hydrogen bonding characteristics and how this changes above and below the glass transition temperature in amorphous sorbitol. We show that the changes in inter-molecular bonding are strongly linked to the fast nanosecond-to-picosecond molecular dynamics occurring in the amorphous materials.

17:00 **Monitoring The Crystallization Of NaCl And NaI With THz ATR Spectroscopy** **T3A-4**

Amin Soltani; Eva Maria Stübling; Martin Koch

We monitor the crystallization of NaCl and NaI out of watery solution using THz attenuated total reflection (ATR) spectroscopy. The data give insight into the complex dielectric function of the solutions during the evaporation of the water

17:15 **Measurement Of The Complex Refractive Index Of Liquids And Biological Substances In The Terahertz Range At The NovoFEL Facility** **T3A-5**

Yulia Choporova; Ivan Azarov; Vasily Shvets; Boris Knyazev

Terahertz ellipsometric measurement system has been commissioned with the Novosibirsk free electron laser being a source of monochromatic radiation. The highest precision of {ψ, Δ} ellipsometric parameters have been achieved for the THz range (0.3° for ψ, 0.01 for cos(Δ)). Complex refractive index of various liquids has been measured in the THz range using the ellipsometer with a silicon-prism internal reflection system. Since the characterization of biologically important highly absorbing substances is one of the important applications for the THz ellipsometry, the measurement technique has been optimized both theoretically and experimentally for water solutions. Precision of the measurement of the absolute values of the real and imaginary parts of the refractive index (n, k) equal to 0.01 is achieved experimentally.

16:00 - 17:30 **T3B - 12 - Devices, Components, and Systems III** **Lecture Theatre 3**

Chairpersons: Haewook Han;

16:00 **Coplanar Stripline (CPS) Emitter And Transceiver Microprobes For Ultra-high Bandwidth On-chip Terahertz Measurements** **T3B-1**

Christopher Matheisen; Michael Nagel; Simon Sawallich

A novel THz emitter and transceiver for on-chip failure location and waveguide inspection is introduced. Based on a flexible PET cantilever it features a CPS waveguide for wearfree capacitive coupling to devices under test (DUTs). Embedded LT-GaAs photoconductive switches allow for ultra-high bandwidth THz pulse generation and detection which is demonstrated in exemplary measurements on CPS structures featuring different types of discontinuities. After coupling to the DUT pulse rise-times as short as 0.6 ps are achieved.

16:30 **A Cost Efficient And Scalable THz-QTDS System** **T3B-2**

Thorsten Probst; Arno Rehn; Jan C. Balzer; Martin Koch

In this work we present a low-cost and compact terahertz quasi time domain spectroscopy (QTDS) system based on inexpensive and commercially available components. The novel scheme allows for compact and robust system design at the lower end of the price segment.

16:45 **Millimeter-Wave WideBand Dielectric Resonator Antenna** **T3B-3**

Li Ying Feng; Kwok Wa Leung

A millimeter-wave wideband cylindrical dielectric resonator antenna (DRA) excited in its HEM113 and HEM115 modes is presented. The two modes are combined to widen the bandwidth, giving a wide 10-dB impedance bandwidth of more than 25%. The variation of the antenna gain is less than 3 dB across the impedance passband (|S11| < -10 dB).

17:00 **Conditioning Of Vertically Aligned Reduced Graphene Oxide Film Electron Emitter For Terahertz Vacuum Electronic Devices** **T3B-4**

In-Keun Baek; Ranajoy Bhattacharya; Jeong Seok Lee; Seontae Kim; Dongpyo Hong; Ohjoon Kwon; Yong Hyup Kim; Gun-Sik Park

The field emission from the edge of vertically aligned reduced graphene oxide (rGO) film was examined experimentally. High current (I > 5 mA) and high emission current density (J > 100 A/cm^2) was obtained using diode configuration. The thermal runaway of sharp protrusions on emission edge are considered to be source for the destructive vacuum breakdowns due to high local emission current. A remarkable field emission stability was achieved using processed field induced evaporation, by removing the protrusions and recovering the totally field emission attributed I-V characteristics.

08:45 - 09:15 **Welcome and Opening Remarks** — **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

16:00 **Polarization Dependence Of Chirp-induced Nonlinear Raman Scattering Spectroscopy Of Aqueous Ions And Organic Liquids In The THz Regime** — **T3C-1**

Stefan Funkner; Shun Nakae; Gudrun Niehues; Hideaki Kitahara; Kohji Yamamoto; Masahiko Tani

We present polarization dependent measurements of coherent Raman spectra of liquids with chirped ps-pulses in the THz regime. In order to detect the coherent Raman spectrum we made use of a, previously introduced, nonlinear pump and probe scheme involving an experimental technique called "spectral focusing". As a result, we are able to resolve spectrally stimulated Raman gain and inverse Raman scattering. Our experiment covers the entire THz range from 10 THz down to 100 GHz. Thereby, we show that different spectral features of aqueous ions and organic liquids can be distinguished using different polarization states of the pump beam

16:30 **Broadband Time-domain Terahertz Radar: Cross Section Measurement And Imaging** — **T3C-2**

Dachuan Liang; Minggui Wei; Jianqiang Gu; Zhen Tian; Chunmei Ouyang; Jiaguang Han; Weili Zhang

We have experimentally constructed a time-domain THz radar system. Full 360-degree RCS measurements on scaled model of Liaoning aircraft carrier and F-22 aircraft fighter are performed. The application of an advanced filtered back projection algorithm allows the reconstruction of a two-dimensional image, which shows the distribution of the scattering points on the model. THz time domain radar will be a powerful candidate tool for THz scattering and imaging researches.

16:45 **Stable CW THz Spectroscopy With PLC-LN Hybrid Phase Modulator** — **T3C-3**

Takuro Tajima; Masahito Nakamura; Ho Jin Song; Jae Young Kim; Katsuhiro Ajito; Akihiko Hirata

The photo-mixing THz generation method is especially promising because it can support the widest frequency range for phase-sensitive spectroscopy and imaging simply with free-running CW lasers by using homodyne detection. However, in the homodyne detection scheme, environmental temperature ambiguity induces sensitive phase variation, especially when a long-fiber setup is used. In this paper, we present the implementation of a photo-mixing-based CW-THz vector spectroscopy system that uses silica-based PLC photonics for compactness and stability. By using the PLC-LN hybrid assembly technique, a photonic THz phase control circuit, comprising electro-optic (EO) modulators, couplers, and waveguides, is hybrid integrated on a 400-mm^2-area of the silica-based PLC, which replaces fiber-optic parts in the previously reported system. We experimentally demonstrated THz generation and vector measurement using an InGaAs photoconductive receiver, wideband uni-traveling photodiode (UTC-PD), and the integrated phase control circuit with temperature control. The measured dynamic ranges are about 95 and 70 dB*Hz at 0.3 and 1 THz, respectively. The variation of the measured phase responses for 2 h in the open air of the experimental room. Although the phase response changed by about ± 2° in 2 h, the expected phase variation in short term is only about 0.8°. Therefore, combined with fast spectral measurement capability, the system is insensitive to the effect of environmental phase variation.

17:00 **Sub-THz Notch Filters Based On Photonic Bandgaps In Overmoded Waveguides** — **T3C-4**

Dietmar Wagner; Walter Kasparek; Fritz Leuterer; Alessandro Marcor; Francesco Monaco; Max Muenich; Emile DeRijk; Harald Schuetz; Joerg Stober; Manfred Thumm; Achim Zeitler

Photonic Bandgaps (Bragg reflectors) in moderately oversized corrugated waveguides can be applied as notch filters in the mm and sub-mm wavelength range. They offer unique options such as very steep frequency slopes, narrow or wide stop bands and very low insertion loss when compared to other technologies such as coupled cavity or Fabry-Pérot type filters. Also several defined stop bands within one frequency band are feasible.

17:15 **Electro-Optic THz-TDS Based On Laser Pulse Spectrum Changes** — **T3C-5**

Igor Ilyakov; Galiya Kitaeva; Boris Shishkin; Rinat Akhmedzhanov

Novel schemes for THz time-domain spectroscopy (THz-TDS) are suggested and approbated. Substantial improvement of the sensitivity compared to the standard electro-optic (EO) detection technique (at high frequencies) and to the previously shown technique based on laser pulse energy changes is demonstrated in experiment.

16:00 - 17:30 **T3D - 14 - High-Field THz Wave Generation and Nonlinear THz Physics II** — **Lecture Theatre 6**

Chairpersons: Kodo Kawase;

16:00 **Nonlinear Refractive Index For Crystals At Terahertz Frequencies** — **T3D-1**

Sergei Kozlov; Arkadiy Drozdov; Ksenia Dolgaleva; Robert Boyd

The lecture is devoted to the analysis of the nonlinearity of the refractive index for crystals at terahertz frequencies. We develop a simple analytical model for calculating the vibrational contribution to the nonlinear refractive index n_2 (Kerr coefficient) of a crystal in terms of known crystalline parameters such as the linear refractive index, the coefficient of thermal expansion, atomic density, and the reduced mass and the natural oscillation frequency of the vibrational modes of the crystal lattice.

17:00 **Nonlinear Response And Ultrafast Dynamics From Superconducting Thin Flims And Metamaterials** — **T3D-3**

Caihong Zhang; Biaobing Jin; Jian Chen; Masayoshi Tonouchi; Peiheng Wu

Recently, metamaterial in the terahertz (THz) region has become an attractive field as a novel approach to control and manipulate the electromagnetic waves. In this papaer, we report our recent development of nonlinear response and ultrafast dynamics from superconducting metamaterials at THz region measured by intense THz pump THz probe system. Both low temperature and high temperature superconducting thin films were studied for comparison.

17:15 **Contact Grating Device With Fabry-Perot Resonator Toward Intense THz Pulse Generation By Optical Rectification** — **T3D-4**

Masaaki Tsubouchi; Keisuke Nagashima; Fumiko Yoshida; Yoshiiro Ochi; Momoko Maruyama

A novel design for a contact grating device with an incorporated Fabry--Perot resonator is proposed for high-power terahertz light (THz) generation. We deposited a multilayer consisting of Ta2O5 and Al2O3 on a magnesium-doped stoichiometric LiNbO3 substrate and fabricated grating grooves on the outermost layer. The multilayer was designed such that conditions for a Fabry--Perot resonator were satisfied for light diffracted by the grating. Consequently, the diffraction efficiency was enhanced by the resonator. The diffraction efficiency of the fabricated device was 71%. THz light generation was also demonstrated with the contact grating device.

16:00 - 17:30 **T3E - 11 - Metamaterial Structures and Applications III** — **Lecture Theatre 7**

Chairpersons: Michael Johnston;

Monday, August 24, 2015

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

16:00 **Engineering The Meta-Resonances Toward Functional Terahertz Devices** **T3E-1**
Jianqiang Gu; Zhen Tian; jiaguang Han; Ranjan Singh; Chunmei Ouyang; Shuang Zhang; Cheng Sun; Weili Zhang
We present unique terahertz response of metasurfaces and proof-of-concept elements and components with an ultimate goal of developing next generation integrated photonic terahertz devices.

16:30 **Slow Light By Hybridized Concentric-Twisted Double Split Ring Resonators And THz Application** **T3E-2**
Mohamamd Parvinnezhad Hokmabadi; Elmer Rivera; Elizabath Philip; Ju-Hyung Kim; Patrick Kung; Seongsin Margaret Kim
Here, we demonstrate that hybridizing two double split ring resonator (DSRR) leads to two distinct characteristics dependent upon the rotational direction of the small SRRs. The large SRRs are stationary while the small SRRs rotate equally. Counter-directional rotation of small SRRs results in a red shift of the first resonance and blue shift of the second one, while co-directional twisting of small SRRs brings about splitting of the first resonance into two distinct modes. Therefore, a terahertz plasmon induced transparency (PIT) window with a slow light characteristic is observed in between two split modes.

16:45 **Perfect Imaging With A Wire Array Metamaterial Fiber** **T3E-3**
Korbinian Kaltenecker; Alessandro Tuniz; Alexander Argyros; Simon Fleming; Boris Kuhlmey; Markus Walther; Bernd M. Fischer
One promising approach to overcome the diffraction limit in THz imaging systems is the metamaterial hyperlens composed of an array of subwavelength scaled metal wires. Here we will present new results on transmission of near-field distributions of different resonant and plasmonic structures providing a distinct longitudinal polarized field pattern through a wire array metamaterial fibre imaged by using terahertz near-field microscopy.

17:00 **Epsilon-near-zero Metal-slit Array Antenna With Holes** **T3E-4**
Tatsuya Sato; Nozomu Koja; Takehito Suzuki
Metamaterials offer unprecedented refractive indices and have a strong potential for evolving into metadevices with on-demand electromagnetic properties today. However, it has yet to be fully understood how an epsilon-near-zero (ENZ) structure can open up the potential of terahertz metadevices with the expected extraordinary performance. We show that an ENZ metal-slit array antenna with holes can manipulate terahertz waves as observed by a terahertz camera. The ENZ structure may provide the potential for developing attractive applications in the terahertz waveband.

17:30 - 19:00 **TS - Poster Session 2** **YIA Lobby**

Chairpersons: Daniel Mittleman;

Terahertz Electro-Optic Properties Of PbZr0.52Ti0.48O3 And BaTiO3 Ferroelectric Thin Films **TS-1**
Lei Chen; Yuan Zhang; Quan Guo; Xiaowei Wang; Yilei Ge; Jianmin Yuan
we prepare PZT and BTO ferroelectric films by pulsed laser deposition on SrTiO3 substrates and study their material characteristics and electro-optic effects in the THz frequency range by measuring the electric field induced birefringence with the THz-TDS. Obvious electro-optic effects are observed in the THz frequency range. The PZT film exhibits a linear electro-optic effect while a predominantly quadratic and slightly asymmetric electro-optic behavior is observed for the BTO film. We also observe an obvious ferroelectric hysteresis phenomenon in BTO film in our experiments. The calculated electro-optic coefficients of the film samples in the terahertz range by means of the Landau-Devonshire free energy theory agree well with the experimental measurements. Our findings indicate that these two materials are potential candidates of THz modulators.

Correlated Terahertz And High Harmonic Generation From Aligned Molecules **TS-2**
Yindong Huang; Chao Meng; Xiaowei Wang; Zhihui Lv; Dongwen Zhang; Wenbo Chen; Jing Zhao; Jianmin Yuan; Zengxiu Zhao
We report the joint measurements of terahertz wave and high harmonic spectra generated from aligned nitrogen molecules. Our results show the yields of terahertz wave and high harmonics are sensitive to the alignment angle. This observation clarifies that electronic structure play an important role in the generation of terahertz and high harmonics from molecules.

Manipulating And Characterizing With Nanorobotics: In-situ SEM Technique For Centimeter And Millimeter Waves **TS-3**
Olaf C. Haenssler; Sergej Fatikow
Combining Scanning Electron Microscopy (SEM) and Microwave Microscopy is resulting in a hybrid microscope with multi-sensorial features. Parallelized measurements in the micro- and mm-wave region and manipulation of micro- and nano-scaled objects will be possible. Nanorobotic positioning stages with end-effectors inside the vacuum chamber of this microscope are controlled by an open-source automation software framework which also obtained live data and images of a Vector Network Analyzer (VNA) and the SEM.

Intense THz To IR Emission From Random 2D Metallic Nanostructures **TS-4**
Liangliang Zhang; Kaijun Mu; Yunsong Zhou; Hai Wang; Cunlin Zhang; X.-C. Zhang
We report an intense (~10mW) and ultra-broadband (~150 THz) THz to infrared (IR) source with a Gaussian wavefront, emitted from nano-pore-structured metallic thin films with femtosecond laser pulse excitation. The underlying mechanism has been proposed as thermal radiation. In addition, an intense coherent THz signal was generated through the optical rectification process simultaneously with the strong thermal signal. This unique feature opens up new avenues in biomedical research.

Powerful 60 GHz FEM With Advanced Bragg Resonator **TS-5**
Nikolai Peskov; Naum Ginzburg; Alim Kaminsky; Sergei Kuzikov; Elkuno Perelshtein; Sergei Sedykh; Vladislav Zaslavsky
Project of powerful FEM operating from Ka- to W-band and aimed to accelerating applications is developed in collaboration between JINR (Dubna) and IAP RAS (N.Novgorod) based on linac LIU-3000. The key components to advance the JINR-IAP FEM into short wavelengths are short-period tapered wiggler, which is responsible for high-quality helical electron beam formation, and advanced Bragg resonator with feedback loop including quasi-cutoff wave, which improves selectivity of the resonators over transverse coordinates and allows of the FEM operation with strongly transverse oversize of the interaction space. Present paper describes recent results on the FEM-oscillator at 60 GHz frequency range. In the proof-of-principal experiment narrow-band excitation of the FEM with multi-megawatt power level and the frequency belonging to designed feedback loop of the Bragg resonator was obtained.

Determination Of Moisture And Thickness Of Leather Using THz-TDS **TS-6**
A. I. Hernandez Serrano; S. C. Corzo Garcia; E. Garcia Sanchez; M. Alfaro; E. Castro Camus
We demonstrate that THz-TDS is novel non-contact technique useful for the determination of moisture and thickness of leather. The results are in good agreement with conventional techniques used in the tanning industry.

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Study On Radiation Source With Negative-index Materials **TS-7**

Dazhi Li; Y. Wang; Y. Wei; Z. Yang; S. Miyamoto

Currently, there is a surge of interest on the research of negative-index material (NIM), which shows many exotic and remarkable electromagnetic phenomena, such as reversed Cherenkov radiation and reversed Doppler shifts. Recent successes in fabricating these artificial materials have initiated an exploration into the use of them to investigate new physics and to develop new applications. As is known, electromagnetic surface wave along the interface between the vacuum and a certain material play an important role in development of a Cherenkov type radiation source. An electron beam travelling along the surface can interact with the electromagnetic surface wave with phase velocity synchronizing the electron's velocity and amplify the wave when oscillation conditions are satisfied. We find that the electromagnetic waves on the surface of a media made of negative-index materials hold special features. With using these features a novel radiation scheme is presented in this paper. We also designed the cell of negative-index material with the help of FDTD simulation. We consider a two-dimensional Cartesian coordinate. The electrons with velocity v initially move in the z direction in vacuum along the trajectories over a finitely thick plate with a perfect conductor substrate, and the electrons are coupled with the transverse magnetic (TM) mode of the electromagnetic wave. The system is assumed to be immersed in a strong external magnetic field such that the electrons move only in the z direction. Using boundary conditions, the dispersion equation between frequency and axial wave number for the wave-guide mode can be directly derived. The growth rate and start current for the system to oscillate can be obtained by numerically solving the equation. And it demonstrates that such a scheme can start oscillating even without external reflectors. A single cell with the type of split ring and wire is designed. With the help of FDTD simulations, we demonstrated that such a structure shows negative permeability and permittivity at about 13 GHz. The details including the beam-wave interaction and dimensions of the designed cell will be reported.

The Circuit Design And Particle-in-cell Simulation For A Ka-band Extended Interaction Klystron **TS-8**

Haiyu Zhang; Ding Zhao; Jirun Luo

An interaction circuit with a double-gap coupled cavity chain for a Ka-band extended interaction klystron (EIK) is designed in this abstract. By the 3D particle-in-cell (PIC) simulation, the output power of 1.26kW is achieved, and the efficiency and the gain reach 22.5% and 33.2dB under the beam voltage and beam current is 14kV and 0.4A, respectively.

Phase Calibration Of Oscilloscopes At Low Frequencies **TS-9**

Joogwang Lee; Chihyun Cho

This paper describes how to calibrate phase response of oscilloscopes, especially at low frequencies from 10 MHz to 1 GHz. The method uses the phase response of a standard mixer calibrated by three-mixer method as the reference phase. We describe basic principles and show results obtained using a balanced mixer and a real-time oscilloscope (1 GHz BW).

Microspectroscopic Infrared Specular Reflection Of Multi-component Urinary Stones At Beamline D7 At The MAX IV Laboratory, Lund Sweden. **TS-11**

Anders Engdahl

Urolithiasis -- a condition when stones form in urinary tract Its causes remain unclear despite many studies. The stones' composition and morphology (constituent distribution, size, shape, colour, and crystalline structure) vary. The components most frequently found are calcium oxalate (monohydrate and dihydrate), apatite, struvite, other phosphates, uric acid , and their mixtures. Knowledge of the composition is crucial to determine the underlying pathology, prescribe treatment, and prevent recurrences. In this work, the potential of multi-spectral IR (mid-infrared and far-infrared) chemical imaging for urinary stone analysis is demonstrated. Chemical imaging is used for heterogeneous samples analysis, providing simultaneous information about their composition and morphology, i.e., distribution of the constituents. MIR and FIR chemical imaging are compared. We demonstrate that for rough samples such as cross-sectioned urinary stones FIR chemical imaging can be advantageous due to diminished diffuse reflection.

Plasmonic Superfocusing Of THz Waves In Metallic V-groove Tapered Waveguide Theoretically Considered By Quasi-separation Of Variables **TS-12**

Kazuyoshi Kurihara; Fumiyoshi Kuwashima; Osamu Morikawa; Kohji Yamamoto; Masahiko Tani

A non-adiabatic superfocusing theory of THz waves in a metallic V-groove tapered waveguide is studied by quasi-separation of variables for the explanation of our recent experimental results (Appl. Phys. Express, vol. 7, 112401, 2014). Approximate analytical solutions are obtained for the two regions at the apex and in the vicinity of it, where as the result the property of plasmonic superfocusing is analytically discussable in detail.

Advancement Of Oscillation Efficiency By Improvement Of Electron Beam Quality In Gyrotron FU CW GIA **TS-13**

Yoshinori Tatematsu; Yuusuke Yamaguchi; Ryoichi Ichioka; Masaki Kotera; Teruo Saito; Toshitaka Idehara

In experiments of Gyrotron FU CW GIA, improvement of the energy conversion efficiency was investigated by two approaches; one is reducing the misalignment between the cavity and magnetic coil axes. The other is the design modification of the magnetron injection gun (MIG) to suppress the electron velocity spread at the cavity. The two effects were separately examined. As a result, increases in the efficiency were obtained by both the reduction of the misalignment and the modification of MIG.

Polymer Based Hybrid Composites For THz Applications **TS-14**

Bin Cai

Terahertz (THz) radiation is broadly defined from 0.1 to 10 THz, sandwiched between microwave and mid-infrared frequency ranges. The THz radiation has been shown to have considerable potential applications in security inspection, spectroscopic imaging, and future communication systems, etc. Currently, considerable breakthroughs are made; however, the devices for controlling or manipulating THz radiation still remains many hurdles need to be overcome, mainly because of the limited availability of suitable materials. For THz optics, the materials with high functionality, flexibility as well as processibility are highly requested. Organic-inorganic composites are considered to be a new class of advanced materials because of their versatile fabrication approaches and potentiality of novel properties, such as optical, nonlinear optical, electronic, magnetic, photovoltaic, and conductive properties. In THz region, many polymers such as polyethylene (PE), polystyrene (PS), and cyclo-olefin polymer (COP) etc. show relatively low propagation loss, however, their applications are limited by their low refractive indices etc. In this study, the optical properties of the polymers are enforced by high performance inorganic particles, by utilizing their scattering property and refractive index tunability, a femto-second (fs) laser/THz radiation separating filter and broadband anti-reflective (AR) coating are realized.

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Urea And Guanidinium Chloride Act As 'Water Structure Breakers': The Debate Revisited By Dielectric Relaxation Study In THz Range **TS-15**

Rajib Mitra; Nirnay Samanta; Debasish Das Mahanta

We have measured the various optical parameters of urea and GdmCl aqueous solutions in the 0.2-3 THz frequency range and fitted the real and imaginary parts of the complex dielectric constants in a triple Debye relaxation model. It was found that the cooperative relaxation dynamics of water gets faster beyond a 'threshold' salt concentration indicating towards a possible rupture of the collective hydrogen bond network of water. Our study shed light to a long debated issue in biophysics that whether the unique property of these salts to denature proteins have any correlation with their interaction with the solvating water molecules.

Self-consistent Modeling Of Terahertz Waveguide And Cavity With Frequency-dependent Conductivity **TS-16**

Kwo Chu; Yu Huang; Manfred Thumm

Ohmic dissipation can lead to excessive wall losses at terahertz (THz) frequencies, while the high-frequency oscillatory motion of conduction electrons tends to mitigate the collisional damping. In this study, a frequency-dependent conductivity is used to model the wall losses on the waveguides and open cavities commonly employed as gyrotron interaction structures. The reduction in Ohmic losses under the AC-conductivity model is shown to be increasingly significant as the frequency reaches deeper into the THz region. Such effects are of considerable importance to THz gyrotrons for which the minimization of Ohmic losses constitutes a major design consideration.

Sub-terahertz Spectroscopy As A Probe For Protein Stability In An Ionic Environment **TS-17**

Oleksandr Sushko; Junyi Qiu; Rostyslav Dubrovka; Richard Pickersgill; Robert Donnan

The sub-terahertz (sub-THz) absorption properties of bovine serum albumin (BSA) protein solutions, are investigated at different concentrations of sodium chloride (NaCl). Initially the proposed technique is validated by tracking the unfolding process of BSA in the concentrated solution of strong denaturant -- GdmCl. Measurements are performed on a quasi-optical table with frequency multiplier heads covering 0.22 -- 0.325 GHz. Results show a minimum THz absorption for a 100 mM concentration of NaCl, indicating the most stable protein conformation. Sub-THz spectroscopy, therefore, facilitates identification of the salt buffer concentration that enables the least dynamically active protein conformation.

Algebraic Reconstruction Technique For Millimeter-wave Holographic Imaging **TS-18**

Lingbo Qiao; Yingxin Wang; Zhiqiang Li; Ziran Zhao; Zhiqiang Chen

Millimeter-wave (MMW) holographic imaging has been intensively investigated for the application of personnel inspection. In order to obtain high resolution images, synthetic aperture technique can be used to form large virtual aperture. However, the effective size of the synthetic aperture is always limited by the beamwidth of the transmitting and receiving antennas. In this paper, algebraic reconstruction technique (ART) is introduced for the reconstruction of MMW images with consideration of the radiation pattern of antennas. Since the effect of the radiation pattern is compensated, high resolution images can be achieved by overcoming the resolution limitation which is determined by the beamwidth of antennas. Simulations are presented to verify the proposed ART based MMW imaging reconstruction method.

Linear Conversion Of Upper-hybrid To Electromagnetic Waves As A Mechanism Of Sub-THz Emission In Laboratory REB-plasma Experiments **TS-19**

Andrey Arzhannikov; Igor Timofeev; Vladimir Annenkov

In laboratory REB-plasma experiments it was found that the most energetic electromagnetic (EM) emissions are basically concentrated near the plasma frequency and its second harmonic. Theoretical analysis accounting for the magnetic field effects showed that the second harmonic emission can be interpreted as a result of coalescence processes between the upper-hybrid (UH) waves generated in the long-wavelength part of the beam-driven strong plasma turbulence. The fundamental emission in this scenario is associated with the conversion of these waves on randomly distributed density perturbations produced by the modulational instability. Such a turbulent regime, however, is usually accompanied by strong plasma heating and is not best suited for generation of EM waves. In order to increase the radiation efficiency in a beam-plasma system, one should create the conditions for the direct energy transfer between the beam-driven and EM modes. In the present work we propose to create regular gradients of plasma density, which can result in the linear mode conversion of the dominant beam-excited waves. We consider the case when the density gradient in a cold plasma is directed obliquely with the angle χ to the uniform magnetic field. The spatial scale of inhomogeneity is assumed to be large compared to the typical wavelength, which makes it possible to use the WKB approximation. The beam drives efficiently UH waves with the fixed longitudinal refractive index determined by the beam velocity. These waves occupy the spectral range from the plasma frequency to the frequency of the upper-hybrid resonance, and each frequency position is corresponded with its own propagation angle Θ. For the typical experimental parameters, the wave frequency is always large in comparison with the electron cyclotron frequency. For each resonant wave in this case we can find the angle χ, at which the dispersion curves of UH and ordinary EM waves appear to be coupled. If we know the frequency and the angle of the dominant resonant mode, we can analyze its propagation in the non-uniform plasma using the dependence of longitudinal to the density gradient refractive index on the plasma density. This analysis shows that the conversion of this wave to the EM mode at the critical surface becomes possible only after its reflection from the higher-density region. Propagation to lower plasma densities results in the absorption of wave energy near the UH resonance. Thus, it is shown that in magnetized plasmas with specifically oriented density gradients the beam-driven UH modes can be converted linearly to the ordinary EM waves escaping the plasma. The importance of this mechanism for the generation of sub-Thz emission in laboratory experiments is investigated using both analytic theories and numerical simulations.

Time-domain Data Truncation Method For Improving Terahertz Absorption Spectrum Reproducibility **TS-20**

Tianyao Zhang; Zhaohui Zhang; Xiaoyan Zhao; Han Zhang; Fang Yan; Fangming Wu; Bingfang Wu

The confounding nature of the etalon-feature in THz frequency-domain spectra can be eliminated by truncating the time-domain data before the echoes. However, the spectra features are sensitive to the window length used to truncate the raw data. In this paper, we presented the impact of random truncation on the THz absorption features of L-Glutamine (Gln) and then put forward with an optimized time-domain data truncation (TDDT) method to improve the spectra reproducibility. Samples consist of Gln at three different concentrations were measured with THz-TDS to assess our method.

Spectral Analysis Of The Optical Pulses Produced By The Interaction Of Optical And THz Pulses In A ZnTe Crystal **TS-21**

Marion Cornet; Jérôme Degert; Emmanuel Abraham; Eric Freysz

The spectra of the optical pulses generated during the interaction of THz and optical pulses in a ZnTe crystal show that, besides sum and difference frequency mixing, spectral components associated to cross-phase modulation are produced.

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Dispersion Equations For Entire Transparency Range Of GaSe **TS-22**
John Molloy; Mira Naftaly; Yury Andreev; Konstantin Kokh; Gregory Lanskii; Valery Svetlichnyi
High optical quality GaSe samples with faces parallel and orthogonal to the optical axes are manufactured. o- and e-wave dispersions are studied by THz-TDS. New dispersion equations are designed that are suitable for application in the entire transparency range from the near IR through the mid-IR and further in the THz range.

THz Spectroscopic Characterization Of Biochar **TS-23**
Lucia Lepodise; Roger Lewis; Stephen Joseph; Joseph Horvat
Fertile dark soils made by humans in the Amazon basin, terra preta, have influenced the manufacture of the biochar based fertilizers. Different types of biochar exist but not all of them are good in improving the quality of the soil. FTIR was used to distinguish between the more and the less fertile biochar.

High Performance THz Detector Based On Ultra-thin LiTaO3 Crystal **TS-24**
Zhiqing Liang; Ziji Liu; Tao Wang; Yadong Jiang; Xuefei Wu; Xing Zheng; Zehua Huang
Research on high performance terahertz (THz) detector is essential for promoting the application of THz science and technology. Lithium tantalate crystal (LiTaO3) was used to fabricate the THz detector in this paper. Polishing process were used to reduce the thickness of LiTaO3 crystal slice obtained the area of 2mm×2mm×10μm LiTaO3 wafer pyroelectric coefficient of 4.7×10^-4Cm^-2K^-1 by chemical mechanical polishing techniques. The THz responsivity for detector tested by lock in amplifier reaches 8.38×104V/W and the lowest noise equivalent power value(NEP) reaches 3.25×10−12W at 20Hz operating frequency use 2.52THz radiation, which is suitable for THz imaging application. Meanwhile it provides a feasible approach for fabricating high responsivity THz detector.

Influence Of Metallic Target Surface Roughness On THz Scattering Characteristics **TS-25**
Xin Huang; Wei Gao; Kejia Wang; Feidi Xiang; Jinsong Liu; Yingyi You
Compared to microwave and infrared, THz radar has higher resolution, stronger secrecy, stronger penetrating ability and stronger anti-interference ability. The development of THz radar system depends on the research of THz radar target characteristics. However, different from microwave band, we must take into account the influence of target surface roughness on THz scattering characteristics during developing the research of THz radar target characteristics. This paper studies the influence of metallic target surface with different roughness on THz scattering characteristics through theoretical calculations and experiment.

Project Of Powerful Broadband FEM-amplifier Of 30 GHz Frequency Range **TS-26**
Ilya Bandurkin; Yury Danilov; Naum Ginzburg; Alim Kaminsky; Sergei Kuzikov; Elkuno Perelshtein; Nikolai Peskov; Andrei Savilov; Sergei Sedykh
Project of powerful high-efficiency FEM-amplifier operating at 30 GHz frequency range and aimed on accelerating applications is developed in collaboration of IAP RAS and JINR. In present paper we discuss conceptual design and results of simulations of the FEM. In the regular wiggler the output power would amount to 20 MW in the frequency band of more than 20% when the grazing regime is utilized. Regime of non-resonant trapping in tapered wiggler allows enhance of output power up to 50 MW with simultaneous widening of the amplification band. Novel broadband RF-input based on the effect of microwave beams multiplication is designed to drive the amplifier.

Frequency Controlled Beam-steering At 0.2THz With Diffraction Enhancement **TS-27**
Chao Li; GuangYou Fang
Benefited from the 'see through' property and the comparatively high resolution available, THz waves have been promising for plenty of applications [1], such as security screening and non-destructive testing. In the frequency band around or above 0.2THz, phased array antennas based on phase shifters are difficult to be designed and fabricated. As a good alternative for fast beam scanning, a 0.2THz band frequency-scanning grating-reflector with planer binary structure was proposed, designed, and measured based on the mechanism of diffraction enhancement.

Impedance Matching At THz Frequencies: Optimizing Power Transfer In Rectennas **TS-28**
David Etor; Linzi Dodd; Claudio Balocco; David Wood
A simple and elegant method for matching the impedance of a typical THz self-complementary bowtie antenna to the high-impedance of a nanodiode is proposed. Two twin-lead balanced lines emerging from the antenna feed-point are used to connect the diode, correct for the reactive component of the antenna impedance and compensate the parasitic capacitance of the diode. Numerical simulations considering a model rectenna with a metal-insulator-metal diode showed that impedances up to several kΩ can be effectively matched.

InP Double Heterojunction Bipolar Transistor For Detection Above 1 THz **TS-29**
Dominique Coquillat; Virginie Nodjiadjim; Agnieszka Konczykowska; Nina Dyakonova; Christophe Consejo; Sandra Ruffenach; Frédéric Teppe; Muriel Riet; Andrey Muraviev; Alexey Gutin; Michael Shur; Jean Godin; Wojciech Knap
We evaluate the optical performance of the InP heterojunction bipolar transistors (DHBTs) designed for 100 Gbit/s circuit applications as a room temperature detector operating above 1 THz. They can operate far above the frequencies at which they have gain and can still rectify THz current and voltage.

3D Printed Flat Optics And InP Heterojunction Bipolar Transistor Based-detector For THz Imaging **TS-30**
Jarosław Suszek; Agnieszka Siemion; Dominique Coquillat; Virginie Nodjiadjim; Agnieszka Konczykowska; Muriel Riet; Artur Sobczyk; Przemek Zagrajek; Norbert Palka; E. Czerwińska; N. Błocki; Andrzej Kolodziejczyk; Nina Dyakonova; Frédéric Teppe; Christophe Consejo; Wojciech Knap; Maciej Sypek
Diffractive optical elements such as hyperbolic lens and quasi-spherical lens converting a divergent terahertz beam into the focal line segment perpendicular to the optical axis was designed. Due to the fact that the length of the line segment was longer than the aperture of the designed elements the non-paraxial approach was used. The structures were designed for the narrowband application as kinoform elements. The theoretical approach, computer simulations and experimental results are presented. In the imaging system, the intensity of the radiation in the focal plane was measured by THz point-like detector based on InP heterojunction bipolar transistor.

A THz-band Emitter Based On A Single-Walled Carbon Nanotube With Encapsulated Fullerenes **TS-31**
Olga Glukhova; Anna Kolesnikova; Mikhail Slepchnkov; Nikita Ryskin
We propose a theoretical model for a THz-band emitter based on a carbon nanopeapod formed by a nanotube (10,10) with three encapsulated fullerenes C60. The radiating element is the free charged fullerene C60, which rapidly oscillates in a potential well created by the atomic framework of the nanotube and several uncharged fullerenes polymerized with the tube, as well as with

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each other. Motion of the charged fullerene and the radiation frequency can be controlled using an external electric field. It was found that stable THz radiation with the frequency of 0.36 THz could be realized at 300 K in the dc electric field of 10 V/m.

High-Speed Frequency-Domain Terahertz Coherence Tomography **TS-32**

Ji Sang Yahng; Choon Su Park; Hwi Don Lee; Chang Seok Kim; Dae Su Yee

High-speed frequency-domain terahertz (THz) coherence tomography is demonstrated using frequency sweeping of continuous-wave THz radiation and beam steering. THz frequency sweeping with a kHz sweep rate and a THz sweep range is implemented using THz photomixing in which an optical beat source consists of a wavelength-swept laser and a distributed feedback laser diode. During the frequency sweep, frequency-domain THz interferograms are measured using the coherent homodyne detection employing signal averaging for noise reduction, which are used as axial scan data via fast Fourier transform. Axial scan data for 100×100 points can be acquired in 100 s while scanning a transverse range of 100×100 mm^2 using a THz beam scanner comprised of a two-dimensional galvanometer scanner and a telecentric f-θ lens.

Experimental And Theoretical Investigations Of The Responsivity Of Field Effect Transistors Based Terahertz Detectors Versus Substrate Thickness **TS-33**

Coquillat Dominique; Jacek Marczewski; Pawel Kopyt; Nina Dyakonava; Sandra Ruffenach; Dmytro But; Frédéric Teppe; Franz Schuster; Benoit Giffard; Wojciech Knap

Phenomena of the radiation coupling to the field effect transistors based terahertz detectors is studied. We show that in the case of flat metallic antennas important part of radiation, instead coupling to the transistors, is coupled to the substrate leading to losses. Experimental and theoretical investigations of the responsivity versus substrate thickness are performed. They clearly show how to minimize the losses by the detector substrate thinning.

Analysis On Scattering And Relationship With Granular Size In THz Spectra **TS-34**

Fangming Wu; Bingfang Wu; Xiaoyan Zhao; Zhaohui Zhang; Han Zhang; Tianyao Zhang; Fang Yan

Scattering is an important phenomenon and distorts the THz absorption spectrum during analysis of materials. It is essential to understand how scattering from samples change the THz signals. In this paper, we present an approach for estimating the relationship between scattering and granular sizes occurring in THz spectra. The samples were made of same solid material but in different granular sizes ranging from 150 μm to 57 μm, the THz-TDS experiment results indicated the absorption curves rose up with the granular size increasing, which met the simulation consequence based on Mie scattering.

Design And Performance Of Plasmonic Lenses Optimized For 325 GHz **TS-35**

David Naylor; Tanner Heggie; Brad Gom; Grace Trimboli; Evgueni Bordatchev

Imaging applications at terahertz (THz) frequencies are limited to relatively low spatial resolution due to the effects of diffraction. A subwavelength aperture can be used to improve the resolution at the cost of low transmission. Plasmonic lenses in the form of bull'seye structures, consisting of a single subwavelength circular aperture surrounded by concentric periodic corrugations, have shown enhanced transmission and beam confinement. In this paper, we discuss the design, fabrication and performance of plasmonic lenses optimized for transmission at 325 GHz.

THz Bandpass Filter Based On Sub-wavelength Holes In Free-Standing Metal Thin-Films **TS-36**

Renu Bhadresha; Johneph Sukham; Arnab Pattanayak; Goutam Rana; Prathmesh Deshmukh; George Jacob; Nisha Sarwade; Siddharta Duttagupta; S. S. Prabhu

The design of a free-standing (substrate-less) metallic hole array is proposed for Terahertz frequencies. The bandpass filtering effect through free standing perforted Aluminium (Al) films is demonstrated using a square array of circular holes on Al films having thickness of ~11 microns. The effect of variation of periodicity and hole diameter on the transmittance due to excitation of surface plasmons and coupling between resonant and non-resonant modes is studied.

A 0.2-THz Coaxial-Waveguide Gyrotron Traveling-Wave Amplifier **TS-38**

Chien Lun Hung; Ruei Song Fang; Deng Ci Yang; Yi Sheng Yeh

Mode competition is a severe problem in the development of a high-power gyrotron traveling-wave-tube (gyro-TWT) amplifier in terahertz (THz) region. To improve the stability of this device, this paper investigates the possibility of using a coaxial waveguide with distributed losses as the interaction structure of a 0.2-THz gyro-TWT. Under stable operating conditions, the achieved performance of the gyro-TWT amplifier, including the output power, efficiency, gain and bandwidth, are predicted.

Analytical Solutions Of The Perfect Absorber For Terahertz Sensing **TS-39**

Piyawath Tapsanit; Masatsuku Yamashita; Chiko Otani

We develop the analytical solutions (ANS) of the hybrid structure comprising the metallic grating (MG) with subwavelength width, the stacked-dielectric layers in front of the MG, and one dielectric layer behind the MG. The ANS are well consistent with the finite difference time domain simulation. We apply the ANS to optimize the flat-surface front-perfect absorber (FPA) with ultrahigh Q-factor up to 3x10^4 based on the coupling between the quasi-waveguide resonance (QWR) and the Fabry-Perot (FP) resonance. The proposed FPA can detect the small variations in refractive indices of thin samples and the presence of thin films with deep-subwavelength thicknesses.

Performance Of Terahertz Quantum-well Photodetectors **TS-40**

Jingyue Jia; Yueheng Zhang

We investigated the performance of terahertz quantum-well photodetectors (THz QWPs) experimentally and theoretically. The photocurrent spectra of both THz QWPs are measured and simulated considering the many-particle effects. The dark current mechanisms are also investigated experimentally and theoretically. Results show that many-particle effects must be considered in the design of the THz QWPs. Also, the scattering assisted tunneling dark current should also be noted to play a very important role in the total dark current of THz QWPs.

Array Configuration Using Resonant-Tunneling-Diode Terahertz Oscillator Integrated With Patch Antenna **TS-41**

Kouhei Kasagi; Safumi Suzuki; Masahiro Asada

We proposed and fabricated an oscillator array composed of three resonant-tunneling-diode terahertz oscillators integrated with slot-coupled patch antennas, which operates without the need for Si lens. We measured the radiation pattern for single and arrayed oscillators, and calculated the output power using the integration of the pattern. The output power of a single oscillator was ~15 μW, while approximately three times higher output power of ~55 μW was achieved at ~1 THz for the array configuration.

Frequency Selective Surface Applications In Millimeter Wave Imaging Diagnostics For Fusion Plasmas **TS-42**

Xing Hu; Calvin Domier; Neville Luhmann

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Both capacitive and inductive frequency selective surface (FSS) filters have been applied in millimeter wave imaging plasma diagnostic systems to protect the imaging arrays from stray ECRH power as well as ensure working bandwidth control. Several new improved FSS filters have been designed and tested.

Wide-band Terahertz Communication At Ambient Atmosphere **TS-43**

Lei Hou; Wei Shi; Suguo Chen; Zhijin Yan; Hong Liu

With the increasingly high demand for wireless communications networks for high-speed transmission, the researchers are trying to extend to terahertz (THz) frequency. THz wave for the transmission rate of the wireless communication can be achieved 10 Gb/s, thousands of times faster than the UWB technology at present. However, terahertz communication is still not perfect in many theories, and many technical problems still to be resolved, such as, the appropriate atmosphere window has not been found; THz radiation is usually less power. To improve the quality of THz communication, further tackling high power THz emission source, high bit rate modulation technology, high sensitivity, anti-jamming receiver technology and sophisticated and reliable high-gain receiving antenna is critical. This paper reports a kind of wide-band THz communication based on a THz time domain spectroscopy (TDS) system, which uses photoconductive antenna as a THz source, ZnTe crystal as a receiver. The photoconductive antenna was fabricated on semi-insulating GaAs with the gap size of 50 μm, was biased using a square wave signal from a function generator with the frequency of 5 kHz and the voltage of 20 V, and was illuminated by a mode-locked Ti: sapphire laser with pulse width of 70 fs and the repetition rate of 80 MHz. The transmission distance between the modulated source and the receiving crystal was about 0.65 m.

Chemical Imaging And Quantification Of RDX/PETN Mixtures By PLS Applied On Terahertz Time-domain Spectroscopy **TS-44**

Joyce Bou Sleiman; Patrick Mounaix; Bruno bousquet; Jean-Paul Guillet; Jean-Baptiste Perraud; Norbert Palka

Chemometric analysis was applied on terahertz absorbance 3D images, in transmission. The goal is to automatically discriminate some explosives on images and quantify mixtures of RDX/PETN in the frequency range of 0.2 -- 3 THz. Partial Least Square (PLS) was applied on THz absorbance multispectral images to quantify individual product inside pure samples and mixtures at each pixel on the image. Then the best score obtained is used to display the samples' images and provide the optimal frequencies combination for recognition purpose.

Terahertz Plasmonic Waveguides Based On A Microstructure Of Metal Rod Array **TS-45**

Borwen You; Wen Jie Cheng; Ja Yu Lu; Toshiaki Hattori; Tze An Liu

Metal rod array (MRA) are presented as the microstructured cladding of a rectangle channel waveguide to guide terahertz (THz) waves. The microstructure cladding is critical to modify the waveguide loss, dispersion, resonance, and pass-band. THz-field resonance and the corresponding modal field are taken as examples to express that the MRA period can be tailored for engineering the waveguide. MRA is agreed as a plasmonic metalmaterial, possessing spoof plasma frequency and dependent on the MRA geometry. The case of THz-field resonance inside the waveguide channel is significant to mimic "plasmonic resonance" in THz region that does not appear in natural metals.

A Directly Heated High Emission Density Low-Temperature Cathode **TS-46**

Shikai Qi; Xiaoxia Wang; Jirun Luo; Mingwei Hu; Yun Li

In order to enhance output power and prolong lifetime of the high-power continuous wave magnetron tubes, a novel Y2O3-Gd2O3-ZrO2 impregnate W sponge layer directly heated cathode is researched. The testing results show that the DC emission density of the cathode can reach 3.58A/cm^2 at a temperature of 1750℃. Lifetime experiment results show that the thermionic emission current density is still above 1.5A/cm^2 after 2600h operation.

Classification Of Materials Using Terahertz Spectroscopy With Principal Components Analysis **TS-47**

Ping Sun; Yun Zou; Wei Liu

Terahertz spectroscopy has multivariable and produces large volumes of data. Principal component analysis (PCA) is a statistics analysis method of dimensionality reduction of multivariate. We studied the feasibility of PCA method for material classification in terahertz region. The results show that PCA is able to differentiate materials obviously if initial variables are chosen properly.

PH Effect On Carrier Transport In Conducting Polymer PEDOT:PSS Investigated By Terahertz And Infrared-visible Spectroscopy **TS-48**

Masatsugu Yamashita

The pH effect on the carrier transport of conducting polymer PEDOT:PSS has been studied by terahertz and infrared-visible spectroscopy. The neutralization of conducting polymer poly (3, 4 ethylenedioxythiophene):poly (stylene sulfonate) (PEDOT:PSS) decreased the carrier concentration and mobility, which lowered the electrical conductivity of PEDOT:PSS by five orders of magnitude with increasing pH from 1.7 to 11.7.

Ultrafast Nonequilibrium Carrier Dynamics Of 2D Materials Measured By Time Resolved THz Spectroscopy **TS-49**

Jaehun Park; Hyejin Choi; Taehyeon Kim; Seonghoon Jung; Mannho Cho

Chalcogenide based compound, especially Sb2Te3 and related compounds, exhibit pronounced structural and optical contrast with rapid phase transition from amorphous to crystalline phase. This makes them suitable candidates for rewritable optical storage media and phase change random access memory. Simultaneously, Sb2Te3 is reported to be one of the best p-type thermoelectric materials at room temperature, and has topological insulator property. Since electrons and phonons play a crucial role in determining the performances of any real devices, a better understanding of the transition mechanism from amorphous phase to crystal phase is imperative. Terahertz time-domain spectroscopy and optical pump-THz probe (OPTP) spectroscopy would give valuable information on the characteristics of chalcogenide compound. In this paper, we will discuss the nonequilibrium ultrafast carrier dynamics in 2 dimensional phase change material {Sb(3)Te(9)}n thin film. The evolution of the optical properties is measured by THz-TDS and OPTP during the phase change from amorphous to crystalline states.

263 GHz Traveling Wave Tube (TWT) Amplifier For Dynamic Nuclear Polarization (DNP) And Electron Paramagnetic Resonance (EPR) Spectroscopy **TS-50**

Sulmer Fernandez Gutierrez; Dennis Gautreau; Jagadishwar Sirigiri; Branko Popovic; Diana Gamzina; Neville Luhmann

We present the circuit design of a 263 GHz Traveling Wave Tube (TWT) amplifier for use in Dynamic Nuclear Polarization (DNP) enhanced Nuclear Magnetic Resonance (NMR). The circuit design achieves a linear gain of 36 dB and output power > 50 W. This work describes the design of the interaction circuit for optimal interaction with a 20 kV, 125 mA elliptical beam using 3D electromagnetic Finite Element Method (FEM) and Particle-in-Cell (PIC) solvers

Interference Of 2 LO Phonon And Continuum Inter-valence Band Transition In P-GaInP Film **TS-51**

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Hironori Sakamoto; Yoshihiro Ishitani; Ken Morita; Bei Ma

Asymmetric optical spectrum profile due to quantum interference between discrete and continuum states was systematically reported by Fano. Interference in semiconductor was found for a system of LO phonon (discrete state) and valence band state (continuum) by Raman spectra. Harris proposed a mechanics of laser without inversion based on the quantum interference of 2 discrete states and a continuum. However, there is no report on the interference of the 2 LO phonon system. Here, we exhibit an evidence of the interference by the excitation of 2 LO modes and inter-valence band transition using p type-Ga0.5In0.5P films. This alloy is known to have 2 LO modes in the same oscillation plane, InP-like LO mode (LO1) and GaP-like LO mode (LO2). Although the experimental Raman spectra of LO2 is broadened asymmetrically in the high energy side, the asymmetry for LO1 is weaker. It is thought that this weak asymmetry is attributed to the cancellation of the broadening of the higher energy side spectra of the LO1 mode and the sharpening of the lower energy side of the LO2 mode. Spectrum fitting was conducted using the theory proposed by Fano. Here, GaP-like TO mode (TO2) observed in a former research was taken into account. The experimental spectrum is well reproduced. asymetry parameter qj, broadening Γj and peak shift ΔEj was obtained from the spectra fitting. Here, index j shows the LO modes of 1 or 2. The peak shift and broadening are from the original respective LO phonon line width and energies obtained from the spectrum fitting result of an undope GaInP film. It is known that asymmetric shape becomes eminent as the decrease in |q|. Because the sign of qj decides which side of peak is broadened asymmetrically, the same sign of q1 and q2 obtained from the fitting account for the reduction of the asymmetry between LO1 and LO2. Since the spectrum broadening was not observed on the peak of InP-like TO mode (TO1), the broadening of LOj phonon peak is not attributed to the degradation of the crystal. The contribution of strain was estimated, and removed on the basis of the energy shift of the TO1 mode. Thus it is thought that observed broadening and peak shift is due to quantum interference. Obtained Γ was compared with other materials (Si, Ge and GaAs). It is found that Γ of polar semiconductor increases more rapidly than that of non-polar semiconductors as the hole density increases. It indicates that the obtained interference strength depends on the electron-phonon interaction strength of materials.We have found quantum interference of 2 LO phonon and valence band state for p-GaInP films, which shows systematic material properties. It is expected that this phenomenon would be a base of the control of absorption spectrum in the THz frequency region using phonon mode

Optically-Tunable Organic Semiconductor Heterojunction P3HT-PCBM For Millimeter-wave Applications **TS-53**

Andre Sarker Andy; Oleksandr Sushko; Theo Kreouzis; Robert S Donnan

The dielectric constant of a photo-sensitive organic semiconductor heterojunction poly(3-hexylthiophene) (P3HT, 95%) and [6,6]-Phenyl C61 butyric acid methyl ester (PCBM, 5%) is estimated using its transmission response using a vector network analyzer driving a quasi-optical (QO) transmissometer. White-light irradiance of 65mW/cm^2 over an area of 2.27cm^2 is used to promote the photo-induced dielectric response of the organic polymer blend; so defining the 'active' state. Estimation of the complex permittivity of the polymer-blend is undertaken for both inactive (dark-state), and active state conditions to observe its tunable dielectric range over the WR-3 waveguide band (220-325 GHz).

Analysis Of Intermolecular Vibrational Modes In Organic Compounds Using Two-dimensional Terahertz Correlation Spectroscopy **TS-54**

Jun Zhou; Shan Tu; Lu Duan; Xin Rao

In this study, the terahertz (THz) absorption spectra of tris(8-quinolinolato) aluminum were measured during 100--300 K. The temporal changes in the absorption spectra were analyzed using two-dimensional correlation spectroscopy (2DCOS). By comparing the cross peaks corresponding to the intermolecular vibrational modes, we concluded that the high-frequency band could be attributed to the vibration of the structure and the low-frequency band to the vibration between the structures. The exact frequencies of the overlapping vibrational bands and their assignments provide a new means to inspect the thermal behavior of the intermolecular vibrational modes.

Far-infrared And THz Spectroscopic Study On Ancient Chinese Papers **TS-55**

Shan Tu; Jun Zhou; Xiujuan Zhang; Linzhi Xiao; Yanbing Luo

In this study we discuss the transmittance, the refractive index of seven ancient paper sheets and five modern paper sheets made in ancient technology in the interval 5-85cm^-1 and 300--1000cm^-1, with terahertz time-domain spectroscopy in transmission mode and Fourier-transform infrared spectroscopy in transmission mode. By analyzing the optical characteristics of these twelve paper sheets, we discuss the link between the ancient and modern paper.

THz Wakefield In Dielectric PBG Structure Driven By Electron Bunches **TS-56**

Jin Xu; Hairong Yin; Zhigang Lu; Lingna Yue; Huarong Gong; Yanyu Wei; Yubin Gong; Wenxiang Wang

The wakefield effects driven by an relativistic electron bunch train in dielectric PBG structure are presented here. The energy of electron beam can be modulated by self-wake or laser modulation. The excited narrow-band THz wakefield is confined in the defect of 2-D dielectric structure when bunches travel through the PBG structure. And the other spectrum signals are freely radiated through the PBG structure.

Effect Of Wood's Anomalies On The THz Transmission Spectra Of Free-Standing Metallic Hole Arrays **TS-57**

Carlo Hill; Andreas Klein; Claudio Balocco; David Wood; Andrew Gallant

A free-standing periodic array of subwavelength rectangular apertures has been designed to exhibit peak transmission which is dominated by localized aperture resonance in the THz region. By varying the incident angle, Wood's anomalies can be introduced; the observed effect upon the localized aperture resonance is reported and compared to FDTD simulations in the absence of plasmonic surface modes. Peak frequency transmission shifts of up to 150 GHz (~15%) while maintaining normalized peak transmission >85% have been observed by VNA CW frequency domain measurements.

Development Of Compact Seeded Terahertz Free-Electron Laser Amplifier System At Kyoto University **TS-58**

Sikharin Suphakul; Kantaphon Damminsek; Zen Heishun; Kii Toshiteru; Ohgaki Hideaki

We are developing a compact seeded terahertz (THz) free-electron laser (FEL) amplifier at the Institute of Advanced Energy, Kyoto University. The system consists of a photocathode RF-gun, a focusing solenoid magnet, a magnetic bunch compressor, focusing quadrupoles, an undulator, a laser system for the RF-gun and a THz parametric generator for seeding. The seeded THz lasers are amplified by FEL interaction inside the undulator. The target radiation wavelength is 300 to 800 μm. As the first step of the development, we evaluate expected power of coherent synchrotron radiations (CSRs). As the result it is found that the bunch charge from 50 to 75 pC will be suitable operation condition.

Equivalent Circuit Model Based On Spectral Green's Function Representation For Photo-Conductive Slot Antennas **TS-59**

Alessandro Garufo; Giorgio Carluccio; Nuria Llombart; Andrea Neto

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

The generation of THz signals resorting to photosensitive semiconductors has been the object of various analysis in the recent years. Typically, such sources consist in a optically pumped semiconductor which is coupled to an antenna to generate THz power. In this paper a theoretical model, based on a spectral Green's function formulation, for infinite slot fed by a THz photoconductor generator is shown. An equivalent circuit model is then derived, which gives a description of the involved THz power generation and radiation mechanisms. Such model is a useful engineering tool for the analysis and the design of photo-conductive slot antennas.

Generation Of Cw-THz Waves With High Frequency Accuracy By Mach-Zehnder-modulator-based Flat Comb Generator For Phase-locking Of THz-QCLs **TS-60**

Isao Morohashi; Yoshihisa Irimajiri; Motohiro Kumagai; Akira Kawakami; Takahide Sakamoto; Norihiko Sekine; Tetsuya Kawanishi; Akifumi Kasamatsu; Iwao Hosako

Generation of cw-THz waves with high frequency accuracy was demonstrated by using a Mach-Zehnder- modulator-based flat comb generator (MZ-FCG). A combination of the MZ-FCG and a highly nonlinear dispersion shifted fiber generated broadband optical combs, and cw-THz waves in the range of 3 THz were generated by photonic down-conversion of two-tone signals extracted from the broadband combs.

A Novel Method For Power Measurement Of A Short Pulse Gyrotron Using Friis Transmission Formula At W-band **TS-61**

Sung Gug Kim; Dong Sung Kim; Eun Mi Choi

In this paper, we introduce a new measurement method for a W-band, high power UNIST short pulse gyrotron using Friis transmission equation. The proposed method is superior to other calorimetric measurements since it provides a real-time power measurement and without calibration. To apply to Friis transmission equation, we derive the directivity of Gaussian beam in detail. Also, to demonstrate the method, we measured the output power based on the proposed method and compared with conventional measurement. The results prove that the proposed new power measurement technique works very well without any limitation applying it to higher average and peak power and long pulse duration.

High Effective Generation And Detection Of THz Waves Using A Laser Chaos And A Super-focusing With Metal V--grooved Waveguides **TS-62**

Fumiyoshi Kuwashima; Takuya Shirao; Toshihiro Kishibata; Yusuke Akamine; Noriyuki Iwao; Manatu Ooi; Masahiko Tani; Kazuyoshi Kurihara; Kohji Yamamoto; Takeshi Nagashima; Makoto Nakajima; Masanori Hangyo

Generation of a wide-range THz waves are investigated from a photoconductive antenna excited using a chaotic oscillation multimode semiconductor laser with optical delayed feedback by an external mirror. The properties of the generated THz wave are compared with those of a case excited by a CW steady state laser. The stable THz wave is obtained from the multimode-laser diode excited photoconductive antenna by using a laser chaos. For a high sensitive detection, a metal V-grooved waveguide (MVG) is also used. The 1.6 times signal is detected using MVG compared with conventional system using Si lens.

Terahertz Characteristics Of InGaAs With Periodically-positioned InAlAs Insertion Layers **TS-64**

Dong Woo Park; Jin Soo Kim; Sam Kyu Noh; Young Bin Ji; Seung Jae Oh; Tae-In Jeon

We present terahertz (THz) generation and detection characteristics of InGaAs with periodically-positioned InAlAs insertion layers (InGaAs PPIL). A THz transmitter with the InGaAs PPIL showed three times higher than that of an InGaAs epilayer without the insertion layer at the current signal for THz generation properties. Also, the detection properties of a THz receiver with the InGaAs PPIL showed over twenty-five times higher than that of a simple InGaAs epilayer. Also current signals of the InGaAs PPIL was improved with increasing the number of the InAlAs insertion layers.

Investigation Of Emission Capability Of Reduced Graphene Oxide Film Cathode For Terahertz Vacuum Electron Devices **TS-65**

Ranajoy Bhattacharya; In-Keun Baek; Jeong Seok Lee; Ranjan Kumar Barik; Seontae Kim; Dongpyo Hong; Ohjoon Kwon; Matlabjon Sattorov; Yong Hyup Kim; Gun-Sik Park

Terahertz vacuum sources with high power are in immediate need for several applications like medical, security, communication, etc. The power and performance of these devices mainly depends on cathode. As structure become smaller, it is very much difficult to obtain high power at terahertz frequency, using conventional low current density thermionic cathodes. As a result development of non-conventional field emission cathode is in progress, which may produce a very high current density with comparatively high current and can help in terahertz research and application. In this work our main aim is to develop and analyze high current density (>10^3A/cm^2) sheet beam film cathode using reduced graphene oxide (rGO)-nano particle composite.

Comparison Of Different Models For Arsenic Activation In HgCdTe **TS-67**

Xiaohao Zhou; Y Huang; Y Huang

Arsenic doping of HgCdTe has proved problematic. Two-step anneals are usually required to activate the dopant. The model frequently used to explain p-type doping with arsenic requests an amphoteric nature of group V atoms in the II--VI lattice. This requires that group VI substitution with arsenic only occurs under mercury-rich conditions either during growth or the subsequent annealing, and includes site transferring of the As. However, there are inconsistencies in the amphoteric model and unexplained experimental observations. A new model, based on defect-mediated diffusion of the arsenic, is therefore proposed.

Progress Of 300 GHz High Order Mode Gyrotron Development **TS-68**

Yasuhisa Oda; Tsuyoshi Kariya; Ryotaro Minami; Ryosuke Ikeda; Ken Kajiwara; Koji Takahashi; Kazuo Hayashi; Tsuyoshi Imai; Keishi Sakamoto

A short pulse high order mode gyrotron for 300 GHz oscillation was tested. The designed oscillation mode is TE32,18 and the gyrotron is operated with a 13T superconducting magnet. The output RF power and its frequency was measured. In the preliminary experiment, the 345 kW power was obtained at 299.85 GHz which corresponds to designed oscillation mode.

Fabrication Of A Terahertz Wave Absorber Based On Dielectric Spheres **TS-69**

Kenichiro Hanai; Keisuke Takano; Fumiaki Miyamaru; Tsubasa Nishida; Makoto Nakajima; Masanori Hangyo; Riad Yahiaoui

A terahertz wave absorber composed of dielectric spheres is proposed. The proposed absorber offers advantages compared to other metamaterial-based absorbers owing to low-cost and flexibility of fabrication that strongly relaxe the constraints for the optical domain. The dielectric spheres composed of titanium oxide (TiO2) are aligned with a hexagonal lattice on an aluminum substrate. The absorption over 90% is obtained at the frequencies of the Mie resonances of the spheres. The impact of the structural parameters on the absorption spectra are investigated with the simulation.

Monday, August 24, 2015

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Wednesday, August 26, 2015

08:45 - 09:00 **Morning Announcements** **Lecture Theatre 1**

09:00 - 10:30 **Plenary Session P5-P6** **Lecture Theatre 1**

Chairpersons: Kiyomi Sakai;

09:00 **Imaging Ultrafast Dynamics On The Nanoscale With THz-STM** **P5**

V Jelic; T Cocker; P Nguyen; C Rathje; G Hornig; J Hoffman; H Sharum; R Miller; S Molesky; Margaret Gupta; J Burgess; G De los Reyes; L Titova; C Ropers; Y Tsui; M Freeman; Frank Hegmann

The ability to directly image ultrafast phenomena with nanometer spatial resolution is essential to our understanding of local excitation dynamics in nanomaterials and devices. We have developed a new approach to ultrafast scanning tunneling microscopy (STM) that couples terahertz (THz) pulses to the scanning tip of a STM. We have used THz-STM under ambient lab conditions to image ultrafast charging dynamics of a single InAs nanodot on GaAs with 0.5 ps time resolution and 2 nm spatial resolution. We are currently developing THz-STM for operation in ultrahigh vacuum with the goal of imaging ultrafast dynamics on surfaces with atomic resolution.

09:45 **It Is Water What Matters: THz Absorption Spectroscopy As A New Tool To Study Solvation Dynamics** **P6**

Martina Havenith

Terahertz (THz) absorption spectroscopy is a powerful tool to study (bio)molecular hydration. The development of THz technology helped to full the experimental gap in this frequency range. These experimental advances had to go hand in hand with the development of theoretical concepts that have been developed in the recent years to describe the underlying solute-induced sub-picosecond dynamics of the hydration shell. This frequency range covers the so-called rattling modes of the ion with its hydration cage and allows to derive major conclusions on the molecular picture of ion hydration, a key issue in chemistry. THz spectroscopy allows the quantification of the hydration shell around ions, and the characterization ion pairs. By a combination of experiment and theory, it is now possible to rigorously dissect the THz spectrum of a solvated biomolecule into the distinct solute, solvent and solute-solvent coupled contributions. Moreover, we highlight recent results that show the significance of hydrogen bond dynamics for molecular recognition. In all of these examples, a gradient of water motion toward functional sites of proteins is observed, the so-called "hydration funnel".

11:00 - 12:30 **W1A - 11 - Metamaterial Structures and Applications IV** **Lecture Theatre 2**

Chairpersons: Can-Ming Hu;

11:00 **Integrated Spoof Surface Plasmon Devices And Circuits** **W1A-1**

Tie Jun Cui

In this presentation, we introduce a planar plasmonic metamaterial on thin metal films with nearly zero thickness. From the theoretical simulations and experiments, we show that spoof SPPs can propagate along a thin metal film by corrugating its edge with periodic array of grooves. Such a planar plasmonic metamaterial can sustain highly localized SPPs along two orthogonal directions in the terahertz and microwave regions in broadband by keeping good modal shape and propagating long distance with low bending loss. The ability to bend spoof SPPs freely on thin film makes the planar plasmonic metamaterial more practical to produce plasmonic devices in the terahertz and microwave frequencies, such as the bends, splitters, filters, polarizers, and resonators. Experiments validate the feasibility of planar plasmonic metamaterial. Based on the above idea, we present the concept of conformal surface plasmons (CSPs), i.e., the surface plasmon waves that can propagate on ultrathin and flexible films to long distances. The flexible ultrathin films can be bent, folded, and even twisted to mould the flow of CSPs. We will also propose and experimentally demonstrate spoof localized surface plasmons (LSPs) on a planar textured metallic disk at the microwave and terahertz frequencies. We design and realize the plasmonic metamaterial using ultrathin metal film printed on a thin dielectric substrate and observe the multipolar plasmonic resonances in both numerical simulations and experiments, including the dipole, quadrupole, hexapole, octopole, decapole, dodeca-pole, and quattuordec-pole modes. The simulation and experiment results have very good agreements. We show that the spoof LSP resonances are sensitive to the disk's geometry and local dielectric environments, and hence the ultrathin textured metallic disk has potential applications as plasmonic sensor in the microwave and terahertz frequencies. Finally, we present active SPP devices using the subwavelength-scale amplifier chips, including the significant amplification of SPP waves and higher-order harmonic generations of SPPs, which result in SPP amplifier and SPP mixer. We also propose an efficient conversion between the conventional spatial waves and the SPP modes. Based on the conversion and passive and active SPP and LSP devices, we propose integrated spoof SPP/LSP circuits to realize a series of functionalities, and give experimental demonstrations.

11:30 **Total Internal Reflection At Conductive Interfaces: Monolayer Graphene For Terahertz Modulation** **W1A-2**

Xudong Liu; Edward Parrott; Benjamin Ung; Emma Pickwell-MacPherson

Here, we investigate non-normal incidence and formulate the equations to describe the total internal reflection (TIR) from a conductive interface such as graphene: we find that for a given optical conductivity, the reflectance can be decreased. By controlling the Fermi level of a graphene layer with a back-gate voltage it will be possible to modulate a terahertz beam intensity between 80% and 4%, which is nearly a factor of two greater than that possible using a normal transmittance configuration.

11:45 **Strong Coupling Of Intersubband Resonance In A Single Triangular Well To A THz Metamaterial** **W1A-3**

Shovon Pal; Hanond Nong; Sergej Markmann; Nadezhda Kukharchyk; Sascha R. Valentin; Sven Scholz; Arne Ludwig; Claudia Bock; Ulrich Kunze; Andreas D. Wieck; Nathan Jukam

We investigate the strong light-matter interactions of intersubband resonances (ISRs) in a triangular quantum well to a THz metamaterial. The large tuning possibility of ISRs with a high quality epitaxial gate enables the device to be electrically driven in-and-out of the coupling regime.

08:45 - 09:15 **Welcome and Opening Remarks** — **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

12:00 **Direct Observation Of Terahertz Wavefront Converted By A Metal Hole Array** **W1A-4**
Shintaro Hisatake; Hai Huy Nguyen Pham; Tadao Nagatsuma
Wavefront conversion by a metal hole array (MHA) has been experimentally observed via a visualization of the continuous-wave terahertz (THz) field. At the resonant frequency of the MHA, curved wavefront of the THz wave (125 GHz) emitted from a horn antenna has been converted to a plane wavefront. Near field visualization at the MHA surface (transmission side) revealed that the field re-emitted from the MHA oscillates in phase. We experimentally confirmed that the MHA acts as a planar THz wave collimator.

12:15 **Sensitivity Improvement Of Split-Ring Resonators For Thin-Film Sensing Using Floating Electrodes** **W1A-5**
Matthias Maasch; Christian Damm
An implementation of split-ring resonators for thin-film sensing is proposed. By creating a cavity with a floating electrode and under-etching of the gap of the split-ring resonator, the electric field lines are concentrated in the material under test. Simulations of the proposed structure yield a relative frequency shift of 19% for a variation of the relative permittivity between 1 and 5 at an operation frequency of 303GHz.

11:00 - 12:30 **W1B - 27 - Metrology II** — **Lecture Theatre 3**

Chairpersons: Thomas Kleine-Ostmann;

11:00 **Wavefront Measurement Of Terahertz Pulses Using A Hartmann Sensor Combined With 2D Electro-optic Imaging** **W1B-1**
Emmanuel Abraham; Harsono Cahyadi; Jérôme Degert; Eric Freysz; Takeshi Yasui
We report on the wavefront analysis of THz pulses emitted by optical rectification of femtosecond laser pulses in ZnTe crystal. The system is based on a Hartmann sensor associated with a 2D electro-optic imaging system.

11:45 **Emission Measurement Of A Full Body Mm Wave Scanner** **W1B-2**
Thomas Kleine-Ostmann; Thorsten Schrader
The emission of a full body scanner Rohde & Schwarz QPS 100 has been measured traceable to the SI units in the operation frequency range of the device between 70 GHz and 80 GHz. The measurements which have been performed with a calibrated spectrum analyzer and calibrated horn antennas are discussed with regard to the safety limits for non-ionizing electromagnetic radiation.

12:00 **Output Noise Temperature Of A Waveguide Cryogenic Noise Source In W-band** **W1B-3**
Tae Weon Kang; Jeong Hwan Kim; Jae Yong Kwon; No Weon Kang
A waveguide cryogenic noise source (CNS) is discussed for noise temperature standards in W-band. The CNS consists of a noise pickup horn, a cavity, an electromagnetic absorber, and a liquid nitrogen container. The output noise temperature (NT) of the waveguide CNS is obtained from electromagnetic radiation of the absorber and the dissipative loss of horn. The waveguide CNS and an ambient temperature noise source serve as reference noise sources. To calibrate an unknown noise source thermal noises emanated from the CNS, the ambient temperature noise source, and the unknown noise source are measured by a dedicated radiometer. Measurement results of a commercial diode noise source are presented.

12:15 **Simple De-embedding And Simulation Technique To Find Permittivity With A THz Vector Network Analyser** **W1B-4**
Jonathan Hammler; Andrew Gallant; Claudio Balocco
A simple and fast method for measuring the dielectric constant with a THz vector network analyser (VNA) has been developed. A numeric de-embedding technique removes free-space propagation effects, then simulation of Maxwell's equations simultaneously fits both permittivity and thickness to measured scattering parameters. Results are presented for semiconductor and dielectric samples within the frequency range 750 GHz to 1.1 THz, showing excellent agreement with prior work. A statistical analysis of uncertainty is performed, which demonstrates the robustness of our method.

11:00 - 12:30 **W1C - 05 - Spectroscopy and Material Properties IV** — **Lecture Theatre 4**

Chairpersons: Jean Leotin;

11:00 **Spectroscopic Nanoscopy Of Biological To Extraterrestric Materials** **W1C-2**
Fritz Keilmann
Near-field optical microscopy (by scattering from an AFM tip, s-SNOM) returns local absorbance from a tiny volume of only (20 nm)3 under the tip apex, thus enabling VIS-to-IR-to-THz mapping at exciting 20 nm resolution. The mid-infrared is ideal for nanoscale chemical recognition by vibrational and phonon contrasts. Highlights will be presented of finding and characterizing natural nanoscale inhomogeneities, chemical as well as structural, in organic solar-conversion films, in bone/shell biomineral matter, and in slices through a cometary dust particle.--Nano-FTIR is no less than the continued success story of FTIR-based chemical analysis into resolutions hundreds, if not thousands of times better than previously attainable. It is a highly welcome solution to nanoanalysis requirements in all nanotechnologies and nanosciences.

11:30 **Hetero-epitaxial Strain Dependence Of Terahertz Conductivity In NdNiO_3** **W1C-3**
Dhanvir Rana; Rakesh Rana; Parul Pandey; Shriganesh Prabhu
The application potential of Terahertz technology in Materials research has unveiled plenty of novel fundamental and technological encompassing a variety of complex systems. Terahertz (THz) time-domain spectroscopy (TDS), in particular, has proven efficacy in exploring the low energy (0.5-10 meV) excitation in the strongly correlated systems. Among these, one of the most promising classes of materials belongs to the 3d-transition metal oxides where competing interactions between the spin, charge, orbital and lattice degrees of freedom exists. The NdNiO3 belongs to one such class of correlated materials which exhibits concomitant insulator-metal (I-M) and antiferromagnetic ordering at ~ 205 K. This system exhibits fascinating tunability of I-M transition by temperature, pressure and epitaxial strain. However, its insulating state is rather debatable. Here, we have investigated the impact of the epitaxial strain on the Terahertz dynamic response of the NdNiO3 and try to establish a novel epitaxial strain induced cause-effect relationship. In this work, we have performed temperature dependent (5- 300 K) THz time-domain spectroscopic (TDS) measurements in the energy range of 0.5 -- 7 meV on NdNiO3 thin films. THz-TDS measurements were carried out on the NdNiO3 epitaxial thin films prepared on (LaAlO3)0.3(Sr2AlTaO6)0.7 [LSAT] (100) and LaAlO3 (LAO) (100) single crystal substrates. The temperature dependent THz conductivity of NdNiO3 (100) films, is obtained by solving Fresnel's equations.[2] The single crystal LAO (100) and LSAT (100) substrates provide -0.3% and +1.7%

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

lattice mismatch for NdNiO3, respectively. The films are 200 nm thick and were found to be partially relaxed with the c-axis parameters as deduced from the reciprocal space map of NdNiO3 is 3.803 Å on LAO and 3.811 Å on LSAT. The temperature dependence of terahertz conductivity (σTHz) provides crucial information about the underlying mechanisms driving the NdNiO3 films and for selected photon energies and is discussed in detail. Our results clearly indicate that the larger Drude carriers are present in the tensile strained film as compared to the compressive strained counterpart. This reduction in the number of electrons in the low temperature phase may be associated with the setting of the unusual AFM order in NdNiO3. Further, we obtained higher values of Drude Plasma frequency for the tensile strained films than the compressive strained films highlighting the weaker electronic correlations in the former. To sum up, the low energy THz-TDS measurements in NdNiO3 films present the subtle electron-electron correlations can be effectively engineered using the hetero-epitaxial strain.

11:45 **Terahertz Spectroscopy Of Modulation Doped Core-Shell GaAs/AlGaAs Nanowires** **W1C-4**

Jessica Boland; Sonia Conesa-Boj; Gözde Tütüncüoglu,; Federico Matteini; Daniel Rüffer; Alberto Casadei; Fauzia Gaveen; Francesca Amaduzzi; Patrick Parkinson; Chris Davies; Hannah Joyce; Laura Herz; Anna Fontcuberta i Morral; Michael Johnston

In order to realize many devices based on semiconductor nanowires, reliable doping is essential. For such devices, it is important that the electron mobility is not compromised by doping incorporation. Here, we show that core-shell GaAs/AlGaAs nanowires can be modulation n-type doped with negligible loss of electron mobility. Optical pump terahertz probe spectroscopy is used as a novel, reliable, noncontact method of determining the doping density, carrier mobility and charge carrier lifetimes for these n-type nanowires and an undoped reference. A carrier concentration of 1.10 ± 0.06 x 1016 cm^-3 was extracted proving the effectiveness of modulation doping in GaAs nanowires. The room-temperature electron mobility was found to be high at 2200 ± 300 cm^2V^-1s^-1 with no degradation in comparison to undoped reference nanowires. In addition, modulation doping was found to enhance both the photoconductivity and photoluminescence lifetimes to 3.9 ± 0.3ns and 2.4 ± 0.1ns respectively, revealing that modulation doping can passivate interfacial trap states

12:00 **Cu2ZnSnSe4 Photovoltaic Thin Film: A Potential Large-area THz Emitter** **W1C-1**

Zhenyu Zhao; Gudrun Niehues; Stefan Funkner; Elmer Estacio; Qifeng Han; Kohji Yamamoto; Jingtao Zhang; Wangzhou Shi; Qixin Guo; Masahiko Tani

I. INTRODUCTION Large-area THz surface emitters receive increasing interest due to their rubastness, and higher damage threshold with better output efficiency, however, such device is either grown by molecular beam epitaxy (MBE) or metal-organic vapor phase epitaxy (MOVPE). These fabrication methods require strict operating environments, while exhibiting extremely low growth rates. To date, it remains a challenge to realize highly cost-effective materials adapted for large-area surface THz emitters. In this work[1], we report the observation of efficient THz radiation from the surface of a Cu2ZnSnSe4 (CZTSe) thin film grown via low-cost sol-gel method. The THz temporal waveform is measured using a THz time-domain spectroscopy (THz-TDS) setup. In addition to the structural and electrical characterization, the mechanism of THz emission from the CZTSe thin film is revealed. II. RESULTS The temporal waveform of THz radiation from CZTSe pumped with a femtosecond laser (800 nm, 80 fs pulses, and 82 MHz rep. rate) is shown in Fig. 1(a), and the corresponding spectrum is shown in Fig. 1(b). The radiation bandwidths of CZTSe is close to 2 THz with a 40 dB dynamic range (the peak-to-noise level ratio of the power spectrum), as is comparable to GaAs under the same excitation power. The energy band bending directions (upward or downward) determine that the surge current direction of p-type semiconductor is opposite to that of n-type material. GaAs exhibits distinct THz polarity dependence due to its surface depletion layer so as to be an ideal reference emitter. As shown in the Fig. 1(b) and Fig. 1(c), n-GaAs exhibits a distinct positive peak THz waveform, while p-GaAs exhibits distinctly a valley THz waveform. The CZTSe shows the same THz polarity as n-GaAs. Such a phenomenon indicates that the band bending direction at the surface of p-type CZTSe is more similar to the n-GaAs rather than p-GaAs. Actually, the surface band of p-type semiconductor is likely to bend upward when the edge of valence band is closer to the Fermi-level at surface area. For upward band bending, negative charges exist at the surface, and holes accumulate in the CZTSe near surface, causing an accumulation layer[2]. The accumulation layer in p-type semiconductor causes the band bending upward but downward in n-type semiconductor. III. SUMMARY In summary, a prominent THz radiation is observed in CZTSe photovoltaic thin film excited by femtosecond laser pulse. The mechanism of THz generation from CZTSe thin film is dominated by acceleration of photocarriers in accumulation layer at the surface of CZTSe. The CZTSe is found to be a potential cost-effective large area THz emitter.

12:15 **Generation Of Terahertz Radiation In Thin Vanadium Dioxide Films Undergoing Metal-Insulator Phase Transition** **W1C-5**

Petr Solyankin; Mikhail Esaulkov; Artem Sidorov; Alexander Shkurinov; Qin Luo; Xi-Cheng Zhang

Generation of terahertz (THz) radiation was observed in epitaxial VO2 films grown on R- and C-cut sapphire substrates above and below the metal-insulator phase transition temperature. Polarization analysis of the emitted THz radiation reveals strong in-plane anisotropy of the conductive phase of VO2 which is not observed for insulating phase, generation efficiency increases up to 30 times after phase transition. Properties of generated THz radiation in VO2 are defined by the displacement photocurrent at the film-air and film-substrate interfaces.

11:00 - 12:30 **W1D - 08 - Sources, Detectors, and Receivers V** **Lecture Theatre 6**

Chairpersons: Gun-Sik Park;

11:00 **Evidence Of 1.5 THz Single-Photon Detection In Quantum Capacitance Detectors Via Telegraph Rate Distribution Asymmetry** **W1D-1**

Brian Pepper; Charles Bradford; Theodore Reck; Pierre Echternach

Quantum Capacitance Detectors (QCDs) are shot noise limited terahertz detectors. Radiation breaks Cooper pairs, causing quasiparticle poisoning of a charge qubit, read out by a microwave resonator. We find asymmetry in the distribution of telegraph transition rates, interpreted as resulting from discrete single-photon events.

11:30 **THz Emission From Grating-coupled AlGaN/GaN Heterostructures: Comparison Between Plasmonic And Thermal Emission** **W1D-2**

Irmantas Kasalynas; Rimvydas Venckevicius; Vytautas Jakstas; Vytautas Janonis; Justas Lauzadis; Gediminas Seniutinas; Edmundas Sirmulis; Gintaras Valusis; Karolis Pozela; Saulius Juodkazis; Pawel Prystawko; Michal Leszczynski

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

The THz emission from large-area-grating coupler placed on the 2DEG AlGaN/GaN heterostructures was measured at frequency range 0.3-30 THz and temperature from 300 to 500 K with high spectral accuracy. The THz emission spectrum below 10 THz was found to be close to the thermal black-body radiation. Indistinct radiation modified with 2DEG plasma resonances was observed at frequencies below 3 THz.

11:45 **Novel Fermi-Level Managed Barrier Diode For Broadband And Sensitive Terahertz-Wave Detection** **W1D-3**

Hiroshi Ito; Tadao Ishibashi

A novel Fermi-level managed barrier (FMB) diode was developed to enable fabrication of a broadband and low noise THz-wave detector. The fabricated quasi-optical FMB diode module could detect signals at frequencies from 200 GHz to 1 THz. The typical measured voltage sensitivity was 1020 V/W, and the current sensitivity was 4.5 A/W both at 300 GHz for the zero-biased condition.

12:00 **Spatially Resolved On-Chip Picosecond Pulse Detection Using Graphene** **W1D-4**

Nicholas Hunter; Alexander Mayorov; Christopher Wood; Christopher Russell; Mark Rosamond; Lianhe Li; Edmund Linfield; Giles Davies; John Cunningham

We present an on-chip time domain terahertz (TD-THz) system in which picosecond pulses are generated in low-temperature-grown gallium arsenide (LT-GaAs) and detected in graphene. The detected pulses were found to vary in amplitude, full width at half maximum (FWHM), and DC offset when sampled optically at different locations along a 50-µm-long graphene photoconductive (PC) detector. The results demonstrate the importance of detection location and switch design in graphene-based on-chip PC detectors.

11:00 - 12:30 **W1E - 17 -MMW and Sub-millimeter Wave Radar and Communications II** **Lecture Theatre 7**

Chairpersons: Shenggang Liu;

11:00 **Low Phase Noise Fully Integrated Millimeter-wave Photonic Source Using Cross Injection Locking** **W1E-1**

Gaël Kervella; Frederic van Dijk; Mehdi Alouini; Mourad Chtioui; Marco Lamponi

We report the stabilization of a 90 GHz RF signal generated from a fully integrated photonic source. The chip consists of two DFB single mode lasers whose optical signals are combined on a fast photodiode to generate a largely tunable heterodyne beat note. By generating an optical comb on each laser, thanks to an external synthesizer, and by optically self-injecting the resulting signal, we mutually correlate the phase noise of each DFB and we stabilize the RF beating on the external reference. The performances achieved beating linewidth below 30 Hz.

11:30 **Dispersion Compensation Of The THz Communication Channels In The Atmosphere** **W1E-2**

Daniel Grischkowsky; Mahboubeh Mandehgar

We demonstrate that dispersive compensation can be achieved for the communication channels within the atmospheric THz windows using the long-path THz-TDS system. However, the THz pulse broadening cannot be eliminated due to the bandwidth reduction of the propagating THz pulse due to the frequency dependent absorption of the channels.

11:45 **A Solid State W-band Radar Profiler For Cloud Observation** **W1E-3**

Dirk Klugmann; Hui Wang; Simon Rea; Brian Moyna; Matthew Oldfield; Peter Huggard; Brian Ellison

Millimetre wave radar has been successfully applied in cloud research for a number of decades. The Rutherford Appleton Laboratory (RAL) has developed a 94 GHz radar based on solid state components and operated in Frequency Modulated Continuous Wave (FMCW) mode. The approach for improving the RF design -- including the implementation of Doppler capability -- and the results of this activity will be presented.

12:00 **Experimental Characterization Of Extremely Broadband THz Impulse Radio Communication Systems** **W1E-4**

Xianbin Yu; Borja Vidal; Michael Galili; Toshio Morioka; Peter Uhd Jepsen; Leif Oxenløwe

Abstract-- We experimentally characterize a ultrabroadband terahertz (THz) impulse radio system with up to 10 GHz repetition rate. We analyze the performance in terms of bandwidth and the features of the THz pulses. A 15 dB bandwidth of 1 THz confirms that this THz impulse system has a great potential of supporting ultrafast data rates, eventually for Terabit wireless communication era. I.INTRODUCTION Wireless data rates have doubled every eighteen months over the last three decades, and are quickly approaching to 100 Gbit/s [1], particularly driven by an increasing demand for much higher speed wireless communication anywhere, anytime. To support such fast wireless data dates at and above 100 Gbit/s, the radiation spectrum naturally falls into the THz (0.1-10 THz) range. So far a lot of efforts have been invested to develop high speed wireless communication systems, and most of them are operating in the millimeter-wave or sub-THz frequency region [2-7]. However, these narrowband frequency windows (< 100 GHz bandwidth) limit the highest achievable data rate. Alternatively, pulsed THz systems have been widely studied and used for THz spectroscopy at low pulse repetition rates of 100 MHz [8]. Recently, such pulsed THz systems have attracted much research interests in developing THz wireless communication because of its huge bandwidth [9]. In this paper, we characterize a 10 GHz repetition rate pulsed THz system by combining an UTC-PD and a PCA. To our knowledge, this is the first time that a THz impulse radio system at such a high rate is experimentally implemented. II.EXPERIMENTAL RESULTS The experimental setup of our pulsed THz wireless communication system is shown in Fig. 1. In the system, 10 GHz optical pulses illuminates an UTC-PD for THz impulse generation, and down-sampled 100 MHz pulses for detecting THz radiation at a PCA. The recorded THz train is presented in Fig.2 (a). 100 ps time interval between two adjacent pulses confirms the success of generating and detecting THz signals at 10 GHz repetition rate. Looking at the details of a THz pulse enlarged in Fig. 2(b), we can observe that a THz pulse entirely lasts around 20 ps, while the width of monocycle-like swing is only 7 ps. Broadening a THz pulse with a long time oscillation here is because its long relaxation time (more than 100 ps). Besides that, we can also observe some echoes in Fig.2 (b) caused by the reflection between the Silicon lens and GaAs chip, which degrades the signal-to-noise ratio. The THz frequency spectra are shown in Fig.2(c), with a 15 dB bandwidth of 1 THz. Such an extremely broadband system can apparently support ultrahigh speed wireless communication. III.SUMMARY Pulse operation of 10 GHz repetition rate is well beyond conventional THz pulsed spectroscopic systems. The pulsed system with an extremely broad bandwidth of 1 THz at 15 dB can definitely be capable of carrying very high data rate, and hence has great potential for ultrafast wireless communication.

12:15 **A Wideband Profiled Corrugated Horn For Multichroic Applications** **W1E-5**

Lingzhen Zeng; Cheukyu Edward Tong; Edward Wollack; David Chuss

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

A wideband profiled corrugated feedhorn was developed for multichroic applications. This feedhorn features a return loss of better than -25 dB and cross polarization peaks below -30 dB, over a fractional bandwidth of >50%. Its performance is close to that of the ring-loaded corrugated feedhorn; however, the design presented is much easier to fabricate at millimeter wavelengths.

14:00 - 15:30 **W2A - 02 - Applications in Biology and Medicine II** **Lecture Theatre 2**

Chairpersons: Biao-Bing Jin;

14:00 **Challenges And Opportunities In Terahertz Biomedical Imaging** **W2A-1**

Joo Hiuk Son

Various biomedical applications utilizing terahertz technology are presented. Technical challenges in such applications are discussed in terms of limited penetration depth, blurred spectral features, and deficient contrast and the feasible solutions to the problems are also suggested.

14:30 **Quantitative Measurement Of Permeabilization In Living Cells By Terahertz Attenuated Total Reflection** **W2A-2**

Marianne Grognot; Guilhem Gallot

Using Attenuated Total Reflection (ATR) imaging technique in the terahertz domain, we demonstrate non-invasive, non-staining real time measurements of cytoplasm leakage during permeabilization of live MDCK cells by saponin at low concentration. The origin of the contrast observed between cells and culture medium is addressed by both experimental and theoretical approaches, and demonstrated to give access to permeabilization dynamics for two close saponin concentrations (50 and 75 µg/ml).

14:45 **Identification Of Antigen-antibody Interaction Using Principle Component Analysis Method In Terahertz Frequency** **W2A-3**

Yiwen Sun; Junlan Zhong; Shengxin Yang

In this paper, we concerned with the spectrum analysis of interaction of recombinant heamaglutining (HA) antigen against its antibody in terahertz frequency using principle component analysis (PCA). 21 liquid samples with different component were divided into positive and negative control groups and measured using THz-TDS in transmission geometry. The spectral pretreatment methods were adopted to make our results more explicit in this study. As a result, HA complexes are distinguished by different scores which indicate the PCA method can be used to identify the antigen-antibody binding interaction in THz frequency.

15:00 **Modulation Of The Hydration Water Around Monoclonal Antibodies On Addition Of Excipients Detected By Terahertz-time Domain Spectroscopy** **W2A-4**

Vincent Wallace; Christopher Van Der Walle; Robert Falconer; Shahid Uddin; Axel Zeitler

Interrogation of the protein hydration layer in the context of the rational design of high concentration monoclonal antibody (mAb) formulations has not yet been reported. Here, terahertz time domain spectroscopy (THz-TDS) was used to show that the hydration layer for 'mAb1' up to 140 mg/ml was perturbed by the addition of 200 mM proline or arginine but not 200 mM sucrose. The hydration layer of 'mAb2' was also shown to be modulated by more complex formulations composed of two or more excipients in buffer. Thus, THz-TDS promises to be a useful tool for protein formulation by providing an improved understanding of solution behaviour at high concentrations and associated mechanisms of control by the addition of excipients.

15:15 **THz Absorption Of Adenine Base In Single-stranded Deoxyribonucleic Acid** **W2A-5**

Marina Komatsu; Yoshimichi Ohki; Maya Mizuno

Deoxyribonucleic acid (DNA) is a basic element of all the living organs. It is a kind of polymer having a repeated structure of nucleotide composed of a deoxyribose, a phosphate, and a base. There are four different kinds of bases; adenine, guanine, cytosine, and thymine. Clarification of the structure of DNA has been of prime importance in medical and biological fields. In addition, a recent research trend that treats DNA as a new polymer material has enhanced the importance of the analysis of DNA. Therefore, in the present research, we try to correlate the number of bases in single-stranded DNA with absorption spectra obtained in a THz range as a first trial of THz spectroscopic analysis of DNA. We obtained THz spectra for various single-stranded DNAs, consisting of 24 to 100 nucleotides with only adenine as their bases. First, we made a solution of DNA. After it was dripped on a diamond substrate, its absorption spectrum was measured in a frequency range from 3 to 18 THz (100 to 600 cm^-1). Nine absorption components in total appear in the range observed. Moreover, the spectral intensity shows a monotonic increase with an increase in the number of nucleotides in the sample. We separated each absorption spectrum into nine components and estimated the integrated molar absorption coefficient for each component by doing numerical integral. As a result, the integrated molar absorption coefficient per nucleotide can be calculated to be 1.0×10^7, 7.8×10^6 and 8.2×10^6 cm/mol for the three absorption components at 482, 518, and 540 cm^-1, respectively, for DNAs with adenine. Using these coefficients, we can estimate the number of nucleotides with adenine in single-stranded DNA with only adenine as their bases by THz spectroscopy.

15:30 **Time Of Flight THz Imaging Of 3D Ex-Vivo Breast Cancer Tumor Tissues** **W2A-6**

Tyler Bowman; Yuhao Wu; Alec Walter; John Gauch; Magda El-Shenawee; Lucas Campbell

This research represents experimental use of a pulsed terahertz time-domain imaging system to obtain time of flight (in-depth) reflection scans from three-dimensional ex-vivo breast cancer tumor tissue. Image processing and volumetric techniques are performed on these THz scans to analyze and enhance the tumor image and assess its boundaries.

14:00 - 15:30 **W2B - 19 - Laser Driven THz Sources I** **Lecture Theatre 3**

Chairpersons: Jianming Yuan;

14:00 **High Power Pulsed Terahertz Radiation From Large Area Plasmonic Photoconductive Emitters** **W2B-1**

Nezih Yardimci; Shang Hua Yang; Mona Jarrahi

Large area photoconductive terahertz emitters are shown as a very promising pulsed terahertz source to generate high power and broadband terahertz radiation since they can accomodate high optical pump power levels without suffering from carrier screening or thermal breakdown. However, their performance is mainly limited by their low optical-to-terahertz conversion efficiency due to the weak time-varying dipole moment induced within the device active area. The induced dipole moment cannot be strengthened since the velocity and the acceleration of carriers are limited by the transport properties of

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

semiconductors. To enhance the low optical-to-terahertz conversion efficiency of conventional large are photoconductive emitters, we present a novel design that incorporates plasmonic contact electrode gratings within the device active area. An efficient optical transmission can be achieved through sub-wavelength gaps between the gratings by the excitation of surface plasmon waves. Moreover, since the transmission is provided by surface plasmons, most of the carriers are generated in a close proximity to the contact electrode gratings. As a result, majority of the photogenerated carriers drift through the metal electrodes. Hence, the induced dipole moment improves significantly. We experimentally demonstrate up to 3.8 mW of pulsed terahertz radiation at an optical pump power of 240 mW, exhibiting more than an order of magnitude higher optical-to-terahertz conversion efficiencies compared with the conventional large area photoconductive emitters.

14:30 **Photomixing And Photoconductive THz Generation Improvement In SI-GaAs After Carbon Irradiation** **W2B-2**

Prathmesh Deshmukh; Abhishek Singh; Sanjoy Pal; Shriganesh Prabhu; S Mathimalar; Vandana Nanal; Ronald Pillay; Gottfried Doehler; Mario Mendez Aller; Sascha Preu

We report significant improvement in pulsed and continuous wave (CW) THz generation when semi insulating GaAs (SI-GaAs) is irradiated with carbon ions. Irradiation has reduced carrier lifetime in SI-GaAs and has increased its resistivity. This has resulted in reduced screening effect and lesser heat dissipation in the THz pulse emitter. Reduced lifetime significantly improves the bandwidth of the CW THz system. In this work, we irradiated SI-GaAs substrate with high energetic carbon ions, which can penetrate into the SI-GaAs up to ~ 2µm depth. THz emission ability of irradiated material via photoconductive and photomixing technique is studied and compared to that of non-irradiated SI-GaAs. Irradiation generates a multitude of defects in the semiconductor wafer leading to a reduction in their carrier lifetime and an increase in the resistivity. Carbon irradiation with an area dose of 10^13ions/cm^2 lowered the carrier lifetime to ~0.27 ps as compared to ~71 ps of non-irradiated SI-GaAs. THz pulse emission is studied using a THz-TDS setup with a 10 fs pulsed laser. At same applied bias (20 V for electrode gap of 25µm) and same optical excitation, irradiated SI-GaAs (~10^13/cm^2 dose) photoconductive emitter was ~ 3 times more efficient than usual non-irradiated SI-GaAs. Logarithmic-periodic devices were tested for THz emission efficiency using a Golay cell detector. The SI-GaAs devices draw a fairly high current of about ~2.7 mA even at a moderate bias of 10 V. The 10^13/cm^2 ion implanted sample in contrast, shows a much lower photocurrent of ~190 µA even for an increased bias of 20V. The generated thermal noise is lower than noise floor of the Golay cell.

14:45 **Effect Of The Plasmonic Enhanced Absorption And Bias Field Enhancement In Nano-Electrode THz Photo-Conductive Antennas** **W2B-3**

Kiwon Moon; Il-Min Lee; Jun-Hwan Shin; Kyeong Sun Choi; Kyung Hyun Park

Metallic nano-electrodes improve the emission efficiency of THz photo-conductive antennas. But the main enhancement mechanism has not been systematically studied. In this study, we experimentally compared the effect of plasmonic enhanced absorption and bias field enhancement at the apex of nano-fingers. We concluded that the bias field enhancement dominates over the plasmon effect at low optical excitation densities. Both effects significantly saturated as the optical excitation power increases. Thus, we fabricated a large-aperture emitter for higher output power, obtained more than 1500 nA of peak-to-peak detector current with 2.5 THz of emission bandwidth.

15:00 **Control Of THz Wave Emission By Tuning Relative Phases Between Two Color Lasers** **W2B-4**

Zhelin Zhang; Yanping Chen; Zhen Zhang; Xiaohui Yuan; Min Chen; Zhengming Sheng; Jie Zhang

THz waves emitted from air filaments induced by elliptical polarized laser pulses are studied both theoretically and experimentally. The relative phases between different polarized laser components play an important role in the THz generation.

15:15 **Generation Of Continuous Wave Terahertz Radiation From Fe-doped InGaAs And InGaAsP** **W2B-5**

Reshma Anamari Mohandas; Joshua R Freeman; Mark C Rosamond; Siddhant Chowdhury; Paul Dean; Alexander Giles Davies; Edmund H Linfield; Lalitha Ponnampalam; Alwyn J Seeds; Martyn Fice

We demonstrate the generation of continuous wave terahertz radiation from Fe-doped InGaAs and Fe-doped InGaAsP photomixers grown by Metal Organic Chemical Vapor Deposition (MOCVD), using a pair of 1550 nm diode lasers. A bandwidth of > 2.4 THz is obtained from the emitters and the effect of doping on emitted power and bandwidth is studied.

14:00 - 15:30 **W2C - 12 - Devices, Components, and Systems IV** **Lecture Theatre 4**

Chairpersons: Weiwei Liu;

14:00 **Overmoded Traveling Wave Tubes For MM And THz Applications** **W2C-1**

Jason Hummelt; Sudheer Jawla; Elizabeth Kowalski; Michael Shapiro; Richard Temkin

High power sources of coherent radiation, producing Watts to tens of Watts of average power, are needed for applications in the millimeter wave and THz regimes. Overmoded traveling wave tubes offer the possibility of meeting these requirements in rugged and simple to fabricate devices. Results on a 94 GHz overmoded TWT confirm the viability of this approach. Designs for a PBG amplifier operating at 250 GHz, based on the successful 94 GHz TWT, are described.

14:30 **Anderson Localization In Terahertz Plasmonic Waveguides** **W2C-2**

Shashank Pandey; Barun Gupta; Ajay Nahata

Abstract-- We present the first experimental demonstration of spatial localization (Anderson localization) of terahertz waves in plasmonic structures. The effect is brought upon by inclusion of disorder in a one dimensional plasmonic lattice. We discuss the effect of disorder on the propagation properties of the waveguide, the appearance of new modes beyond the stop band, and their transport properties. We also measure the spatial properties of the localized mode and compare the localization length to other experimental demonstrations. The results are consistent with prior published theoretical works. Anderson or strong localization of waves is an interference phenomenon in a highly scattering or disordered medium. Although localization of electron waves was first proposed in disordered atomic structures [1], the phenomenon has been observed for matter waves and photons across a broad range of electronic and photonic structures in the scale of all dimensions [2-3]. Nevertheless, almost all experimental realizations have been reported using optical frequencies, since a number of materials exist that exhibit low loss. In general, such a condition is difficult to realize at terahertz (THz) frequencies. Here we report the first demonstration of localization of terahertz surface plasmon polaritons (SPPs) using one-dimensional (1D) arrays of disordered subwavelength holes on metal surfaces. In order to observe the effect of disorder, we fabricate THz plasmonic waveguides by creating 1D arrays of rectangular holes on metal films. The devices are fabricated via laser ablation of metal foils; the process has an inherent tolerance of less than 1 %. The transmission properties of waveguides with a 1D periodic array of holes have been investigated earlier [4]. Here, we introduce disorder in the waveguides by changing the periodicity of the holes by using a model d = < d > ±

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

σ, where d is the periodicity (< d > = 250 μm) and σ is a fraction of d, as shown schematically in Fig. 1. For each value of σ, eight independent waveguides were fabricated and tested. The average periodic spacing determines the first Brillouin zone, beyond which the propagating modes experience high loss, νB = c/2 d = 0.6 THz. Fig. 2(a) shows the transmission spectrum for waveguides with disorder ranging from 0% to 25 %. The three modes below 0.6 THz correspond to propagating modes associated with the dimensions of the rectangular holes. For σ < 25%, we do not see any modes above νB. However, for two of the waveguides with σ = 25%, we observe clear evidence of a mode beyond the Brillouin zone. Fig. 2(b) shows the behavior of the spectrally isolated mode for two different waveguides having 25% disorder. The spatial variation can be modeled using the expression E (x) ~ E0 exp (- |L- L0 |/ξ), where ξ is the localization length and L0 is the location on the waveguide where a spatial localized maximum is observed.

14:45 **Sub-terahertz Wave Radiating Array Consisting Of Nine Photomixers For Illuminating Smoky Environment** **W2C-3**

Naofumi Shimizu; Ken Matsuyama

We previously proposed a sub-terahertz (THz) illuminator suitable for use with a THz camera when exploring objects in and behind smoke at the scene of a fire. The illuminator contains multiple photomixers and each photomixer generates incoherent sub-THz waves. Incoherency of the generated sub-THz waves is expected to enable us to raise their intensity by increasing the number of photomixers in operation, which makes it possible to achieve very bright sub-THz illumination. Consequently, objects being search for in or behind smoke can be illuminated clearly with the illuminator and visualized with a THz camera even though they are surrounded by thick and/or high-temperature smoke. Our preliminary imaging experiment with two photomixers indicated that the use of incoherent sub-THz radiation eliminates the interference pattern on the radiation profile and enables us to acquire clear images. We also confirmed that sub-THz active imaging ensures a clear view in a simulated smoky environment. However, we used only one or two photomixers as the radiation source in that preliminary study. The radiation power for active imaging was not sufficient. Therefore, we carried out our imaging experiment within a limited distance. In this paper, we report on a sub-THz wave radiating array consisting of nine antenna-integrated uni-traveling carrier photodiode modules developed for extending the range of the sub-THz active imaging in a smoky environment. When the radiated sub-THz waves were incoherent, all modules illuminated uniformly in the same area and the illumination power increased linearly by increasing the number of modules in operation. These illumination characteristics indicate that the range of the active imaging in a smoky environment will be extended up to 1 meter or more by using the array.

15:00 **Recent Advances In Modelling And Characterization Of Uncooled Antenna-coupled Bolometer Arrays** **W2C-4**

Jerome Meilhan; François Simoens; Jean-Louis Ouvrier-Buffet; Antoine Hamelin; Baptiste Delplanque

The CEA-Leti THz uncooled imaging arrays rely on a dedicated pixel architecture where a resonant dielectric cavity combined to antennas processed above the CMOS read-out-circuit ensure the optical coupling. Performance improvements of the new prototyped designs are presented through modelling and characterizations in the range above and below 1 THz.

15:15 **Photoconductive Antennas Based On Low Temperature Grown GaAs On Silicon Substrates For Broadband Terahertz Generation And Detection** **W2C-5**

M. Klos; R. Barthold; J. Klier; M. Stolze; J.-F. Lampin; René Beigang

We present investigations of photoconductive antennas (PCA) based on low temperature grown GaAs (LT GaAs) on silicon substrates for terahertz (THz) detection and generation. The PCAs consist of 2 μm thick layers of LT GaAs bonded on a high resistivity silicon substrate in order to reduce the intrinsic absorption losses around 8 THz due to a strong phonon resonance in GaAs. Using 20 fs long pump pulses around 800 nm and dipole antennas with dipole length between 20 μm and 60 μm a maximum bandwidth above 10 THz and a maximum dynamic range exceeding 90 dB at 0.5 THz were obtained. The average output power was measured with a calibrated detector to be 5 μW at a repetition rate of 80 MHz.

14:00 - 15:30 **W2D - 11 - Metamaterial Structures and Applications V** **Lecture Theatre 6**

Chairpersons: Chao Zhang;

14:00 **Terahertz Metasurfaces For Antireflection Coatings** **W2D-1**

Hou-Tong Chen; Li Huang; Abul Azad; Toni Taylor

We demonstrate a new strategy of ultrathin terahertz antireflection coatings employing metasurfaces. The antireflection performance is determined by the metasurface structure design rather than the properties of materials being used, and it is scalable to operate at any relevant wavelengths and substrates of arbitrary refractive index.

14:30 **Plasmon Resonances Of Terahertz Absorption In Nano-patterned Graphene** **W2D-2**

Lei Du; Gang Chen; Lin Wang; Xiaoshuang Chen; Wei Lu

The plasmon resonances in graphene and graphene field effect transistors (GFETs) are investigated by electromagnetic simulations of the behavior of photo-generated carriers with applied bias voltage. Our results show a strong absorption in THz regime in patterned graphene field effect transistor, offering a perspective application in far-infrared photodetectors.

14:45 **Electromagnetic Field Enhancement In Metallic Metamaterials: A Potential For Compact Terahertz Free-electron Lasers** **W2D-3**

Seontae Kim; In-Keun Baek; Ohjoon Kwon; Anirban Bera; Ranajoy Bhattacharya; Sattorov Matlabjon; Sun-Hong Min; Gun-Sik Park

Our recent efforts suggest that there exists strong electromagnetic field enhancement in our recently proposed metallic metamaterial. Of particular importance here is the potential for the realization of compact terahertz free-electron lasers (THz-FELs) using this structure. We present the capability of controlling electromagnetic field enhancement, which must be one of the main issues in developing the compact THz-FELs. Moreover, switching and sensing abilities of this structure could also be investigated for other metal-based THz applications. The numerical and experimental works will be presented in the conference.

15:00 **Micro Fabricated Spoof Surface Plasmon Polariton Structures For THz Applications** **W2D-4**

Andreas K. Klein; Yi Pan; Claudio Balocco; Dagou Zeze; Andrew Gallant

An inexpensive method to produce spoof surface plasmon polariton structures has been presented. The structured surface quality and limits of the method are discussed. A THz Vector Network Analyzer is used in a double knife-edge scattering experiment to characterize the structures and the results are compared with the theoretical predictions

15:15 **Fully-Integrated And Electronically-Controlled Millimeter-Wave Phase Modulator** **W2D-5**

Mohammed Reza Hashemi; Shang Hua Yang; Tongyu Wang; Nelson Sepúlveda; Mona Jarrahi

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

We present a fully-integrated and voltage-controlled millimeter-wave phase modulator based on vanadium dioxide (VO2). It consists of a resonant reconfigurable meta-surface fabricated on a thin VO2 film integrated with voltage-controlled heating electrodes. By varying the applied voltage to the heating electrodes, the dielectric properties of the VO2 layer is controlled and the resonance frequency of the meta-surface is shifted accordingly, introducing a considerable phase shift. We experimentally demonstrate the highest reported phase shift of 60º at 85 GHz through a fully integrated, voltage-controlled device platform by varying the control voltage from 0 V to 14 V.

14:00 - 15:30 **W2E - 21 - Gyro-Oscillators and Amplifiers III** **Lecture Theatre 7**

Chairpersons: Alexander Litvak;

14:00 **Efficient Frequency Step-Tunable Megawatt-Class D-Band Gyrotron** **W2E-1**
Gerd Gantenbein; Andrey Samartsev; Konstantinos Avramidis; Guenter Dammertz; Manfred Thumm; John Jelonnek
Results of latest experimental studies on the frequency step-tunable (D-band) megawatt class gyrotron which is under development at IHM (KIT) are presented. The goal of the short pulse (~ 1 ms) experiments was to study the performance of an upgraded cavity with longer cylindrical section. Target was to achieve significantly better efficiencies by introducing a cavity with a higher quality factor. The new design of the cavity was numerically optimized using the EURIDICE code.

14:30 **Hysteresis And Frequency Tunability Of Gyrotrons** **W2E-2**
Toshitaka Idehara
We present the first devoted experimental and theoretical study of hysteresis phenomenon in relation to frequency tunability of gyrotrons.

14:45 **High Speed Frequency Modulation Of A 460 GHz Gyrotron For Application To The 700 MHz DNP Enhanced NMR Spectroscopy** **W2E-3**
Toshitaka Idehara; E.M. Khutoryan; Y. Tatematsu; Y. Yamaguchi; A.N. Kuleshov; O. Dumbrajs; Y. Matsuki; T. Fujiwara
The high speed frequency modulation of a 460 GHz Gyrotron FU CW GVI (the official name in Osaka University is Gyrotron FU CW GO-I) was achieved by modulation of acceleration voltage of beam electrons. The modulation speed fm can be increased up to 10 kHz without decreasing the modulation amplitude δf of frequency. δf was increased almost linearly with the modulation amplitude of acceleration voltage δVa. At the δVa=1 kV, δf=53 MHz in the case of fm<10kHz. The frequency modulation was observed as both the variation of the IF frequency in the heterodyne detection system measured by an oscilloscope and the width of frequency spectrum measured on a frequency spectrum analyzer. Both results well agree reasonably. The experiment was performed successfully for both a sinusoidal wave and a triangle-wave modulations. By using the frequency modulation, we have a possibility to compensate the decreasing of the enhancement factor in high frequency DNP-NMR spectroscopy for example, 700 MHz. In addition, high speed frequency modulation is useful for frequency stabilization by PID control of acceleration voltage by feeding back of fluctuation of the frequency. The frequency stabilization in long time is also important for application of DNP-NMR spectroscopy to analysis of complicated protein molecules.

15:00 **Dual-Frequency, 126/84 GHz, 1 MW Gyrotron For The Upgrade Of The TCV EC-System** **W2E-4**
Jean-Philippe Hogge; Stefano Alberti; Falk Braunmueller; Jérémy Genoud; Trach-Minh Tran; Minh-Quang Tran; Konstantinos Avramidis; Ioannis Gr. Pagonakis; Jianbo Jin; Stefan Illy; Gerd Gantenbein; John Jelonnek; Fabio Cismondi
The TCV tokamak is presently undergoing major heating upgrades, installing a neutral beam for direct ion heating and increasing the electron cyclotron (EC) power injected in X-mode at the third harmonic (X3) and second harmonic (X2). The EC-system upgrade consists of adding two dual-frequency, 84/126GHz, gyrotrons for X2 and X3 heating with a 1MW rf-power per gyrotron at both frequencies and 2s pulse length. The design of the dual-frequency gyrotron presented in this paper is based on the 140GHz W7-X gyrotron and has been carried out within a European collaborative effort. A partial re-design of some internal components (triode-gun, cavity, QO-launcher and collector) allows to obtain powers in excess of 1MW and a very-high gaussian content (>97%) at both frequencies without depressed collector.

15:15 **Development Of A Wide-Band Window In HE1,1 Guide For Gyrotrons** **W2E-5**
Lawrence Ives; Michael Read; Thuc Bui; David Marsden; Geroge Collins; William Guss; Richard Temkin; Jeffrey Neilson
This presentation will describe development of a gyrotron direct coupler that converts whispering gallery power from the RF circuit into an HE11 mode in corrugated waveguide inside the vacuum envelope. The power will be extracted from the gyrotron through a Brewster window for broadband operation. The corrugated waveguide output eliminates requirements for Mirror Optical Units (MOU) currently used to convert Guassian mode output into modes suitable for corrugated waveguide transmission systems. This method eliminates RF power lost in the MOU and significantly reduces the cost of the system. Far field measurements of the coupler at low power indicated conversion of the whispering gallery mode to the HE11 mode exceeded 97%. High power tests in a pulsed gyrotron at MIT appeared to indicated a degradation in gyrotron performance; however, subsequent testing indicated the degradation was caused by the electron gun and/or RF circuit. Consequently, additional tests will be performed following repair of the gyrotron. The diamond Brewster window is facilitated by integration into the corrugated waveguide. While a diamond Brewster window for a Gaussian mode would be prohibitively large and expensive, integration into the waveguide reduces the size to slightly less than required for a conventional single frequency, disk window. Assembly of the window is nearing completion with tests planned at General Atomics in fall 2015. The window will be installed in the transmission line used for the DIII-D tokamak and tested to the highest power and pulse length available. This presentation will describe the design of the coupler and window and present available test results. Plans for integration into a gyrotron will also be presented.

16:00 - 17:30 **W3A - 16 - MMW systems, Transmission Lines and Antennas II** **Lecture Theatre 2**

Chairpersons: Nuria Llombart-Juan;

16:00 **On-chip THz-Frequency Tuneable Plasmonic Circuits** **W3A-1**
Jingbo Wu; Alexander Mayorov; Chris Wood; Divyang Mistry; Lianhe Li; Edmund Linfield; A. Giles Davies; John Cunningham

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

We demonstrate the excitation and electrostatic modulation of a planar, resonant plasmonic circuit, comprised of a two-dimensional electron system (2DES) integrated into three different on-chip, terahertz-frequency coplanar waveguides. We utilise a Schottky gate formed across the 2DES in one device to create a resonant cavity in which the carrier concentration, and therefore the cavity resonant frequency, can be tuned by application of a negative DC gate bias, or using an external magnetic field. Using this technique, we demonstrate tuneable plasmon and magnetoplasmon generation and detection at frequencies up to ~ 400 GHz, by injection of terahertz pulses into the 2DES from the waveguide region.

16:30 **Development Of High Power Gyrotrons And Mm-wave Launcher For ITER** **W3A-2**

Koji Takahashi; Ryosuke Ikeda; Yasuhisa Oda; Takayuki Kobayashi; Ganji Abe; Masami Isozaki; Hiroyuki Shidara; Shinichi Moriyama; Keishi Sakamoto; Ken Kajiwara

Recent progress of high power long pulse gyrotrons developed by JAEA is described. Multi-frequency oscillation at 203GHz, 170 GHz, 137 GHz and 104 GHz were successfully performed. The oscillation of 1MW/200s (η=47%) were also demonstrated. The millimeter (mm)-wave design of mm-wave launcher, which is installed at the equatorial port, to attain the poloidal beam steering with transmission efficiency of 98% has been successfully obtained.

17:00 **Medium-Range Propagation Flexible Waveguides At Millimeter-Wave And Submillimeter-Wave Frequencies** **W3A-3**

Maria Alonso-delPino; Nuria Llombart Juan; Marco Spirito

This contribution presents the development of medium range flexible propagation waveguides for next generation wired data systems at millimeter and sub-millimeter wave frequencies.

17:15 **Electron Cyclotron Waves For Current Drive And Neo-Classical Tearing Mode Mitigation In A DEMO Machine** **W3A-4**

Giovanni Grossetti; John Jelonnek; Emanuele Poli; Dirk Strauss; Alessandro Vaccaro; Hartmut Zohm

In this paper we present preliminary results of the analysis on driving current and mitigating Neo-classical Tearing Mode instabilities, using Electron Cyclotron waves, as input for Port Plug development and integration in DEMO. The study has been carried out in a joint collaboration between the Karlsruhe Institute of Technology (Karlsruhe, Germany) and Max Planck Institute for Plasma Physics (Garching, Germany), within the EUROfusion PPPT-Work Package Heating and Current Drive activity. The assessment has been exploited for a pulsed DEMO machine and it has been constrained by requirements imposed by tritium self-sufficiency and structural components integrity.

16:00 - 17:30 **W3B - 13 - R&D,Future Applications, and Market Directions** **Lecture Theatre 3**

Chairpersons: Xi-Cheng Zhang;

16:00 **Terahertz Technology For Industrial Applications** **W3B-1**

Don Arnone; Phil Taday

An overview is presented of recent industrial applications of Terahertz and some of the key challenges and solutions towards further the introduction of Terahertz systems into production environments.

16:30 **Application Of T-Ray Gyrotron Developed For Real-Time Non-Destructive Inspection To Enhanced Regeneration Of Cells** **W3B-2**

Seong-Tae Han; Woo-Jae Lee; Ki-Sang Park; Sung-Wook Choi; Juhwan Yoon; Jung Sun Yoo

Active real-time THz imaging system (ARTIS) for non-destructive inspection (NDI), requires a powerful T-ray source capable of illuminating large inspection area at a time. A sub-THz gyrotron satisfying such a unique requirement is proven to be effective not only for NDI but also for bio-medical application such as enhanced regeneration of cells.

16:45 **A THz Tomography Imaging System** **W3B-3**

Aleksander Sesek; Andrej Svigelj; Janez Trontelj

The imaging of the internal contents of a multilayer material, organic tissue, or just structural properties of the object behind a barrier is commonly desired in many aspects of the field of medicine or industry. THz waves have the ability to penetrate in to many materials and therefore enable the observation of the object interior. In the paper a 3D THz imaging system is presented, along with a method for the tomographic imaging is described. With the obtained images the properties of the material layers can be determined through observation of amplitude and the phase of the reflected THz wave. With the tomographic method described and the THz system used, many further applications development or material properties investigations can be carried out. The presented THz system was proven to be mature enough to support and upgrade research and development in the THz region. The obtained results are promising and open new research and development opportunities.

17:00 **K-band Wearable CW-Doppler System For External Urodynamics Study** **W3B-4**

Seiji Matsumoto; Yasuhito Takeuchi; Hidehiro Kakizaki

K-band wearable CW Doppler system is developed for external urodynamics study. The sensor is finger mountable to direct sensing beam parallel to running urea drop in air. It yields audio frequency Doppler signal of the target. The frequency spectrum time pattern allows to estimate speed and flow volume time curve of urination, for urological diagnosis. In urological field a patient's urination behavior is one of very important diagnostic information for his or her lower urinary tract function. Such examination in non-contact mode is called external urodynamics study, where traditionally a mess-cup or a turbine generator forming a toilet-like instrument accepts patient's urination to record quantity-time curve and/or flow rate mechanically. However, patient must go to such instrumentation toilet at limited installation such as hospital. Natural, undisturbed urination of patient own condition can't be monitored in this way. To cope with this issue our non-contact, ultrasound and MMW Doppler external urodynamics study systems have been proposed, with feasibility using phantom, in so old days in 1988 at this conference (1). Our renovated instrumentation here presented is to staff it as patient wearable, finger mount device to allow him or her to check own urination pattern daily at anytime, anyplace in own living environment for own practice. A MMIC stripline resonator oscillator in K-band (24GHz) and homodyne detector diode pair are integrated on one side of a 20mm dia. circuit board where its other side across ground plane is patch antenna pair for transmission and reception. Gross directivity for Doppler sensitivity is so wide as 60 or more degree cone. The Doppler unit is cased by plastic enclosure to form finger mountable style. The Doppler audio signal at detector diode output is recorded for off-line FFT analysis to have Doppler spectrum and flow rate estimate. When patient urinates with this device mounted at finger supporting his genital or next to her orifice, a Doppler audio signal and spectrum can be obtained typically like shown in fig.1a,b. A ridge trace of the spectrum (Fig.1c) yields uroflow curve substitute. Urologist can diagnosis lower urinary tract function based on one-gaze of the Doppler spectrum, even without uroflow curve substitute. The sensor unit is designated for battery operation including wireless transmission of the Doppler audio signal to recording and signal processing device. For disinfection reason the K-band system

08:45 - 09:15	**Welcome and Opening Remarks** **Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;**	**Lecture Theatre 1**

is preferred than its ultrasound ancestor (2) because sealed washable design is possible in K-band system while ultrasound ancestor (2) can't. Summary: K-band finger mount wearable CW Doppler system is developed for external urodynamics study for anytime anywhere natural unconstrained urination in patient own living environment and for own practice. This device, and its gross concept, will make an evolution in urology for patient conducted own healthcare.

17:15 **Plasma Glow Dynamics Of Pulsed Nitrogen Discharge Induced By The Powerful Terahertz Waves** **W3B-5**
Alexander Sidorov; Alexander Vodopyanov; Mikhail Glyavin; Alexey Luchinin; Sergey Razin; Andrey Fokin
We present the first results of studying a pulsed (20 μs) discharge in nitrogen, which is produced by high-power (40 kW) focused beam of terahertz (0.67 THz) waves. The time dynamics of the discharge plasma glowing is studied in a wide range of wavelengths (300--650 nm) and gas pressures (0.5--350 Torr). An assumption is made about the determining role of long-living metastables of nitrogen N2 (A3Σu+) in the observed dynamics of the discharge afterglow.

16:00 - 17:45	**W3C - 05 - Spectroscopy and Material Properties V** **Chairpersons: Jan Balzer;**	**Lecture Theatre 4**

16:00 **Subsurface Nanoimaging By THz Pulse Near-Field Microscopy** **W3C-1**
Haewook Han; Kiwon Moon; Hongkyu Park; Jeonhoi Kim; Youngwoong Do; Lee Soonsung; Gyseok Lee; Hyeona Kang; Jin-Woo Kim
Terahertz time-domain spectroscopy (THz-TDS) has recently been a powerful tool for probing fundamental low-energy dynamic processes in solid-state materials and devices. Understanding such low-energy THz dynamics has become crucial for developing next-generation electronic and optical devices. To realize THz-TDS with subwavelength resolution, various types of near-field imaging techniques have been combined with THz-TDS. At present, scattering-type scanning near-field optical microscopy (s-SNOM) seems to be the most viable technique that can offer nanoscale resolution and broadband THz spectroscopy simultaneously. In this work, we report a THz s-SNOM system that has recently been developed by combining a homemade tapping-mode AFM and a conventional THz-TDS system. Using off-axis parabolic mirrors, the incident THz pulse was focused on an AFM probe. The pulse scattered from the probe tip was focused on a THz photoconductive antenna to measure the far-field. To attain nanoscale resolution we fabricated a tungsten probe with an apex diameter of less than 100 nm by using an electrochemical etching method. The total electric field at the probe tip is the sum of the incident field, the specularly reflected field at the sample surface, and the scattered field that includes all the information about near-field interaction. The scattered field is a nonlinear function of the probe-sample distance, and thus the scattered field is the sum of the harmonics of the dithering frequency (Ω). To extract the scattered field from the total field, the nth-harmonic component of the photocurrent in the THz antenna was measured by demodulation at nΩ. We used a metallic grating embedded in a dielectric layer. A 30 nm thick gold grating with a period of 800 nm was fabricated on an insulating Si substrate using holographic lithography followed by e-beam evaporation. After depositing a Si3N4 layer, the sample surface was flattened using a chemical-mechanical polishing process. The AFM topographic image, shows no sign of the subsurface grating structure becuase of the polishing process. However, in the near-field images the metallic grating under the flat surface was clearly revealed. The subsurface lateral resolutions were estimated to be 90, 90, and 80 nm for the first three hanrmonics. We also obtained the spatiotemporal and spatio-spectral images. The lateral resolution of the spatio-spectral image was also nearly frequency-independent, which has not been achieved with THz s-SNOM. In our measurements, the scattered THz pulses exhibit no transient oscillations within a time delay of ~5 ps after the main peak. Therefore, the spectral images are very smooth and clean. This is very important for spectroscopic near-field material imaging and recognition because the reliable spectroscopic analysis of near-field images is difficult with transient oscillations.

16:30 **Time-domain Optical Pump - Terahertz Probe Spectroscopic Imager For Carrier Lifetime Measurements In The Pico- To Microsecond Regime** **W3C-2**
Jens Neu; Marco Rahm
We demonstrate a spatially resolved method to measure carrier lifetimes and carrier distributions based on optical pump - terahertz probe spectroscopy. The pump-probe delay range spans from 600ps to 200μs. The spatial resolution is sub-wavelength being better than 50μm (< λ center /6 at 1THz).

16:45 **Ultrafast THz Modulation Characteristics Of Photo-induced Metal-Insulator Transition Of W-doped VO2 Film** **W3C-3**
Zhaohui Zhai; Zeren Li; Yang Xiao; Qiwu Shi; Liguo Zhu; Wanxia Huang; Qixian Peng
The ultrafast terahertz modulation characteristic during photoinduced metal-insulator transition (MIT) of W-doped VO2 film was investigated at picoseconds time scale using time-resolved terahertz spectroscopy. The phase transition dynamic process was dramatically suppressed in W-doped VO2 film, which could be ascribed to the lattice distortion and enhanced electron-electron interaction caused by W substitution for V. The transient complex terahertz conductivity of W-doped VO2 film at different pump-probe delay times were extracted and can be well fitted by Drude-Smith model, which provide significant insights into the dynamic properties of MIT in nanogranular VO2 film.

17:00 **Carrier Dynamics In Graphene Studied By Ultra-broadband Optical-pump/terahertz Probe Spectroscpy** **W3C-4**
Sho Ikeda; Masatsugu Yamashita; Chiko Otani
Carrier dynamics in single-layered graphene has been studied by reflection-type of THz time domain spectroscopic ellipsometry (THz-TDSE) and optical-pump/THz-probe spectroscopy (OPTP). We successfully determined the frequency-dependent complex sheet conductivity of photo-excited monolayer Graphene from 0.3 to 16 THz. By analyzing with Drude model, the time dependence of Drude weight and carrier scattering rate in Graphene were estimated. It is found that Drude weight decreases and carrier scattering rate increases after photo-excitation, which contribute to the negative photoconductivity in graphene.

17:15 **Terahertz And Infrared Spectroscopy Of Bacterial Nanofilaments** **W3C-5**
Konstantin Motovilov; Zarina Gagkaeva; Lenar Kadyrov; Elena Zhukova; Aiyyna Tobokhova; Artem Grebenko; Petro Barzilovich; Victor Torgashev; Maxim Savinov; Vadim Grinenko; Mikhail Belyanchikov; Konstantin Sidoruk; Martin Dressel; Boris Gorshunov
Bacterial filaments represent the class of extremely interesting highly organized biological structures. Some of them are associated with long-range electron transport phenomena, like in bacteria Shewanella oneidensis MR-1. These bacteria are able to reduce different oxidants by electron transfer via extracellular appendages, which are supposed to be a part of periplasmic

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

membrane filled with complexes of multiheme conductive cytochromes. By means of terahertz and infrared (THz, IR) spectroscopy we have measured the dielectric response of nanofilaments of electrogenic bacteria Shewanella oneidensis MR-1 in wide frequency and temperature ranges. THz-far-IR spectra are dominated by absorption due to bound water. At helium temperatures and at sub-THz frequencies a boson-peak-like excitation is detected that is typical for disordered materials. The observation is in agreement with the heat capacity measurements. The reference experiments were performed on lyophilized powder of bovine cytochrome C and bovine serum albumin.

17:30 **The Origin Of Water's Dielectric Excess Wing** **W3C-6**

Paul Ben Ishai; Saroj Tripathi; Kodo Kawase; Alex Puzenko; Yuri Feldman

It is demonstrated that the thermal origin of the excess wing in the THz portion of the dielectric spectrum of water is the same as that of the main dielectric peak. The implication is that models positing the free rotation of water molecules to account for the Excess wing are not correct. A self-terminating Proton cascade is one possible explanation.

16:00 - 17:30 **W3D - 08 - Sources, Detectors, and Receivers VI** **Lecture Theatre 6**

Chairpersons: Ken Wood;

16:00 **Performance Of The 4.7-THz Local Oscillator With Quantum Cascade Laser On Board Of SOFIA** **W3D-1**

Heiko Richter; Michael Greiner-Bär; Martin Wienold; Lutz Schrottke; Klaus Biermann; Holger T. Grahn; Heinz-Wilhelm Hübers

The design and the performance of a 4.7-THz local oscillator (LO) for the GREAT (German REceiver for Astronomy at Terahertz frequencies) heterodyne spectrometer on SOFIA, the Stratospheric Observatory for Infrared Astronomy, are presented. The LO is based on a quantum-cascade laser, which is mounted in a compact mechanical cryocooler. It delivers up to 150 µW output power into a nearly Gaussian shaped beam around the frequency of the fine structure line of neutral atomic oxygen, OI, at 4.7448 THz.

16:30 **Strongly Enhanced Emission Of Terahertz Radiation From Nanostructured Ge Surfaces** **W3D-2**

Chul Kang; Jung Woo Leem; Inhee Maeng; Jae Su Yu; Chul-Sik Kee

We report strong emission of terahertz radiation from germanium wafers with nanostructured surfaces. The power of the terahertz radiation from a Ge wafer with an array of nano-bullets is comparable to that from n-GaAs wafers, which have been widely used as a terahertz source. We find that the THz radiation from Ge wafers is even more powerful than that from n-GaAs for frequencies below 0.6 THz. Our results suggest that introducing properly designed nanostructures on indirect band gap semiconductor wafers is a simple and cheap method to improve the terahertz emission efficiency of the wafers significantly.

16:45 **THz Mixtenna Chips And Quasi-optical Mixers for Focal Plane Imaging Applications** **W3D-3**

Jinchao Mou; Dalu Guo; Quan Xue; Xin Lv

THz mixtenna chips and quasi-optical mixers for focal plane imaging applications are presented. Firstly, the THz Schottky diodes with the cutoff frequency of 3.2 THz are designed and fabricated. Then, the mixtenna chips are designed, by extending the two pads of the diode to a differentially-fed antenna. Finally, the 325 GHz quasi-optical mixer and mixer array, which consist of the mixtenna chip integrated with the silicon lens, are studied and measured.

17:00 **Increasing The Bandwidth Of Dielectric Rod Waveguide Antennas For Terahertz Applications** **W3D-4**

Alejandro Rivera-Lavado; Luis Enrique Garcia-Muñoz; Dmitri Lioubtchenko; Sascha Preu; Daniel Segovia-Vargas; Antti Räisänen

in this contribution, the combination of Dielectric Rod Waveguide DRW antennas with photomixer-based sources in the terahertz range is studied. They are a cost-affordable and more compact alternative to dielectric lenses, which makes them especially appealing for arrays configurations, either for increasing the generated power or for beam steering applications. DRW antennas are limited in band, since such antennas radiates in the endfire direction only when the fundamental mode is supported. For avoiding such limitation, the use of embedded planar lenses is proposed.

16:00 - 17:30 **W3E - 22 -Free Electron Lasers and Synchrotron Radiation** **Lecture Theatre 7**

Chairpersons: Gian-Pierro Gallerano;

16:00 **Robust, Long-life Photocathodes** **W3E-1**

Lawrence Ives; Eric Montgomery; Thuc Bui; Lou Falce; David Marsden; George Collins

Advanced accelerators and light sources use photoinjectors to produce the high quality electron bunches for acceleration and conversion to RF and light energy. The principal component in the photoinjector is a cathode, which must efficiently produce electron bunches using the photoelectric effect when triggered by an incident drive laser pulse. Calabazas Creek Research, Inc. (CCR) and the University of Maryland (UMD) are developing an advanced photocathode capable of high quantum efficiency (QE) and long life. The goal is a simpler, more cost effective photoinjector for commercial and scientific applications. CCR developed advanced material for controlled porosity tungsten structures and successfully implemented it into thermionic cathodes for microwave and millimeter-wave RF sources. UMD demonstrated that photocathode lifetime could be extended by gently heating a sub-surface reservoir of cesium with a diffusion barrier, allowing cesium migration to the photoemissive surface. This resupplies cesium in a controlled process and rejuvenates the QE [2]. The QE is maintained by a continuous source of cesium, replenishing that lost by evaporation, back-bombardment, or contamination. UMD is focused on the detailed physics of photoemission with the goal of identifying materials and operational procedures to improve efficiency and lifetime. CCR is building a high vacuum facility for photocathode fabrication and designing a vacuum suitcase for transport to user facilities. This presentation will describe the fundamental research at UMD and the fabrication facility being assembled at CCR. Planned tests using an RF gun at SLAC National Accelerator Laboratory will also be described.

16:30 **Measurement Of Coherent Transition Radiation From Electron Beam Using Large-apeture Photoconductive Antenna** **W3E-2**

Koichi Kan; Kimihiro Norizawa; Atsushi Ogata; Shunichi Gonda; Masao Gohdo; Tomohiro Toigawa; Takafumi Kondoh; Jinfeng Yang; Shouichi Sakakihara; Hiromi Shibata; Itta Nozawa; Yoichi Yoshida

Generation of femtosecond electron bunches has been investigated for a light source based on electron bunches and improvement of time resolution in time-resolved measurements. In this study, temporal electric fields from electron bunches using a photoconductive antenna (PCA) with radial microstructures were measured. Radially polarized terahertz (THz) pulses

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from femtosecond electron bunches with energy of 32 MeV and charge of 170 pC were generated by coherent transition radiation (CTR). Electric-field-induced current from the PCA depending on THz electric field was measured.

16:45 **Selective Mode Excitation In A Multimode THz Slow-Wave Structure By A Relativistic Bunch Train** **W3E-3**

Sergey Antipov; Dan Wang; Mikhail Fedurin

A number of methods for producing sub-picosecond beam microbunching have been developed in recent years. A train of these bunches is capable of generating THz radiation via multiple mechanisms like transition, Cherenkov and undulator radiation. We utilize a bunch train with tunable spacing to selectively excite high order TM0n - like modes in a multimode structure. In this paper we present experimental results obtained at the Accelerator Test Facility of Brookhaven National Laboratory

17:00 **Present Status Of CAEP THz FEL Facility** **W3E-4**

Yuhuan Dou; Xiaojian Shu; Xingfan Yang; Ming Li; Derong Deng; Hanbin Wang; Xiangyang Lu; Xu Zhou

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 will be tuned in range of 1~3 THz and the average output power will be about 10 W. Much effort has been done for the THz FEL facility. The system mainly consists of a GAAS photoemission DC gun, superconducting accelerator, the hybrid wiggler, optical cavity. In this paper, the design considerations and present status are presented.

17:15 **Influence Of The Synchronism Detuning On Single Mode Operation Of Two-Channel Planar FEM** **W3E-5**

Peter Kalinin; Andrey Arzhannikov; Stanislav Sinitsky; Vasiliy Stepanov; Naum Ginzburg; Nikolay Peskov; Vladislav Zaslavsky; Aleksandr Sergeev

Paper presents experimental results on spectral measurements of high-power 4-mm radiation generated by a two-channel planar free electron maser (FEM) at variation of electron energy and magnetic field of undulator. It was shown that the single mode operation of the FEM is achieved at satisfying the condition of the undulator synchronism shifted to the detuning, predicted by theory for maximum of the electron efficiency.

17:30 - 19:00 **WS - Poster Session 3** **YIA Lobby**

Chairpersons: Gun-Sik Park;

Raman Scattering And Terahertz Spectroscopic Characteristics Of Longitudinal Optical Phonons In I-GaAs/n-GaAs Epitaxial Structures **WS-1**

Hideo Takeuchi; Asai Souta; Shuichi Tsuruta; Takahiro Sumioka; Masaaki Nakayama; Hideo Takeuchi

We have investigated longitudinal optical phonons (LO) characteristics in i-GaAs/n-GaAs epitaxial structures. The LO phonons and LO phonon-plasmon coupled modes were observed in the Raman scattering spectra, whereas only the coherent LO phonon was detected in terahertz spectroscopy. We conclude that the initial polarization is responsible for emission of the coherent-LO-phonon terahertz wave.

Measurement Of The Dielectric Properties Of The Skin At Frequencies From 0.5 GHz To 1 THz Using Several Measurement Systems **WS-2**

Sasaki Kensuke; Maya Mizuno; Kanako Wake; Soichi Watanabe

The dielectric properties of skin layers, which are the epidermis, dermis, and subcutaneous fat, were measured using several measurement systems. Measurement was conducted in vitro from 0.5 GHz to 1 THz. Measurement results indicated good agreement between each measurement system at a tissue temperature of approximately 35 °C.

Dielectric Properties Of CaZrO3 Investigated By THz-TDS. **WS-3**

Lubos Baca; Marian Janek; Zuzana Kovacova; John Molloy; Mira Naftaly

Calcium zirconates (CaZrO3) are known for their interesting optical, electrical, and physico-chemical properties. The electronic, electro-mechanical, and conductive properties of CaZrO3 doped with specific trivalent rare earth ions promote upconversion processes, where the absorption of two or more lower-energy photons leads to the emission of a higher energy photon. The upconversion materials are based on the f-f transitions of rare earth dopants, which show rich luminescence spectra consisting of a large number of distinct transition lines. Thus upconverting phosphor materials based on CaZrO3 can be synthesized which are suitable for diode lasers, display devices, and other photonic applications with excitation in the near infrared (NIR) region.[1] Only a few reports dedicated to dielectric or spectral properties of CaZrO3 in the far infrared region can be found in the literature. For this reason we have investigated the effect of Er3+ and Li+content on 2 mol % Yb3+ doped CaZrO3, which were sintered for 1 hour at two different temperatures, 1300 and 1500 °C. The preliminary results achieved by the THz-TDS technique in the transmission mode, using femtosecond-laser driven photoconductive emitter and electro-optic detector in the frequency range of about 0.2-3.0 THz are shown in Figure 1. The material absorption as function of refractive indexalmost doubled when the Er3+content in the material decreased from 5 to 1 mol % (A4 ~ 5 mol %, A8~ 2 mol %, A12~ 1 mol %), while the refractive index (RI) increased from 3.25 to 3.80. This behaviour is strongly affected by sintering temperature as the ample A12 sintered at 1300°C showed more than 5 times lower absorption and the RI of 3.11. The addition of Li+ ions to the structure increased both absorption and RI to 3.72. The X-ray diffraction patterns proved the stuctural similarity of perovskite materials sintered at different temperatures, however, the higher temperature induced slightly higher crystallinity in the studied samples. The differences in their dielectic behaviour and electronic conductivity may therefore be attributed to the improved crystals order, but better understanding of these systems require a more detailed investigation.

Terahertz Imaging With Micro-bridge Structure Detector Array And 2.52THz Far Infrared Laser **WS-4**

Jun Wang; Jun Gou; Weizhi Li; Yadong Jiang

A room temperature operating terahertz (THz) detector with low thermal conductive micro-bridge structure is presented using metal thin film as THz wave absorber. Vanadium oxide is acted as thermal sensitive material and |TCR| of the film is ~2%/K. The detector array is fabricated on silicon substrate with read-out integrate circuit. THz wave transmission imaging could be obtained with the micro-bridge focal plane array and 2.52THz far infrared CO2 pumped laser.

Improvement Of Terahertz Imaging Using Lock-in Techniques **WS-6**

Marcin Kowalski; Dominique Coquillat; Przemyslaw Zagrajek; Wojciech Knap

We present results of improvement of THz images registered at the frequency of 300 GHz. The improvement is achieved by processing of both phase and magnitude information provided by lock-in amplifier. The active imager uses a continuous-wave tunable radiation source. We investigate capabilities of utilizing phase and intensity information in order to obtain more accurate shape of object. Results of processing images in order to obtain more details are shown. Improvement of the image resolution and quality by composition of selected elements of both amplitude and phase-based images using specific fusion

methods is presented.

Experimental Investigation Of Powerful THz Gyrotrons For Initiation Of Localized Gas Discharge **WS-7**

Mikhail Glyavin; Sergey Golubev; Aleksander Sidorov; Sergey Razin; Andrey Fokin; Alexey Luchinin; Alexander Litvak; Mikhail Morozkin; Alexander Vodopyanov; Vladimir Semenov; Elena Rakova; Gregory Nusinovich; Aleksander Tsvetkov

Results of experimental tests of a high-power sub-terahertz gyrotron with a pulse solenoid are presented. The operating frequency corresponds to the atmospheric transparency window (0.66-0.67 THz). The output power up to 200 kW in single 50 microsecond pulses was obtained. The 0.3THz / 0.5 MW tube is under experimental tests. Gas discharges have been realized in a wide range of pressures (0.01 - 1500 Torr) and different gases. Such discharges can be used as the pointed source of UV/VUV radiation, including the projection lithography.

Research On Calibration Method Of Comb Generator **WS-8**

Pengwei Gong; He Jiang; Wen Xie; Hongmei Ma; Chuntao Yang

We use two methods described in this paper for Agilent U9391F comb generator calibration. By analyzing and comparing the results of two methods, we confirm that the calibration method based on electrooptic sampling system is more potential and suitable for wideband or even ultra wideband comb generator calibration. Calibration method based on digital sampling oscillscope can be used in lower band comb generator calibration when the calibration cost is taken into account. Research on calibration method base on electrooptic sampling system is meaningful for harmonic phase reference.

Terahertz Spectroscopical Investigation Of Cocrystal Formation Process Of Piracetam And 3-hydroxybenzoic Acid **WS-9**

Yong Du; Huili Zhang; Zhi Hong

The cocrystal of piracetam and 3-hydroxybenzoic acid under grinding condition has been characterized by terahertz spectroscopical technique. Spectral results show that the vibrational modes of the cocrystal are different from those of the corresponding parent materials. The dynamic process of such pharmaceutical cocrystal formation has also been monitored directly with THz spectra.

Study Of The Properties Of BaGa4Se7 Crystal In The Terahertz Region **WS-10**

Wentao Xu; Yuye Wang; Chao Yan; Degang Xu; Jiyong Yao; Fei Fan; Pan Duan; Zhen Yang; Jia Shi; Hongxiang Liu; Jianquan Yao

The far-infrared properties of a newly grown crystal, BaGa4Se7, were investigated with a THz-TDS system. Refractive indices and absorption coefficients of this material between 0.1THz-1THz were obtained. The measured properties predicts potential application of BaGa4Se7 in THz-DFG. THz-DFG using BaGa4Se7 was analyzed theoretically and the phase-matching conditions were calculated. It seems that a promising prospect of THz application can be expected by using BaGa4Se7 as the NLO crystal.

A Multi-lab Intercomparison Study Of THz Time-domain Spectrometers **WS-11**

Mira Naftaly; John Molloy

This paper will present the first results of a multi-lab study comparing results obtained by THz time-domain spectroscopy on a set of standard materials. Measurements of refractive indices and absorption coefficients reported by participants will be collated and analyzed, and best practice guidelines recommended.

Dynamical Properties Of Terahertz Radiation From Coherent Longitudinal Optical Phonon-Plasmon Coupled Modes In An Undoped GaAs/n-type GaAs Epitaxial **WS-12**

Takahiro Sumioka; Hideo Takeuchi; Masaaki Nakayama

Coherent optical phonons are one of potential candidates for terahertz radiation sources. It is well known that longitudinal optical (LO) phonons couples with plasmon, which results in lower and upper LO phonon-plasmon coupled (LOPC) modes. The frequencies of the LOPC modes depend on a carrier density. Thus, the coherent LOPC mode can be utilized as a frequency tunable terahertz radiation source. In our previous work, we demonstrated that the coherent LOPC modes are clearly observed in undoped GaAs/n-type GaAs (i-GaAs/n-GaAs) epitaxial structures. In the i-GaAs/n-GaAs epitaxial structure, surface Fermi-level pinning produces a considerable built-in electric field in the i-GaAs layer, which enhances terahertz radiation from coherent LO phonons because of electric-field induced LO-phonon polarization. The enhancement of terahertz radiation from coherent LO phonons is advantageous in generating terahertz radiation from the LOPC modes. In this work, we have investigated the dynamical properties of terahertz radiation from the lower and upper LOPC modes in an i-GaAs/n-GaAs epitaxial structure with the use of time- domain terahertz spectroscopy. The sample of the i-GaAs/n-GaAs epitaxial structure was gown on an n-type (001) GaAs substrate by metalorganic vapor phase epitaxy. The thickness of the i-GaAs (n-GaAs) layer was 200 nm (3.0 μm), and the doping concentration in the n-GaAs layer was 3.0x10^18 cm^-3. The excitation light source was a mode-locked Ti:sapphire laser with a pulse duration of 60 fs, a repetition rate of 90 MHz, and a peak wave-length of 800 nm. Time-domain terahertz signals were detected at room temperature using an optical gating method with a photoconductive dipole antenna fabricated on a low-temperature-grown GaAs layer. We initially measured the time-domain terahertz wave, and performed the time-portioning Fourier transform (FT). From time-portioning spectra at various delay times, it was clarified that there exist four kinds of FT band. The lowest frequency broad band is due to a monocycle signal in time domain, the so-called first burst, originating from a surge current of photogenerated carriers flowing through the i-GaAs layer. The sharp band labeled LO originates from the coherent LO phonon. The two bands labeled LOPC(-) and LOPC(+) are attributed to the lower and upper LOPC modes, respectively. We confirmed that the frequencies of the LOPC modes are determined by a photogenerated carrier density, which demonstrates that the LOPC modes are generated in the i-GaAs layer. The lifetimes of the LOPC modes are much shorter than that of the coherent LO phonon, while are comparable to that of the monocycle-signal band. This fact indicates that the surge current acts as plasmon. The very short lifetime of the LOPC mode reflects an escape time from the i-GaAs layer. Furthermore, the spectral shapes of the LOPC modes depend on delay time: The frequency shifts toward a higher frequency side with increasing delay time. This tim

Detection Properties Of Spiral-Antenna-Coupled Microbolometer Fabricated On Si3N4/SiO2 Membrane At 200 GHz Band **WS-13**

Takashi Uchida; Akihito Matsushita; Takashi Tachiki

Spiral-antenna-coupled Bi microbolometer was fabricated on a Si3N4/SiO2 membrane. The DC sensitivity of the device was 335 W^-1 and the responsivity was 110 V/W at 220 GHz for Ib = 1.0 mA. These values are over 10 times higher than those of the Bi bolometer fabricated on a dielectric substrate. The NEP was estimated to be 4×10^-10 W/Hz^1/2 for a modulation frequency at 1 kHz.

Refractivity Of Water Vapor At Terahertz Frequencies -- Comparison Of Measurements With Models **WS-15**

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Thomas Bendall; Richard Hills; Mira Naftaly; John Molloy
Refractivity of water vapor at THz frequencies was calculated using three different models. These did not agree. A direct measurement was made using time-domain spectroscopy and the correct form of the refractivity model was determined.

Improving Frequency Stability Of A 0.67 THz Gyrotron By Delayed Reflection **WS-17**
Maria Melnikova; Alexandra Tyshkun; Andrey Rozhnev; Nikita Ryskin; Yulia Novozhilova; Mikhail Glyavin
Effect of delayed reflection from a remote load on operation of a gyrotron is considered. Improving of frequency stability by the wave reflected from the load is demonstrated. Theoretical analysis for quasi-linear model of a gyrotron are presented. The theoretical results are in good agreement with numerical simulations for the high-power 0.67 THz gyrotron.

Investigation on the High Gain Sheet Beam Extended Interaction Klystron with Strong-coupling Multiple-gap Cavities in W-band **WS-18**
Cunjun Ruan; Renjie Li; Jun Dai
A strong-coupling five-gap barbell output cavity is investigated combined with the design of W-band sheet beam extended interaction klystron (SBEIK), which may have many advantages of resonant mode separation, gap fields coupling and RF energy exporting with high efficiency. Then the output cavity is used to construct a high gain W-band SBEIK with eight multiple-gap cavities. With the sheet beam voltage of 75kV, and the current of 4A, the output power can attain to 32kW with the gain high than 50dB. The result agrees very well with the one-dimensional calculation program.

Terahertz Characterization Of Hydrogen Bonded Materials **WS-19**
Kei Takeya; Ryohei Takahashi; Kodo Kawase
We measured the temperature and frequency dependence of the complex dielectric constants of hydrogen-bonded materials in the THz range over a wide temperature range (20-240 K), using THz-TDS with a gas-cooling cryostat. For all samples, the real dielectric constant ε' increased with frequency and temperature in the THz region. A local maximum of ε' at a few THz was estimated from the Sellmeier equation of all of the samples. The temperature and frequency dependence of the imaginary dielectric constant ε" was well represented by the mathematical model for ice in the GHz range. Ice exhibits increasing absorption with frequency in the THz range, due to the low-frequency tail of the infrared absorption band. This behavior was also observed in gas hydrates. Finally, we showed that the dielectric constant of gas hydrates in the THz range can be analyzed using a method similar to that used for ice. The complex dielectric constants in the THz range contribute to the infrared polarization and phonon absorption of the water molecules in the hydrogen-bonding matrices. Therefore, THz-TDS is particularly useful for structural studies of gas hydrates.

High-efficiency Broadband THz Wave Modulator Based On Phthalocyanine-compound Organic/silicon Films **WS-20**
He Ting; Zhang Bo; Shen Jing-ling
We report a high efficiency, broadband terahertz (THz) modulator following a study of phthalocyanine-compound organic films irradiated with an external excitation laser. More than 99% modulation depth and broadband can be achieved by using external CW laser which under low power irradiation. Three phthalocyanine compounds are CuPc, AlClPc and SnCl2Pc. We used 2 mm-thick, high resistive Si films as substrates. Using thermal evaporation we deposited 200-nm thick film on the substrate, and without using thermally annealed. A 450nm CW semiconductor laser was used as the optical modulating source. Both transmission and reflection modulations of each organic/silicon bilayers were measured by using THz time-domain and continuous-wave systems. The experimental result shows that THz wave amplitude modulation efficiency of the three films quickly increased by increasing external laser power. The result presents that AlClPc/Si and CuPc/Si films can achieve more than 99% modulation efficiency, and the SnCl2Pc/Si is 96.3%. Moreover, these modulation effects can be achieved by a relatively lower modulating laser power. For the AlClPc/Si film with the highest modulation efficiency, the external laser power is 94.3mW, the corresponding intensity is 1.57x10^2mW/cm^2. By using the dielectric parameters at 0.59 THz, we obtained the plasma frequency and then extracted the carrier density, which is 1.78x10^19number/cm^3 for AlClPc/Si, 2.84x10^18 number/cm^3 for CuPc/Si, and 7.59x10^17 number/cm^3 for SnCl2Pc/Si. The results show the strong attenuation of the transmitted and reflected THz waves revealed that a nonlinear absorption process takes place at the organic/silicon interface, and also explains why the AlClPc/Si films has better modulation efficiency than the others.

Characterization Of Transmission Lines Using Low Loss Polymers Up To 320 GHz **WS-21**
Emilien Peytavit; Sylvie Lepillet; Guillaume Ducournau; Jean-François Lampin
Thin film grounded coplanar waveguides using Parylene-C and Cyclic-Olefin-Copolymer (COC) as low loss thin film have been fabricated and characterized up to 320 GHz. Attenuation around 1.75 dB/mm has been measured at 300 GHz with ~5-µm-thick Parylene-C film, close to the attenuation obtained with Cyclo-Olefin Copolymer film of similar thickness.

Multi-band Metamaterials With A Distinguished Angular Sensitivity **WS-22**
Norman Born; Lorenz Schneider; Jan Balzer; Ibraheem Al-Naib; Ranjan Singh; Ajanth Velauthapillai; Maik Scheller; Jerome Moloney; Martin Koch
A metasurface with an ultrahigh angular sensitivity to the angle of incidence at a chosen frequency is presented. Strongly interacting metamolecules are arranged such that a novel functionality of a metamaterial structure with multiple Fano resonances arises. Tuning the lattice constant of the structure enables a precise control of the angular response. We experimentally demonstrate equal responses for changes in azimuthal and for altitude angles of incidence. The concept could be used to enhance angle of arrival measurements, to determine the direction of a propagating wave or enhance the sensitivity of detectors by shielding them from scattered or unwanted signals.

Tunneling Time Delay Detection Based On Polarization-resolved THz Detection **WS-25**
Zhihui Lü; Dongwen Zhang; Xiaowei Wang; Zengxiu Zhao; Jianmin Yuan
Employing a novel polarization-resolved detection, we precisely measured the polarization of terahertz emission from ionized gases in two-color field composed of circular polarized fundamental beam and linear polarized second harmonic. It shows that the polarization of the THz emission rotates with the phase delay and forms an attoclock. The polarization angular deviations of THz emissions in different laser intensities and different atoms reveal the distinct tunneling time delays. The polarization-resolved THz detection can be used to study tunneling ionization.

High Power THz Quantum Cascade Laser At ~ 3.1 THz **WS-27**
Junqi Liu; Tao Wang; Yuanyuan Li; Fengqi Liu; Jinchuan Zhang; Shenqiang Zhai; Lijun Wang; Shuman Liu; Zhanguo Wang
The development of quantum cascade laser at ~3.1 THz is reported. The material was designed with bound-to-continuum active region and grown by Veeco GEN-II solid source molecular beam epitaxy. Devices were processed using standard photolithography and wet chemical etching. Lasing is observed up to a heat-sink temperature of 110 K in pulsed mode with

total light power above 1W at 10 K. A liquid nitrogen package is achieved.

Magnetron Injection Gun For A Multi-Frequency Gyrotron **WS-28**

Yuusuke Yamaguchi; Yoshinori Tatematsu; Teruo Saito; Vladimir Manuilov; Jun Kasa; Masaki Kotera

A triode electron gun was developed to realize step-frequency tunability in a sub-THz gyrotron. The helical electron beams are formed with high-laminarity such that the velocity spreads are maintained at low levels in a wide operation range. The stable oscillations were experimentally confirmed at expected frequencies from 162 to 265 GHz with powers of the order of 1 kW.

Tunable Feeding Point THz Antenna With Butterfly Type Slot Based On Ceramic Material Substrate **WS-29**

Jinling Zhang; Xi Gan; Bingqian Yang; Shuhua Wen; Ke Gao; Zhanqi Zheng

A new type of tunable feeding point Terahertz (THz) slot antenna with a butterfly type metallic body structure on ceramic substrate is proposed in this paper. Slots are produced by symmetrically cutting a copper plate. Implementation of the based slot body offers a better directivity and radiation efficiency. Full-wave simulation results showed that the THz band slot antenna works at 0.224THz with a -10dB bandwidth of 11.60GHz and the maximum directivity is 11.8dBi. It is very flexible and convenient to adjust the center frequency of antenna by properly adjusting the feed point position. These interesting THz slot antenna was suggested a promising application in various fields such as biosensors, artificial vision restoration system and THz communication system.

Terahertz Spectroscopic Analysis Using A Metallic Hole Array **WS-30**

Chengchen Yang; Shinya Suzuki; Toru Kurabayashi; Shinichi Yodokawa; Satoshi Kousaka

We focused on terahertz wave spectroscopy using a metallic hole array (MHA), which can be applied as a frequency shift of the transmission spectra for substance detecting and its alteration. The transmission spectra have been studied by the use of FDTD simulation. As an experiment we coated PMMA on MHA followed by irradiation with and without ultraviolet light (UV). The shift of the transmission spectra indicates the changes of thickness and the dielectric constant of PMMA layer. We also covered a collodion film on MHA as a stage for a substance sample for minute trace of the substance detection. It showed a potential to be applied to sensitive detection for small amounts of substances and slight variation of the characteristic features.

Terahertz Fiber Laser Based On A Novel Crystal Fiber Converter **WS-31**

Pengxiang Liu; Wei Shi; Degang Xu

We proposed a novel GaAs-based crystal fiber converter for efficient THz difference frequency generation, which combines the single-mode THz fiber and the quasi-phase-matching configuration. Calculations were performed on the characteristics of energy conversion and output beam focusing. Theoretical results indicated that the proposed THz fiber laser can provide high power and high brightness THz source.

Terahertz Metallic Ridge Waveguide Mach-Zehnder Interferometer **WS-32**

Mareike Stolze; Marko Gerhard; Rene Beigang; Marco Rahm

We present phase-sensitive measurements of terahertz electric fields using a Mach-Zehnder interferometer integrated in a metallic ridge waveguide. The waveguide was fabricated in a two-step process of conventional CNC machining and subsequent laser micro machining of channels of the required depth into parallel aluminum plates. This allowed the realization of a macroscopic coupling taper and a microscopic structure of the ridge, respectively. The deposition of lactose into one interferometer arm showed that the output amplitude signal carries information of the investigated lactose. The specimen phase information gets mapped onto the amplitude spectrum.

Reflection Spectroscopy On Solutions Of Biological Materials In Millimeter Wave Frequency **WS-33**

Toru Kurabayashi; Kyohei Konishi; Shinichi Yodokawa; Satoru Kosaka

We attempted to analyze a solution of biological matter of sugars, amino-acids, and electrolytes using a millimeter-wave reflection spectroscopy. The sensitivity for the concentration of solutes was improved markedly, when an adequate dielectric layer was inserted at the interface of incident side of the solution as impedance matched layer. The sensitivity was covered fully in the range of adequate blood sugar level of human as 0.07-0.16 g/100ml H2O in the case of glucose solution.

Indium Antimonide (InSb) Waveguide Based THz Sensor **WS-34**

Shourie Ranjana J; Piyush Bhatt; Prathmesh Deshmukh; Bagvanth R. Sangala; Satyanarayan M . N; Umesh G; Prabhu S. S

I. INTRODUCTION THz science is gaining its potential in the field of sensing and imaging. Some of the molecules have their vibrational or rotational energy transitions in the THz frequency range, which put us to explore, identify and classify them. THz sensing of chemicals and biomolecules has been demonstrated using parallel plate waveguides [1], antennas [2], metamaterials [3] etc. The objective of this paper is to investigate the sensing capability of a Semiconductor--Insulator--Semiconductor (SIS) THz InSb based plasmonic waveguide with stubs along waveguide acting as sensing elements. The frequency dependent permittivity of InSb calculated using Drude free electron model in the THz region is similar to that of metals (Ag, Au) in the optical region, where surface plasmons can be localized making InSb a good candidate for THz Plasmonic devices. We experimentally demonstrated the transmission characteristics of the InSb waveguide [4] using THz time-domain spectroscopy (THz-TDS). The BSA is a standard protein molecule [5]. We measured the THz absorption coefficient for two different concentrations of BSA dissolved in DI water (BSA-W) loaded in our device, vary significantly over the frequency range 0.2 -- 1.0 THz. II.RESULTS A standard THz-TDS setup was used to characterize the transmission properties of the InSb waveguide with width G = 740 μm and stub length L=990 μm (Fig. 1 Inset). Few micro litres of the prepared BSA-W solution was dropped into one of the stubs, thereby changing the refractive index of the medium inside the stub as shown in Fig.1 (inset). The effective absorption coefficient (αeff) as a function of linear frequency (f) of the measured spectra is defined [6] as,THz transmission measurement with DI water in the stub of width W ~ 740 μm is considered as a reference Eref and measurements carried out with 0.5mg/ml and 1mg/ml of BSA concentrations as Esample to determine of BSA. THz transmission measurement with empty waveguide (air) is considered as reference Eref to determine of DI water.Before each sample measurement, transmission of THz beam in the InSb waveguide and with stub filled with DI water (reference) was measured. All measurements were repeated to observe the consistency in the results. As the BSA-W concentration increases, the number of absorbing bulk water molecules decreases, leading to decrease in . The decrease in with the increasing concentration of the BSA molecules is consistent with the reported [5, 6] results. This characteristic of the InSb waveguide demonstrates the promising sensing capability of the device to function as a THz-bio sensor. A minute change in the concentration of the medium and even a micro liter quantity inside the stub shows prominent change in the calculated absorption coefficient, thereby making InSb waveguide, a promising candidate for THz sensing.

Increased Terahertz Emission From SI-GaAs Deposited With Sub-wavelength Spacing Metal Line Array **WS-36**

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Maria Angela Faustino; Lorenzo Jr. Lopez; Jessica Pauline Afalla; Joselito Muldera; Mark Jayson Felix; Arnel Salvador; Armando Somintac; Elmer Estacio

Increased terahertz (THz) emission of surface modified semi-insulating gallium arsenide (SI-GaAs) is reported. A metal line array with sub-wavelength spacing was fabricated via e-beam deposition and THz measurements were done in the transmission excitation geometry. Results show an order of magnitude THz broadband emission enhancement. Pump-power dependent measurements were also utilized which shows a non-linear dependence with the THz integrated intensity. This broadband enhancement is currently attributed to super transmission owing to a non-linear optical effect that may be related to surface plasmon resonance.

Low Noise Readout Circuit For THz Measurements Without Using Lock-in Technique **WS-38**

Cezary Kolacinski; Dariusz Obrebski; Jacek Marczewski; Przemyslaw Zagrajek

The lock-in technique is commonly used for measurements of very small DC signals in the presence of overwhelming noise. However, phase sensitive detection has its own limitations and it cannot be always easily applied in every test setup configuration. This work deals with a low noise readout circuit intended to operate with FET-based THz detectors, which in fact can replace the lock-in equipment and eliminate the need of THz wave modulation. This circuit can be also successfully deployed for processing of small DC signals produced by other sensors or detectors.

Terahertz Bandpass Frequency Selective Surface With Improved Out-of-Band Response **WS-39**

Amir Ebrahimi; Shruti Nirantar; Withawat Withayachumnankul; Madhu Bashkaran; Sarath Sriram; Said Al-Sarawi; Derek Abbott

A second-order bandpass frequency selective surface (FSS) for terahertz applications is experimentally demonstrated in this paper. The proposed FSS is designed using miniaturized element unit cells that enable analysis of their frequency by an equivalent circuit model. A transmission zero is introduced in the upper stopband of the transmission response for improving the out-of-band performance. Numerical and experimental results show a harmonic-free response up to three times the passband center frequency.

Real Time THz Imaging Based On Frequency Upconversion **WS-40**

Patrick Tekavec; Vladimir Kozlov; Ian McNee; Yun-Shik Lee; Konstanin Vodopyanov

We demonstrate video rate-terahertz imaging based on upconversion of THz pulses to the infrared. Mixing of narrow bandwidth THz pulses (centered at 1.5 THz) with strong IR pulses at 1064 nm generates sidebands separated from the IR spectrum by the THz frequency. Removal of the strong IR background enables high speed detection of the upconverted signal with a CMOS camera. Real time imaging of concealed objects is demonstrated with this system.

System Performance Of The Upgraded POST **WS-41**

Sheng Li; Wen-ying Duan; Kun Zhang; Dong Liu; Qi-jun Yao; Sheng-cai Shi

POST (POrtable Submillimeter Telescope) is a submillimeter telescope working in the 500 GHz band. The antenna is a dual-offset Cassegrain type with a diameter of 30 cm. Here we present its performance including the receiver noise temperature, RF noise temperature and far-field antenna beam pattern measured at 462 GHz and 493 GHz respectively. Antenna pointing accuracy is also evaluated. Detailed measurement results will be presented.

Performance Evaluation Of Phase-Locking For THz-QCL **WS-42**

Yoshihisa Irimajiri; Motohiro Kumagai; Isao Morohashi; Akira Kawakami; Shigeo Nagano; Norihiko Sekine; Satoshi Ochiai; Shukichi Tanaka; Yuko Hanado; Yoshinori Uzawa; Iwao Hosako

We are developing a low noise superconducting heterodyne receiver based on a hot electron bolometer mixer (HEBM) and a THz Quantum Cascade Laser (THz-QCL) as a local oscillator at 3THz for atmospheric and astronomical observations. The best value of the uncorrected receiver noise temperature of 1,200 K (DSB) which corresponds to 8 times quantum limit was achieved. We demonstrated phase-locking of a 3 THz-QCL using the HEBM and evaluated its performance.

Enhancement Of Terahertz Radiation With Circularly Polarized Two-color Fields **WS-43**

Chao Meng; Wenbo Chen; Zhihui lv; Xiaowei Wang; Yindong Huang; Dongwen Zhang; Zengxiu Zhao; Jianmin Yuan

We demonstrate an enhancement of terahertz wave generation from plasma produced by circularly polarized two-color fields when the laser intensity is high enough to saturately ionize the gas. Comparing to the linear two-color fields, the conversion efficiency of co-rotating circularly polarized two color-fields is about 40% higher

Enhanced Performance Of THz Bandpass Filter Based On Bilayer Reformative Complementary Structures **WS-44**

Feng Lan; Ziqiang Yang; Zongjun Shi; Xiaopin Tang

In this paper, a dual-resonance bandpass THz filter using a modified four-split CELC (MFC) metal-dielectric-metal structure with improved transmission performance is presented. The experimental results on THz time-domain spectroscopy (TDS) are in good agreement with simulations. Results show that the bandpass filter resonated at 0.315THz with substantial improvements in the low losses, steep skirts, high out-of-band rejection and slight in-band fluctuations.

Broadband Characteristics Of Ultrahigh Responsivity Of Asymmetric Dual-Grating-Gate Plasmonic Terahertz Detectors **WS-45**

Fuzuki Kasuya; Tetsuya Kawasaki; Shinya Hatakeyama; Stephane Boubanga Tombet; Tetsuya Suemitsu; Taiichi Otsuji; Guillaume Ducournau; Dominique Coquillat; Wojciech Knap; Yuma Takida; Hiromasa Ito; Hiroaki Minamide; Denis V. Fateev; Vyacheslav V. Popov; Yahya M. Meziani; Akira Satou

Recently, we reported on ultrahigh intrinsic responsivities of the so-called asymmetric dual-grating- gate (A-DGG) plasmonic detectors based on InP high-electron- mobility transistors at room temperature with zero source-drain bias. The ultrahigh responsivities originate from strong hydrodynamic nonlinearities of plasmon in the two-dimensional electron channel, efficient coupling of THz wave and plasmon via the grating gates, and asymmetric placement of the gates which induces huge unidirectional photocurrent. In this work, we measure the intrinsic responsivity of an A-DGG plasmonic detector with geometrical parameters different from those measured previously, and we report on the responsivity over 100 kV/W at 200 GHz and 50 kV/W at 300 GHz. By comparison with the previous results, we demonstrate that broadband characteristics of the responsivity depend much on the geometrical parameters.

Coherent Absorption Of Terahertz Pulses By A Checkerboard Metasurface **WS-46**

Yoshiro Urade; Yosuke Nakata; Toshihiro Nakanishi; Masao Kitano

When two counter-propagating waves coherently illuminate a medium with a specific amount of dissipation, the incident radiation can be perfectly absorbed in the medium due to wave interference. This system is called coherent perfect absorber (CPA).

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Here, we consider a CPA for artificially structured surfaces or metasurfaces (two-dimensional metamaterials). According to our previous theoretical work (Y. Nakata et al., Phys. Rev. B 88, 205138, 2013), the condition for a CPA is frequency-independently satisfied if metasurfaces have self-complementarity. Here, self-complementarity means the invariance of metasurfaces under interchanging their metallic parts and their holes. A checkerboard geometry is an example of self-complementary structures. In this paper, we experimentally demonstrate a CPA by a self-complementary metasurface.
We prepared a self-complementary metasurface with checkerboard-like geometry. The metasurface was illuminated by two counter-propagating terahertz pulses emitted from a photoconductive antenna. We measured the electric fields of the pulses for two cases: The metasurface is illuminated by (i) a single pulse (one of the two pulses is blocked) and by (ii) both pulses. From the experimental result, we estimated the absorption as 99.1% below the diffraction frequency of the metasurface.
In conclusion, we observed that the checkerboard metasurface works as a nearly perfect absorber when illuminated by two counter-propagating terahertz pulses simultaneously.

The Influence Of Electrode Position On The Current-Voltage Characteristics And Terahertz Radiation In A High-Tc Superconducting Device **WS-48**

Toshiaki Hattori; Kaveh Delfanazari; Hidehiro Asai; Manabu Tsujimoto; Takanari Kashiwagi; Takeo Kitamura; Takashi Yamamoto; Wade Wilson; Richard Klemm; Kazuo Kadowaki
The influence of electrode position on the current-voltage characteristics (IVC) and broadly tunable terahertz (THz) radiation emitted from two pentagonal mesa structures consisting of the intrinsic Josephson junctions in a high-Tc superconducting device is investigated.

Multi-photon Response Of Photon-number-resolving Superconducting Single Photon Detector **WS-49**

Peng Gu; Limin Zhao; Chao Wan; Lin Kang; Labao Zhang; Peiheng Wu
A new photon-number-resolving superconducting single photon detector is fabricated and tested. To integrate the resistors connected to the nanowire, we used one step of electron-beam lithography and four subsequent photolithography steps. A micro cavity was introduced to the structure in order to gain relatively high quantum efficiency. The device fabricated could resolve 6 photons.

Optical Fiber Coupled THz Transceiver **WS-50**

Tae-In Jeon; Hyeon Sang Bark; Young Bin Ji; Seung Jae Oh; Sam Kyu Noh
We made optic fiber coupled THz transceiver module which can freely move at any position. The measured THz pulse is 1 nA peak-to-peak amplitude, 1,000:1 signal-to-noise ratio, and 2.0 THz bandwidth when the THz pulse is reflected by metal surface. The GS and FT bio-samples are measured using the THz module. The THz reflection from GS sample is 6% bigger than that of FT sample. Because the transceiver module has small unit to emit and detect THz signal, the module will develop to THz endoscopy which will be used in-situ biomedical measurement in future.

Development Of Terahertz Pulse Time-domain Reflectometry System For Transmission Line Failure Analysis **WS-51**

Takanori Okada; Shigeki Nishina; Tsuyoshi Ataka; Masaichi Hashimoto; Akiyoshi Irisawa; Motoki Imamura
A time-domain reflectometry (TDR) unit is developed that scans for faults in transmission lines with high spatial resolution by transmitting a terahertz wave pulse down the transmission line and measuring the reflected wave. Photoconductive switches illuminated by femtosecond laser pulses are used for generating and detecting wideband electrical pulses. By this method, failure points in transmission lines can be identified at a resolution surpassing that of conventional electrical TDR.

Atmospheric Profiling Synthetic Observation System At THz Wave Band **WS-52**

Qijun Yao; Dong Liu; Zhenhui Lin; Wenying Duan; Jing Li; Zheng Lou; shengcai shi; Hiroyuki maezawa; Scott Paine
We introduced a dual-THz-band SIS (Superconductor- Insulator-Superconductor) heterodyne radiometer system which is under developing for the atmospheric profiling synthetic observation system project (APSOS). This THz system is intended to have a durable and compact design to meet the challenging requirements of remote operation at Tibetan Plateau. The system as well as its major components such as antenna tipping, quasi-optics, cryogenics, SIS mixers and FFTS backend will be discussed thoroughly. Some scientific simulation focusing on the atmospheric profiling components at THz bands will also be investigated.

Large Bandwidth Mesh Half-wave Plates For Millimetre And THz Wave Astronomy **WS-53**

Giampaolo Pisano; Peter A.R. Ade; Carole Tucker; Ming Wah Ng
Millimetre and sub-millimetre astronomical polarimeters have traditionally been based on birefringent Half Wave Plates (HWPs) used as polarisation modulating elements. Although moderate bandwidth can be achieved using the Pancharatnam designs there are limitations in terms of diameters, weights and associated losses. In addition, the rapid advance in array detector technology at these wavelengths has created a pressing need for large diameter HWPs which exceed those possible with crystalline materials. The first metamaterial HWP was developed using an air-gap mesh filter technology, which demonstrated the feasibility. This was subsequently replaced by a more robust dielectrically embedded version which can be fabricated in much larger diameters than are available to crystalline plates and being basically a plastic material is also much lighter. The present development in this area is focussed on achieving large bandwidths (over 100%), large diameters (500mm or larger) and low losses (<1% at cryogenic temperatures). Here we review different approaches to the design and show how a trade-off of the different HWP parameters (transmissions, differential phase-shift, cross-polarisation, absorptions) can lead to optimal performances for specific instrument configurations.

Monitoring The Water Content Of Plant Leaves With THz Time Domain Spectroscopy **WS-54**

Ralf Gente; Norman Born; Ajanth Velauthapilla; Jan C. Balzer; Martin Koch
We present an automated measurement setup which employs a fiber-coupled THz time domain spectrometer for simultaneous monitoring of the change in leaf water content of several plants at once. Moreover, it combines the collected THz spectra with data from other sensors. While the strong absorption of THz radiation by polar liquids like water tends to a problem in most biological and medical applications, it is a reliable indicator for leaf water content. We take this well-known basic principle to a level where biological experiments which explore the physiological behavior of plants under different drought stress condition become possible.

Compact Diffractive Optical Components For Terahertz Beam Manipulation **WS-55**

Linas Minkevicius; Karolis Madeikis; Bogdan Voisiat; Vincas Tamosiūnas; Gintaras Valusis; Gediminas Raciukaitis; Irmantas Kasalynas

Zone plates of the conventional design and the complex with integrated band-pass filter apertures were fabricated on the metal film and highly resistive silicon substrate using the direct laser writing. The focusing performance of the diffractive components was studied measuring the 0.6 THz frequency beam profiles along the optical axis. The compact lenses with the focal length of 5 and 10 mm and the numerical aperture up to 0.5 was experimentally demonstrated with the preference for the silicon components due to less pronounced standing waves effect between the detector and the zone plate.

3D-Printed Terahertz Bragg Fiber **WS-56**

Alice L. S. Cruz; Alexander Argyros; Xiaoli Tang; Cristiano M. B. Cordeiro; Marcos A. R. Franco

In this paper we demonstrate the terahertz propagation in Bragg fiber manufactured through rapid prototyping technique using low cost 3D printer. The fiber was numerically and experimentally characterized using software based on beam propagation method (BPM) and a terahertz time domain spectrometer (THz-TDS). The transmission structures indicate a good agreement between numerical and experimental data.

BiCMOS Integrated Waveguide Power Combiner At Submillimeter-Wave Frequencies **WS-57**

Maria Alonso-delPino; Daniele Cavallo; Harshitha Thippur-Shivamurthy; Hao Gao; Marco Spirito

This contribution presents the development of an integrated power combiner in Bi-CMOS technology employing artificial dielectric layers (ADLs) at submillimeter wave frequencies. The power is gathered from frequency multiplier chains into a single waveguide which is loaded with ADL in order to reduce the structure footprint.

Progress On THz Applications For Plasma Diagnostics **WS-58**

Angelo A. Tuccillo; Giuseppe Galatola-Teka; Federica Causa; Gian Piero Gallerano; Emilio Giovenale; Francesco Cuttaia; Michael Johnston; Marco Zerbini; Andrea Doria

The Terahertz (THz) band of the electromagnetic spectrum is defined as the frequency range between microwaves and mid-infrared light [1,2]. Since 2010 a successful collaboration between ENEA Frascati and the Photonics Group at Clarendon Laboratory, Oxford University, has been in place to extend the use of THz Time Domain Spectroscopy (TDS) techniques to harsh environment applications, namely Tokamak Plasma diagnostics for Fusion research [3]. The simultaneous use of large portions of the electromagnetic spectrum in the form of THz pulses produced with femtosecond mode-locked lasers provides an appealing tool to diagnose plasma phenomena spanning above and below the plasma frequency [4]. THz pulses can be used as very sensitive and versatile probes of widely varying plasma parameters especially for diagnostic applications in Tokamaks where plasma characteristics are non-uniform and evolve during the discharge. We designed and assembled a table-top free-air THz-TDS setup based on a femtosecond infrared laser pulse (790 nm) and photoconductive GaAs plates [2]. The system has been designed with a great deal of flexibility, to experiment different solutions for coupling optical systems, path difference scan and Group Velocity Delay (GVD) compensation. Recently we used a commercial Advantest TAS7500TS Terahertz Analysis System for a preliminary test of the long range optics and to measure the spectroscopic properties of materials and components relevant for Plasma Physics diagnostics, over an unprecedentedly large spectral range.

Terahertz Emission By Nanoporous GaP(111)B **WS-59**

Alexander Atrashchenko; A. Arlauskas; R. Adomavicius; A. Korotchenkov; N.V. Ulin; A. Krotkus; P. Belov; V. Evtikhiev

We have studied the emission of terahertz radiation from nanoporous semiconductor matrices of GaP excited by the femtosecond laser pulses. We observe 3-4 orders of magnitude increase of terahertz radiation emission from the nanoporous matrix compared to bulk material. We believe that a drastic increase of sample surface might be responsible for the observed effect. Thus, the porous matrices are found to be a promising material for THz radiation sources.

Terahertz Source With Graphene P-n Junction **WS-60**

Jingping Liu; Dayan Ban; Safieddin Safavi-Naeini; Huichang Zhao

Terahertz technology has wide application prospect in many fields, but the lack of high power terahertz sources which have simple structure and work at room temperature limits its development. There are conventional approaches for terahertz wave generation, such as microwave upconversion, tube sources, photon-mixing, optically-pumped gas lasers, p-doped Ge lasers and free electron lasers. Nevertheless, the conventional terahertz sources are not user-friendly (either bulky, complicated, power-hungry, or inefficient). Terahertz quantum cascade lasers are promising coherent terahertz sources, but they cannot be operated at room temperature. Clearly, there is a pressing and continuing need for the development of compact, easily-operable, high-performance solid-state terahertz sources. The mono-layer of graphene offers unique and new opportunities for the design and development of terahertz and electro-optic devices. Graphene is regarded as a direct zero bandgap semiconductor. It has bipolar field effect, i.e. the Fermi level can be changed by the gate voltage to form n-type or p-type graphene rather than doping. The band gap between the n-type graphene and the p-type graphene can be tuned from 0eV because of the zero band gap feature of intrinsic graphene. Terahertz photon energy is very small compared to the band gap of most commonly-available semiconductors. The zero band gap is advantageous in terms of terahertz wave generation because a small effective band gap could be created by turning the Fermi energy level in a gate-controlled graphene p-n junction. We have fabricated and measured the graphene device with two top gates. The measurement results show that the external gate biases can effectively induce a p-n junction in the graphene layer. It is therefore possible to employ this gate-controlled graphene based p-n junction for terahertz wave generation. For n-type graphene, extra electrons are induced by electrostatic field and are accumulated in the graphene layer, resulting in population inversion. When the forward bias gets to a certain value, the electrons of high energy level move to the p-type graphene, and recombine with the holes in p-type graphene to generate terahertz photons. In spite of carrier losses due to Auger recombination and other mechanisms, electrons could be injected to the p-graphene region through ballistic transport, leading to electron-hole radiation recombination. For example, terahertz photons at 1 THz frequency correspond to about 4.3 meV energy. Therefore when the induced n-type Fermi level is elevated by 2.15meV, it is possible to radiate terahertz photon if the electrons in n-type graphene are injected to p-type graphene to recombine with holes under a forward bias.

Influence Of Metal Resistivity On Transmittance Of Checkerboard Patterns In Infrared Region **WS-61**

T. Higashira; T. Kageyama; K. Kashiwagi; H. Miyashita; K. Takano; M. Nakajima; Sang-Seok Lee

Checkerboard patterns (CPs) are a kind of metamaterials which are attracting much attention for their application to sensing devices. In this study, we have investigated the electromagnetic responses of CPs in infrared (IR) region. We have fabricated CPs with two different metals and measured the transmittance to clarify the influence of metal resistivity of CPs on transmittance. As a result, we have successfully confirmed experimentally metal resistivity influence on transmittance characteristics of CPs even in IR region not only THz region.

THz Photo-Injector FEM With The Negative-Mass Bunch Stabilization **WS-62**

Ilya Bandurkin; Sergei Kuzikov; Vladimir Bratman; Andrei Savilov

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Both the duration and the power of spontaneous coherent radiation of a short electron bunch produced by a photo-injector gun and moving along the helical wiggler can be substantially increased if the guiding magnetic field is approximately twice as strong as the resonance one. In such regime, axial Coulomb repulsion of the electron leads to their mutual attraction (similar to the negative mass effect in gyrotrons) which slows down bunch degradation and increases the radiated energy.

Quasi-optical Transmission System For A Pulsed ESR System By Using A Gyrotron As A Light Source **WS-63**

Seitaro Mitsudo; Chihiro Umegaki; Yutaka Fujii; Yoshinori Tatematsu

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.

A W-Band Corrugated Output Horn And Window For Gyro-devices **WS-64**

Paul McElhinney; Craig Donaldson; Liang Zhang; Adrian Cross; Huabi Yin; Wenlong He

A W-band corrugated horn incorporating a broadband vacuum window for use in a gyro-device as a quasi-optical launcher has been designed, manufactured and experimentally measured. This horn, including a 3 disk vacuum window, converts a cylindrical TE11 mode into the free space TEM00 mode over the frequency band of 90--100 GHz with a reflection better than -30 dB and a coupling efficiency of ~99.4%

The Experimental Results Of Fast Switching System For Millimeter Wave Transmission Using Photo-excited Semiconductor **WS-65**

Mun Seok Choe; Kyu-Sup Lee; Nan Ei Yu; EunMi Choi

Photo-excited semiconductor switching system for fast control of millimeter wave is developed and tested with an oversized corrugated horn ($D/\lambda > 10$) and quasi-optical mirror setup. Semi-insulating GaAs (100) having direct band-gap shows fast switch ON-OFF (< 100 ns) whereas semi-insulating Si (100) having indirect band-gap shows fast switch ON (< 100 ns) and slow switch OFF (< 1 ms) for the millimeter-wave regime.

Status Of ENEA 250 GHz Cyclotron Autoresonance Maser Project **WS-66**

Silvio Ceccuzzi; Luca Amicucci; Alex Bruschi; Paolo Buratti; Mariano Carpanese; Federica Causa; Franco Ciocci; Giuseppe Dattoli; Domenico De Meis; Emanuele Di Palma; Andrea Doria; Gian Piero Gallerano; Saul Garavaglia; Emilio Giovenale; Alessandro Lampasi; Giuseppe Maffia; Luca Mezi; Francesco Mirizzi; Alberto Petralia; Gian Luca Ravera; Giuliano Rocchi; Elio Sabia; Ivan Spassovsky; Angelo A. Tuccillo; Pietro Zito

The conceptual design study of a high-power high-frequency Cyclotron Auto-Resonance Maser (CARM) has been undertaken at the ENEA-Frascati research center in 2013. CARMs could be effective mm-wave sources for electron cyclotron waves and plasma diagnostics in magnetic confinement fusion reactors. The project is advancing quickly with the technical design of some major parts now completed and ready to enter the realization phase. Subsystems under conceptual or detailed design are presented together with the outlook of next steps.

Submillimeter-wave Properties Of Zn2SiO4 Ceramics **WS-67**

Liviu Nedelcu; Cezar Dragos Geambasu; Marian Gabriel Banciu; Atsushi Iwamae; Takashi Furuya; Masahiko Tani

Zinc silicate ceramics have been prepared by using conventional solid-state reaction method. Morphological, structural, and dielectric characterizations of the samples were performed using scanning electron microscopy, X-ray diffraction, and terahertz time-domain spectroscopy. Experimental data will be discussed and compared with some commercial dielectrics (quartz, alumina, sapphire, teflon, etc.). The low dielectric loss obtained for Zn2SiO4 ceramics recommend this type of materials for applications in submillimeter-wave devices.

An Envelope-detector-based Transceiver Is Demonstrated In Both OOK Transmission And Frequency-modulated Continuous-wave Radar At 300 GHz. **WS-68**

Atsushi Kanno; Norihiko Sekine; Yoshinori Uzawa; Iwao Hosako; Tetsuya Kawanishi

Envelope-detector-based transceiver configurations are useful for both digital signal transmission and radar systems in the terahertz band. A dual-purpose transceiver is demonstrated using a 1-Gb/s on-off keying signal and 12.5-GHz-bandwidth frequency-modulated continuous-wave radar.

Estimation Of Carrier Density Of Wide Bandgap Semiconductor <beta>-Ga2O3 Single Crystals By THz Reflectance Measurement **WS-69**

Shingo Saito; Takeyoshi Onuma; Kohei Sasaki; Akito Kuramata; Norihiko Sekine; Akifumi Kasamatsu; Masataka Higashiwaki

In order to estimate carrier density on widegap semiconductor β-Ga2O3, we made a measurement of THz reflectance spectra of β-Ga2O3 samples by using a THz time-domain spectroscopic method. The tails of reflectance structures were shifted to higher energy side with increasing the doping density. We treated the structure is caused by plasmon, and calculated the carrier density of each samples. The carrier densities obtained by the THz reflection measurements showed a good agreement with the results by Hall-effect measurements. These results indicated that THz spectroscopy is a useful method to estimation of carrier density of β-Ga2O3 samples.

Terahertz Emission From Non-vertically Aligned Semiconductor Nanowires **WS-70**

Ieva Beleckaitė; Gediminas Molis; Ramūnas Adomavičius; Aloyzas Siusys; Anna Reszka; Arūnas Krotkus; Janusz Sadowski

In this work THz emission of the non-vertically aligned GaMnAs and InGaAs nanowires (NWs) were investigated for the first time. THz emission azimuthal dependencies on different nanowire layers were measured. In addition THz pulse amplitude dependencies on an angle between the incident laser beam and a normal to the sample surface were accomplished for the removed NW layer. The investigated layers can be used in rotating polarization THz emitters. This application is very important because the principle of half wave plate cannot be used due to a wide spectrum of the THz pulses.

Circularly Polarized Terahertz Leaky-Wave Antenna With Metamaterial Scatterers **WS-71**

Shaghik Atakaramians; Yasuaki Monnai; Withawat Withayachumnankul

We propose a leaky-wave antenna to generate circularly polarized highly directional terahertz beam using metamaterial scatters. A microstrip line is loaded with a series of complementary electric-LC and electric-LC resonators to generate respectively Ex and Ey components. The 900-phase difference and almost unity amplitude ratio of Ex and Ey are achieved by relative positioning of the resonators on and off the stripline and optimizing the gap size. Moreover, the phase front of the radiated wave can be adjusted to a specific direction by controlling the period of the resonator array. These highly directional planar antennas can be utilized in short-range THz communication, sensing and imaging applications.

Monday, August 24, 2015

08:45 - 09:15 **Welcome and Opening Remarks** — **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

08:45 - 09:00 **Morning Announcements** — **Lecture Theatre 1**

09:00 - 10:30 **Plenary Session P7-P8** — **Lecture Theatre 1**

Chairpersons: Xi-Cheng Zhang;

09:00 **SubTHz Photons In The Universe And In My Life** **P7**

Philippe Goy

Keep our eyes open. This could be my maxim, especially in Abstract. 2015, international year of LIGHT. We have natural photons detectors. However, there are not simple spectrum detectors. Three orders of magnitude frequency below these visible photons are the THz and sub-THz photons, the main topics of this conference series. They played also a fundamental role all along my life, and recently for everybody when understanding the evolution of the Universe as a whole, or in the amazing single photon quantum games.

09:45 **Frontiers Of Sub-cycle Terahertz Science: The Fast, The Strong And The Small** **P8**

Matthias Hohenleutner; Fabian Langer; Olaf Schubert; Sebastian Baierl; Thomas Maag; Christoph Lange; Michael Porer; Christoph Pöllmann; Philipp Steinleitner; Max Eisele; Markus A. Huber; Markus Plankl; Tyler L. Cocker; Rupert Huber

Phase-locked few-cycle pulses in the ultrabroadband terahertz (THz) spectral window have become a powerful tool to access low-energy elementary dynamics in solids, on time scales shorter than a single oscillation cycle of light. Here, we tackle the role of excitons and their dynamics in modern dichalcogenide mono-layers and exciton-polariton condensates. Furthermore, intense THz pulses are used as atomically strong bias fields to explore high-harmonic generation by dynamical Bloch oscillations in bulk solids. Finally, we develop a novel microscope that introduces sub-cycle resolution on the few-nm length scale. The experiments reviewed here challenge modern quantum theories and spark hope for electronics and magnetic storage at optical clock rates.

11:00 - 12:30 **H1A - 02 - Applications in Biology and Medicine - 04 - Applications in Industry** — **Lecture Theatre 2**

Chairpersons: Danniel Mittleman;

11:00 **Large-Area Transmission And Reflection Imaging With 640x480 Pixel Terahertz Camera** **HA1-1**

Tsutomu Ishi; Takao Morimoto; Takayuki Sudou; Naoki Oda

An active terahertz (THz) imaging system that can easily be switched between a transmission and a reflection mode is developed. The system consists of a compact THz source that operates at room temperature, optical system utilizing polarization and two 640x480 pixel uncooled THz cameras. In order to take an image of a large sample, a part of the imaging system is moved at a fixed distance and a series of images taken are combined to one elongated image. Concealed nonmetallic object detection in an envelope is demonstrated.

11:15 **The Analysis Of Hydration Processes In Porous Materials Using Terahertz Pulsed Imaging** **HA1-2**

Samy Yassin; Kirby Lam; Edward Kwok; Lynn Gladden; Axel Zeitler

Solvent penetration in porous solids is a very important property that limits the performance of a range of materials in industrial applications. Here we show how terahertz pulsed imaging (TPI) can be used to investigate the uptake of water into a range of such materials at two examples in the pharmaceutical sciences and catalysis by using depth resolved tracking of the water/solid interface over time upon exposure of the porous solid to water. TPI is an exciting characterisation technique to study such solvent transport processes due to its millisecond time resolution and the transparency of ceramics and polymers to terahertz radiation. These properties make TPI unique to investigate fast processes compared to other measurement modalities.

11:30 **An Evolutionary Algorithm Based Approach To Improve The Limits Of Minimum Thickness Measurements Of Multilayered Automotive Paints** **HA1-3**

Soufiene Krimi; Jens Klier; Joachim Jonuscheit; René Beigang; Ralph Urbansky; Frank Ellrich; Georg von Freymann

We present a novel numerical approach to decrease the limits of the minimum paint thickness measurements of individual layers in multilayered structures using terahertz pulsed technique in reflection geometry. This method combines the benefits of model-based material parameters extraction, a generalized transfer matrix method, and an evolutionary optimization algorithm. The proposed approach has been successfully applied to resolve individual layer thicknesses down to 5 µm in multilayered automotive paint samples.

11:45 **High-resolution Interdigitated Back Contact Solar Cell Inspection Using Terahertz Microprobes** **HA1-4**

Simon Sawallich; Christopher Matheisen; Michael Nagel; Ilkay Cesar

Terahertz near-field microscopy is presented as a new characterization tool for photovoltaic applications: High-resolution sheet resistance measurements at interdigitated back-contact (IBC) solar cell samples are conducted, revealing previously undetectable features with lateral dimensions as small as a few tens of µm. Despite the very high maximum resolution the method is reasonably fast and suited for full wafer-scale inspection tasks.

12:00 **Effects Of Mm-waves On Human Fibroblasts In-vitro** **HA1-5**

Gian Piero Gallerano; Andrea Doria; Emilio Giovenale; Andrea De Amicis; Stefania De Sanctis; Sara Di Cristofaro; Valeria Franchini; Florigio Lista; Elisa Regalbuto; Antonella Sgura; Elisa Coluzzi; Jessica Marinaccio; Roberto Bei; Massimo Fantini; Monica Benvenuto; Laura Masuelli

A comprehensive study of the in-vitro exposure of human fibroblasts to millimeter waves in a wide spectral region is under way. The evaluation of different biological endpoints as result of exposure to pulsed radiation in the frequency range 100 - 150 GHz with the ENEA Compact FEL is reported. A new exposure set-up for irradiation to CW radiation in the range 18-40 GHz will also be presented.

12:15 **Investigation Of Pharmaceutical Film Coating Process With Terahertz Sensing, Optical Coherence Tomography And Numerical Modelling** **HA1-6**

Hungyen Lin; Yue Dong; Chunlei Pei; James Elliott; Yaochun Shen; Axel Zeitler

08:45 - 09:15	**Welcome and Opening Remarks** **Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;**	**Lecture Theatre 1**

Terahertz in-line sensing was successfully demonstrated on a production scale setting for measuring the coating thickness of individual pharmaceutical tablets during the film coating process. This paper reports on recent research progress to exploit terahertz in-line sensing, optical coherence tomography and numerical modelling to better understand the pharmaceutical film coating process.

11:00 - 12:30	**H1B - 20 - Quantum Cascade Lasers II** **Chairpersons: Juncheng Cao;**	**Lecture Theatre 3**

11:30 **Double Pulse Injection Seeding Of A Terahertz Quantum Cascade Laser** **H1B-2**

Sergej Markmann; Hanond Nong; Shovon Pal; Negar Hekmat; Sven Scholz; Nadezhda Kukharchyk; Arne Ludwig; Sukhdeep Dhillon; Xavier Marcadet; Claudia Bock; Ulrich Kunze; Andreas D. Wieck; Nathan Jukam

Double-pulse injection seeding is used to modify the spectral emission of a terahertz quantum cascade laser (THz QCL). Two broad-band THz pulses delayed in time imprint a modulation on the single THz pulse spectrum. The resulting seed enables modification of the QCL emission spectrum, even though, the spectral bandwidth of each THz pulse is much broader than the QCL gain bandwidth. For a proper time delay between the pulses, the seeded THz QCL emission can even be switched from a multimode to a single mode regime.

11:45 **Far-field Engineering Of Metal-metal Terahertz Quantum Cascade Lasers With Integrated Horn Antennas** **H1B-3**

Feihu Wang; Iman Kundu; Lianhe Li; Edmund Linfield; Giles Davies; Souad Moumdji; Raffaele Colombelli; Juliette Mangeney; Jerome Tignon; Sukhdeep Dhillon

The far-field of metal-metal terahertz quantum cascade lasers is greatly improved through integrated and stable planar horn antennas on top of the QCL ridge. The antenna structures introduce a gradual change in the high modal confinement of metal-metal waveguides and permit an improved far-field, showing a five times increase in the emitted output power. The two dimensional far-field patterns are measured at 77K and compared to electromagnetic simulations. The influence of parasitic high order transverse modes are restricted through the engineering of antenna structure (ridge and antenna width) to couple out the fundamental mode only.

12:00 **Efficient Terahertz-wave Generation In Mid-infrared Quantum-cascade Lasers With A Common Dual-upper-state Active Region** **H1B-4**

Kazuue Fujita; Akio Ito; Masahiro Hitaka; Tatsuo Dougakiuchi; Tadataka Edamura; Masamichi Yamanishi; Seungyong Jung; Mikhail Belkin

We report the performance of room temperature, single mode terahertz sources based on intracavity difference frequency generation in mid-infrared quantum cascade lasers with a common dual-upper-state (DAU) active region. As a result of designing of DAU active region for giant optical nonlinearity, the DAU devices with a dual-period buried distributed feedback grating operate in two single-mode mid-infrared wavelengths at 10.7 μm and 9.7 μm, and produce single-mode THz output at ~2.9 THz with a side mode suppression ratio of ~25 dB. A high mid-infrared to THz conversion efficiency of 0.8 mW/W2 is obtained at room temperature, which is highest in THz DFG-QCLs. The DAU active region design may offer advantages for intra-cavity terahertz generation in mid-IR QCLs over heterogeneous-type active region designs in terms of higher values of optical nonlinearity for THz DFG.

11:00 - 12:30	**H1C - 10 - Modeling and Analysis Techniques I** **Chairpersons: Chao Zhang;**	**Lecture Theatre 4**

11:00 **Modulation Of Terahertz Radiation Based On Dc-ac-field Tuned Coherent Dynamics Of Dipolaritons** **H1C-1**

Wei Zhang

We propose an effective and convenient way of modulating the THz emission by dc and ac fields based on the coherent dynamics of dipolaritons, quasiparticles formed by the direct exciton, indirect exciton and photon in semiconductor double quantum wells embedded in microcavities. With the help of resonant tunneling, photon-assisted transport, and the dark Floquet states, we may generate efficient THz radiation (with tunable frequency and appreciable radiation power) or quench the THz emission by tuning the ac and dc fields.

11:15 **Steady-State Thermal Analysis Of An Integrated 160 GHz Balanced Quadrupler Based On Quasi-Vertical Schottky Diodes** **H1C-2**

Souheil Nadri; Linli Xie; Naser Alijabbari; John Gaskins; Brian Foley; Patrick Hopkins; Robert Weikle

This work reports on a steady-state thermal analysis of a 160 GHz balanced quadrupler, based on a quasi-vertical varactor Schottky diode process, for high power applications. The chip is analyzed by solving the heat equation via the 3D finite element method. Time-Domain Thermoreflectance (TDTR) was used to measure the thermal conductivity of the different materials used in the model. A maximum anode temperature of 64.9 C was found from the simulation. The addition of an extra beam lead connected to the block, for heat sinking, was found to reduce this maximum temperature to 41.0 C.

11:30 **Comparison Of Model-Based Material Parameter Extraction In Frequency- And Time-Domain** **H1C-3**

Daniel Stock; Peter Haring Bolívar

We compare physical material-model based schemes for time-domain and frequency-domain analysis of measurement data. Such approaches can be used to extract materialparameters from measurements acquired by THz time-domain spectroscopy (TDS) systems. A detailed intercomparison of both analytic methods is presented. Cases with resonance features and limited dynamic range are considered.

11:45 **A Network Formulation For Characterization Of Plasmonic Interactions In A Semiconductor Nanodimer** **H1C-4**

Thomas T Y Wong; Zhijing Hu; Tao Shen; Yanlin Li

An effective-field approach is employed to arrive at a the total dipole moment induced on a nanodimer by a terahertz electric field. The implemented formulation is aided by the use of networks synthesized from the polarizability of the particles, enabling close form expressions to be obtained. Salient features such as field enhancement and spectral shift in the surface plasmon resonance frequency exhibited by a nanodimer comprise of conductive particles are revealed by the calculated total dipole moment. The method can be directly extended to gain insight to polarization interactions in larger clusters with only a moderate increase in computation effort.

Monday, August 24, 2015

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

12:00 **Hybrid Analysis Of Terahertz Photoconductive Antennas Using Energy Balance Transport Model** **H1C-5**
Ramin Emadi; Navid Barani; Asad Amirhosseini; Reza Safian
A photoconductive antenna with tip-to-tip rectangular electrodes has been numerically investigated in the terahertz (THz) frequency band. Through a hybrid simulation employing an optoelectronic software, Silvaco, and a full-wave electromagnetic solver, CST, we will show that for analysis of photoconductive antennas in high power applications, energy balance transport model compared to the drift-diffusion model become more accurate due to the consideration of diffusion associated with the carriers temperature.

11:00 - 12:30 **H1D - 08 - Sources, Detectors, and Receivers VII** **Lecture Theatre 6**

Chairpersons: Mona Jarrahi;

11:00 **Emission And Detection Of Terahertz Radiation In Double-Graphene-Layer Van Der Waals Heterostructures** **H1D-1**
Stephane Boubanga Tombet; Deepika Yadav; Stevanus Arnold; Takayuki Watanabe; Victor Ryzhii; Taichii Otsuji
We report on experimental observation of terahertz emission and detection in a double graphene layer heterostructure with two independently contacted graphene layers separated by a thin h-BN tunnel-barrier layer. The bias voltages/doping causes the inter-graphene-layer population inversion with the possibility of photon-assisted resonant-tunneling transitions between the conduction bands and valence bands of the two graphene layers. We demonstrate that this can enable the realization of devices such as resonant terahertz detectors and emitters.

11:30 **Fast Pyroelectric Response Of Semiconducting YBaCuO Detectors With High IR Sensitivity; Development Of THz Imaging Arrays** **H1D-2**
Xavier Galiano; Annick Dégardin; Vishal Jagtap; Alain Kreisler
Introduction. The semiconducting phase of YBa2Cu3O6+x (YBCO) with a low oxygen content (x < 0.5) offers key advantages for developing uncooled thermal sensors: bolometers or pyroelectric detectors. Moreover, YBCO can be deposited in an amorphous form (a-YBCO) at low-temperature processing conditions (150 °C, typically), which are compatible with CMOS readout circuitry integration. Recently, very promising performances in terms of infrared detectivity and fast pyroelectric response have been reported with a-YBCO film detectors.
Experiment. In order to confirm the a-YBCO potential for room temperature imaging, planar structures - about 300 nm thick a-YBCO film connected to two metal pads - were patterned on SiOx/p-Si substrates. The device was illuminated with a VCSEL diode source modulated at frequency f. The device current was then readout with a low noise preamplifier and synchronously detected at f. The lock-in amplifier was also used to measure the device noise current in a 1 Hz bandwidth.
Results. Unbiasing the device allowed eliminating the resistive / bolometric low pass response, and the associated Johnson noise as well. The resulting high pass behavior is typical of a pyroelectric response, i.e., sensitive to the capacitance current (thermally modulated electrical polarization). For this high-pass f^+1 behavior, the frequency cut-off at about 35 kHz can be related with the a-YBCO dielectric relaxation. The higher frequency low-pass response - close to f^-1/2 behavior typical of thermal diffusion across the substrate - is limited by the current preamplifier at about 3 MHz. Noise measurements allowed to extract NEP values below 15 pW/Hz^½, with detectivity D* above 10^9 cm.Hz^1/2/W in the 500 Hz to 100 kHz range.
THz development. Due to a-YBCO reflectivity in the THz range, coupling of the radiation to the a-YBCO sensing area is being performed using a planar antenna. We have considered the design of antenna arrays; a 32x32 array demonstrator has been designed. A major outcome is the overall array size, according to the criteria of both THz bandwidth and inter-pixel cross talk. Another aim is to test the impedance matching between the antenna and the a-YBCO patch using FTIR spectroscopy measurements on such dense arrays of adequately loaded micro-antennas.
Acknowledgments. This work was supported by UPMC Univ. Paris 06. The devices were processed at the CTU-Minerve facilities (Univ Paris Sud 11, Orsay, France).

11:45 **500 GHz Sensor System In SiGe For Gas Spectroscopy** **H1D-3**
Klaus Schmalz; Philipp Neumaier; Ruoyu Wang; Johannes Borngräber; Wojciech Debski; Mehmet Kaynak; Dietmar Kissinger; Heinz-Wilhelm Hübers
A 500 GHz sensor system for gas spectroscopy is presented, which includes a SiGe transmitter (TX) array and a SiGe receiver (RX). The integrated local oscillators of the TX-array and RX chips are controlled by two external phase-locked loops (PLL). The reference frequency of the TX-array PLL is modulated for 2f absorption spectroscopy (second harmonic detection). The performance of the sensor system is demonstrated by the 2f absorption spectra of methanol and acetonitrile.

12:00 **A Turn-key Cryogenic Superconducting Bolometer Detector System** **H1D-4**
Adam Woodcraft; Peter Ade; James Cox; Chris Dunscombe; Rashmi Sudiwala; Tyrone Jones; Ken Wood
We describe a complete, commercially available, cryogen-free superconducting bolometer detector system. This allows detection of Terahertz radiation at frequencies from 0.1 to 20 THz, with a system optical NEP of ~ 3 pW/rtHz, a useful modulation frequency range from 5 Hz to > 1 kHz and a linear dynamic range over 60 dB. The range of detection frequencies can be precisely defined using metal mesh filters. The system is entirely self-contained and requires only an electrical supply in order to operate. Continuous operation is possible for a period of several months or even longer.

12:15 **Antenna-Coupled Microcavity Enhanced THz Photodetectors** **H1D-5**
Daniele Palaferri; Yanko Todorov; Stefano Barbieri; Djamal Gacemi; Yuk Nga Chen; Angela Vasanelli; Lianhe Li; Giles Davies; Edmund Linfield; Carlo Sirtori
We report on the implementation of 5 THz quantum well photodetector exploiting a patch antenna cavity array. The benefit of our plasmonic architecture on the detector performance is assessed by comparing it with detectors made using the same quantum well absorbing region, but processed into a standard 45{degree sign} polished facet mesa. Our results demonstrate a clear improvement in responsivity, polarization insensitivity and background limited performance. Peak detectivities in excess of 5x10^12 cmHz^1/2/W have been obtained, a value comparable with that of the best cryogenic cooled bolometers.

11:00 - 12:30 **H1E - 21 - Gyro-Oscillators and Amplifiers IV** **Lecture Theatre 7**

Chairpersons: Manfred Thumm;

11:00 **Recent Experimental Results Of The European 1MW, 170 GHz Short-Pulse Gyrotron Prototype For ITER** **H1E-1**

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Tomasz Rzesnicki; Ioannis Gr. Pagonakis; Andrey Samartsev; Kostantinos Avramidis; Gerd Gantenbein; Stefan Illy; John Jelonnek; Jianbo Jin; Carsten Lechte; Markus Losert; Bernhard Piosczyk; Manfred Thumm

A short-pulse prototype tube has been designed and manufactured at KIT in order to support the development of the European 1MW, 170 GHz, CW gyrotron for ITER. The aim of the tests is the validation of the design of the most critical components such as electron gun, cavity, beam tunnel and quasi-optical mode converter. First experimental results will be presented in this paper.

11:15 **Development Of A High Power 300 GHz Band Gyrotron For Practical Use In Collective Thomson Scattering Diagnostics In LHD** **H1E-2**

Teruo Saito; Jun Kasa; Yuusuke Yamaguchi; Yoshinori Tatematsu; Masaki Kotera; Shin Kubo; Takashi Shimozuma; Kenji Tanaka; Masaki Nishiura

A high power 300 GHz band pulse gyrotron has been designed and fabricated based the design concept for stable and single mode oscillation that has been experimentally verified with a prototype gyrotron. It will be practically use in the collective Thomson scattering (CTS) diagnostics in the Large Helical Device (LHD). The oscillation frequency is 303 GHz and the design calculation predicts stable oscillation of over 300 kW power at fundamental harmonic resonance.

11:30 **Novel Self-consistent Linear Theory Of A Gyrotron Oscillator And Experimental Validation** **H1E-3**

Stefano Alberti; Jeremy Genoud; Falk Braunmueller; Jean-Philippe Hogge; Minh Quang Tran; Trach Minh Tran

Based on a linearized set of self-consistent equations describing the time-dependent self-consistent waveparticle interaction in a gyrotron oscillator, a spectral approach is used for determining the spectrum of stable and unstable self-consistent eigenmodes. The model is an extension of a recently developed model based on a moment approach in [1] and retains all the relevant system inhomogeneities such as cavity-wall and magnetic field profiles. It is shown that this model predicts a new set of eigenmodes in addition to the set of eigenmodes issued from the cold-cavity modes. The model, the numerical implementation together with results for a real gyrotron cavity will be presented, discussed and compared to experimental results.

11:45 **Further Experiments Of A W-band Gyro-TWA Based On A Helically Corrugated Interaction Region** **H1E-4**

Wenlong He; Craig Donaldson; Liang Zhang; Paul McElhinney; Huabi Yin; Jason Garner; Kevin Ronald; Adrian Cross; Alan Phelps

Latest results of a W-band gyro-TWA with a helically corrugated waveguide and a cusp electron gun for operation at a high pulse repetition rate are presented. Performance upgrades of input coupler, output window, corrugated horn, pulsed power system and beam collector with water-cooling capability were realized. With an input seed signal from an 1.5 W, 90-96 GHz solid state source the amplification gain and minimum bandwidth were measured from the experiment.

12:00 **Development Status Of Gyrotron Setup For ITER ECW System** **H1E-5**

Grigory Denisov; Alexander Litvak

The paper presents development status of a gyrotron setup for ITER. Twenty four such setups are to be used for heating and current drive in ITER plasma. The setup includes a gyrotron in a superconducting magnet and several tens of other components. Recently the main required gyrotron parameters were demonstrated. In the last year tests confirmed 95% reliability of gyrotron operation. Now a prototype of complete gyrotron setup is assembled and it is under thorough testing.

14:00 - 15:30 **H2A - 06 - Protein Dynamics and Molecular Spectroscopy - 07 - Spectroscopy of Gases,Liquids, and Solids** **Lecture Theatre 2**

Chairpersons: Axel Zeitler;

14:00 **Terahertz Dynamics Of Amorphous (Bio)Pharmaceutical Mixtures** **H2A-1**

Juraj Sibik; Axel Zeitler

The molecular dynamics of amorphous materials and its relation to the physico-chemical changes in the organic glasses is still a topic of a dispute in the scientific community. Terahertz spectroscopy however provides very important experimental evidence on the fast dynamics in the overlapping region between the molecular relaxations and structural excitations, which is extremely sensitive to both dynamical and structural changes in the amorphous systems. We show how this information can be utilised to enhance the long-term stability of amorphous pharmaceutical systems and cryo-preserved proteins.

14:30 **Spatiotemporal Features Of Nucleic Acid Hydration And Their Changes During Denaturation Revealed By THz Spectroscopy** **H2A-2**

Heyjin Son; Jinyoung Jung; Sunmyoung Kim; Jaehun Park; Jungmin Jang; Kihoon Eom; Inkyung Park; Gun-Sik Park

Dynamics and structure of water network around nucleic acid have been subjects of intensive studies due to their contributions to biological process. Here, we identified spatiotemporal features of DNA hydration through examining fully-hydrated DNA solutions by THz spectroscopy. The results suggest the presence of weakly bound water beyond tight-binding hydration layer with the timescale of 11.6ps and the thickness of 7.6Å. Also, we will present changes in the hydration water during DNA denaturation at the conference.

I. INTRODUCTION

rimary function of DNA is transferring genetic information to RNA or another DNA accurately. This function is associated with a conformational change of DNA from double helix to single strand, so-called DNA denaturation. However, it is reported that considerable amount of water molecules interacts with double helical DNA. Studies on changes in structure and dynamics of surrounding water caused by denaturation have attracted researcher's attentions, as the surrounding water is critical to stabilizing double helix structure. Thus far, behaviors of these water molecules upon DNA denaturation have been examined by various techniques such as NMR, dielectric measurement and neutron scattering. Development of THz spectroscopy enables scientists to observe picosecond-dynamics of water directly. Conventional techniques measured relatively slow water motions (up to 100ps) such that they examined tightly bound water adjacent to DNA. However, recently, more flexible DNA-bound water is observed by fluorescence spectroscopy and expected to play a role in recognition process due to its dynamic nature. Although several studies have been done to understand structural and dynamical properties of surrounding water upon DNA denaturation, a relationship between behavior of water and DNA denaturation is not clear yet. In this paper, we determine the extent of DNA-bound water in the range of picosecond timescale and its changes during DNA denaturation using THz spectroscopy.

II. RESULTS

A twelve base-paired duplex is dissolved in buffer and aqueous solutions at several DNA concentrations are examined by THz time-domain spectroscopy. We assumed that measured dielectric spectra of DNA solutions mostly originate in water because

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

dielectric response of dehydrated DNA film is low-loss and dispersionless. Both dielectric constants and volume fraction of DNA molecule with hydration water are extracted using following Bruggeman effective medium theory. Relaxation time of reorientational motion of DNA hydration water is obtained to be 11.6ps from Double Debye model. This timescale is much faster than nanosecond-timescale of tightly bound water observed by NMR or dielectric measurement but still slower than 7ps of bulk water. Therefore, 11.6ps of reorientation time demonstrates the presence of weakly bound water around DNA. From the volume fraction of DNA plus hydration water, the average radius of DNA with hydration water is calculated to be 24.4Å

14:45 **Low-frequency Vibrational Dynamics Of Poly(lactic Acid) Stereocomplex Studied By THz Spectroscopy And Solid-state DFT Simulation** **H2A-3**

Feng Zhang; Keisuke Tominaga; Michitoshi Hayashi; Houng-Wei Wang; Takashi Nishino

Polymers, ranging from familiar synthetic plastics to natural biopolymers, play an essential role in everyday life. The low-frequency vibrations control their macroscopic thermal, mechanical and various other important properties. This work presents a comprehensive investigation of the low-frequency normal modes of crystalline polymer systems using poly(lactic acid) stereocomplex (scPLA) as an example. The scPLA sample can be easily prepared with high crystallinity and shows sharp peaks in THz spectroscopy. More importantly, several THz bands exhibit interesting temperature dependence, such as anomalous frequency shift and very weak relaxation effect, indicating the peculiar vibrational dynamics of scPLA. The successful interpretation of these phenomena may suggest a solution to the question as to how the microscopic atomic normal mode structures and dynamics affect the macroscopic properties of scPLA, such as its sound mechanical properties compared with its homo-crystallinity systems. The solid-state density-functional-theory simulation has allowed us to reproduce the peak positions of the THz modes measured at 78 K. By applying a recently developed mode-analysis method, the nature of THz modes has been quantitatively characterized as a combination of intermolecular translations, librations and intramolecular vibrations. Preliminary discussions will be made on this basis to provide insight into the anomalous temperature dependence of THz modes.

15:00 **Accelerated Terahertz Water Dynamics Under Osmotic Interaction Of Lipid Bilayers And Polyethylene Glycol** **H2A-4**

Kihoon Eom; Heyjin Son; Jin-Young Jeong; Jungmin Jang; In-Kyung Park; Seonmyeong Kim; Gun-Sik Park

Intracelluar water is expected to have different physical properties from those of bulk water. Using polyethylene glycol, we induce model intracellular environment on DMPC lipid solution and we shows the accelerated movement of non-hydrogen bonding (NHB) water molecules interacting with DMPC in polyethylene glycol (PEG) solution from the dielectric response in the terahertz range. With the measurement in the GHz range, detailed behavior of hydration water is also analyzed.

15:15 **Sensitive Analytical Gas Spectroscopy Based On Free-electron Laser And Multistage Tunable Fabry-Perot Interferometer** **H2A-5**

Vitaly Kubarev

New method of sensitive analytical gas spectroscopy based on terahertz free-electron laser (THz NovoFEL) and multistage tunable mesh Fabry-Perot interferometers (MST-FPI) is proposed. In the method a molecule is identified by a spectral position of its individual separate narrow absorption lines. Required tunable narrow laser line can be produced by THz NovoFEL and MST-FPI in spectral range of 90-240 μm (1.2-3.3 THz). Balanced lock-in detection of the line absorption increases sensitivity of the method.

14:00 - 15:30 **H2B - 14 - High-Field THz Wave Generation and Nonlinear THz Physics III** **Lecture Theatre 3**

Chairpersons: Dino Jaroszynski;

14:00 **Effect Of Nonlinearity On Surface Plasmon Polaritons In Graphene In The Terahertz Region** **H2B-1**

Matthew Sanderson; Yee Sin Ang; Chao Zhang

The effect of a strong electric field (≥4kV/cm) on the properties of surface plasmon polaritons (SPP's) is investigated. It is found that when a strong enough field is applied, the TM SPP dispersion can move up into the light cone. It is further found that when considering the problem of exciting SPP's using a prisim (ie. excitation from evanescent waves), optical bistability is possible as a sufficiently high field.

14:30 **Out-of-plane THz Electric Field Enhancement In Vertical Nano-slit Arrays** **H2B-2**

Yannik Waeber; Salvatore Bagiante; Justyna Fabianska; Thomas Feurer; Hans-Christian Sigg

We report an out-of-plane electric field enhancement in the terahertz range, using a non-conventional planar nano-slit array. Both simulations and experiments demonstrate that the field enhancement and the transmission coefficient are comparable with those observed in a planar slit array. This novel geometry is realized using standard thin film technology and thus will open the way for many new experiments where strong out of plane THz fields are needed. The planar process allows fabrication of slits with sub-nanometer gap size.

14:45 **Ultrafast Electron Field Emission From Gold Resonant Antennas Studied By Two Terahertz Pulse Experiments** **H2B-3**

Krzysztof Iwaszczuk; Maksim Zalkovskij; Andrew Strikwerda; Peter Jepsen

Ultrafast electron field emission from gold resonant antennas induced by strong terahertz transient is investigated using two THz pulse experiments. It is shown that UV emission from nitrogen plasma generated by liberated electrons is a good indication of the local electric field at the antenna tip. Using this method resonant properties of antennas fabricated on high resistivity silicon are investigated in the strong field regime. Decrease of antenna array Q-factor due to ultrafast carrier multiplication in the substrate is observed.

15:00 **High Power Terahertz Emission At Plasma And Double Plasma Frequencies During REB-Plasma Interaction** **H2B-4**

Andrey Arzhannikov; Alexandr Burdakov; Vladimir Burmasov; Ivan Ivanov; Alexandr Kasatov; Sergey Kuznetsov; Maksim Makarov; Konstantin Mekler; Sergey Polosatkin; Vladimir Postupaev; Andrey Rovenskikh; Stanislav Sinitsky; Vladislav Sklyarov; Vasilii Stepanov; Igor Timofeev; Leonid Vyacheslavovj

Studies of plasma emission in terahertz band during interaction of an intense relativistic electron beam (REB) with plasma have considerable interest as bases for creation of high power terahertz generators on new fundamental principles. Strong plasma turbulence pumped by the beam at presence of magnetic field can generate sub-terahertz and terahertz radiation with frequencies close to the upper- hybrid plasma frequency and at its double value. To study the plasma emission processes in these frequency bands we have created the specialized GOL-PET facility (PET -- plasma emission of terahertz). The GOL-PET facility consists of a device to produce a plasma column with the density (2×10^14 ÷ 5×10^15) cm^(-3) in magnetic field up to 4.5 T and the accelerator U-2 that generates an electron beam with its current density (1 ÷ 4) kA/cm^2 in the plasma at the

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

electron energy above 0.6 MeV. The pulse duration of the beam is 6 μs. The diameter of the plasma column is 5 cm and its length is 2.5 m. The plasma density is measured by a CO2-interferometer and by a multichannel Thomson scattering system. The beam current is measured by pulse current transformers and the energy of the injected beam electrons is defined from measurements of the voltage of an accelerator diode. Energy deposition of the electron beam in the plasma is calculated from measurements by diamagnetic probes distributed along the plasma column. The electromagnetic wave emission from the plasma is analyzed by an eight-channel polychromator and a dual-channel polarimeter. The total energy content in the microsecond pulse of the terahertz radiation is measured by a calorimeter from Thomas Keating Limited. In the experiments we have recorded the temporal dynamics of spectrum and polarization of THz radiation at the upper- hybrid plasma frequency and at its double value for various plasma and beam parameters. The specific power density of the radiation reaches the level ~ 1 kW/cm^3 in 0.2 ÷ 0.6 THz frequency band. The spectral power density this terahertz radiation is located close to the upper-hybrid plasma frequency (220 ÷ 260 GHz) and at its double value (430 ÷ 480 GHz). Results of experimental studies at the GOL-PET facility will be presented in this paper.

15:15 **Optical Depolarization In Liquids And Second Harmonic Generation From The Surface Induced By Intense THz Pulses** **H2B-5**

Sergey Bodrov; Aleksey Murzanev; Yury Sergeev; Yury Malkov; Andrey Stepanov

The terahertz Kerr effect and terahertz induced optical second harmonic generation from the surface of different materials were investigated using intense THz pulses. Terahertz Kerr nonlinear coefficients and relaxation times for several liquids were measured. The significant increase of the optical second harmonic signal when strong THz field was applied were demonstrated and discussed theoretically.

14:00 - 15:30 **H2C - 11 - Metamaterial Structures and Applications VI** **Lecture Theatre 4**

Chairpersons: Yusuke Kajihara;

14:00 **Epsilon-Near-Zero Lens For Beamshaping Of Sub-Terahertz Waves** **H2C-1**

Víctor Torres; Víctor Pacheco-Peña; Bakhtiyar Orazbayev; Jorge Teniente; Miguel Beruete; Miguel Navarro-Cia; Mario Sorolla; Nader Engheta

The focal properties and radiation characteristics of an epsilon-near-zero metamaterial lens are investigated numerically and experimentally in the D-band. The experimental focusing enhancement of the lens is ~16 dB. The directivity of the lens antenna configuration at 144 GHz is ~18 dBi and the corresponding gain scan loss below 3 dB is achieved for angles up to ±15 deg.

14:15 **Active Modulation Of Terahertz Wavefront** **H2C-2**

Yan Zhang; Xinke Wang; Jingwen He; Zhenwei Xie

Terahertz (THz) radiation has attracted a lot of attentions due to its fascinating potential applications. Wavefront modulation of the THz radiation will benefit the applications of THz imaging and communication. We propose a novel approach to actively modulate the wave-front of the THz radiation based on the THz hologram formed with photon-generated carriers. The diffracted THz beam will come into special amplitude and phase distribution. Experiment results demonstrate the validity of this new method.

14:30 **Time-domain High-speed Read-out Of Terahertz Resonator Arrays With Sub-single-resonator Resolution** **H2C-3**

Michael Nagel; Christopher Matheisen; Simon Sawallich

Planar resonator arrays are becoming increasingly important for THz sensing applications. Minute amounts of sample substances placed at the array surface can be detected with orders of magnitude enhanced sensitivity compared to pure transmission because of resonator-induced local field enhancement. However, for further optimization of sensitivity and read-out speeds as well as advanced scientific investigations of sub-wavelength-scale EM properties, a non-invasive method for high-resolution field sampling is required. In this work, we demonstrate photoconductive microprobes for the high-resolution and high-speed near-field read-out of resonator arrays at acquisition speeds of up to 3 ms/resonator.

14:45 **Plasmonic Metasurfaces: From Perfect Absorption To Phase Modulation** **H2C-4**

Jiaming Hao

In this work, we developed a theoretical model for the MIM resonator configuration based on temporal coupled-mode theory. The model incorporates a full description of the scattering properties (including both amplitude and phase) of the structure, and can predict a general criterion that tailors the system as perfect absorber or full-range phase modulator via tuning coupled-mode parameter -- the absorptive quality factor Qa and the radiative quality factor Qe. it is found that the single-port resonator system presents a sequence of interesting characteristics. As Qa increases, the system first acts as over-damped resonator with limited reflection phase range variation till Qa is equal to Qe. At the critical matching point (Qa=Qe), no reflection is obtained for the system, it behaves as perfect absorber. When the absorptive quality factor goes on increasing, the functionality of the system has been transformed again to use as under-damped oscillator with full-range phase variation and high reflection properties. In short, The competitions between two Q factors can generate a variety of physical effects discovered previous based on MIM systems with different geometries. The competitions between the two Q factors can generate a variety of physical effects discovered previously based on MIM systems with different geometries. Finite-difference- time-domain (FDTD) simulations and terahertz experiments were also performed to demonstrate our ideas.

15:00 **Flexible Film With Paired Cut Wires For A Uniquely High FOM Above 300** **H2C-5**

Koki Ishihara; Yuki Takebayashi; Takehito Suzuki

Wireless communication in the terahertz waveband is progressing by synthesizing unique compounds including man-made metamaterials. However, it has still not been fully shown how metamaterials can be the basis for structures with a high refractive index and no reflection or how they could lead to potential metadevices. Here we achieve a uniquely high potential of figure of merit (FOM=Re(n)/Im(n)) above 300 at 0.29 THz by a flexible film structure consisting simply of cut wires. The results here offer a way ahead for many applications with on-demand electromagnetic properties.

15:15 **Launching Terahertz Surface Wave With Desired Directions** **H2C-6**

Xueqian Zhang; Yuehong Xu; Zhen Tian; Jianqiang Gu; Chunmei Ouyang; Weili Zhang; Jiaguang Han

Polarization-switchable anomalous SW launching are experimentally demonstrated in a terahertz metasurface platform. The findings illustrate the significance of not only the phase control in SW launching, but also the near-field microscopy in understanding of the interactions between electromagnetic wave and subwavelength structures. Besides, we also find that this unique approach would enable promising applications in polarimetry and refractive index sensing. The proposed mechanism in the terahertz frequencies could also be expanded to the other bands of the broad electromagnetic spectra.

Monday, August 24, 2015

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

14:00 - 15:30 **H2D - 08 - Sources, Detectors, and Receivers VIII** **Lecture Theatre 6**

Chairpersons: Gerd Gantenbein;

14:00 **Superconducting Detectors For Terahertz Imaging** **H2D-1**
Jian Chen
Superconducting detectors based on niobium nitride (NbN) hot electron bolometers (HEBs) have been studied for terahertz (THz) imaging. The performances of HEB as the heterodyne mixers and direct detectors are reported.For the performance as a heterodyne mixer at 0.65 THz, the system DSB noise temperature of less than 550 K and the intermediate frequency (IF) gain bandwidth (GBW) of higher than 3.5 GHz have been obtained at 4.2 K and 0.65 THz.For the direct detector, a method initially used for enhancing the stability of HEB mixer was used for driving the HEB by the microwave injection, which has a frequency less than the IF-GBW and can drive the HEB detector to its optimum operating region immediately. The noise equivalent power (NEP) of better than 14 pW/√Hz and the responsivity of higher than 3 kV/W at the optimum region were estimated around 0.65 THz. The linear response was also obtained with the help of a THz signal source and a wire grid.

14:30 **First Absolute Power Measurement Of A Terahertz Time Domain Spectroscopy System Based On InGaAs/InAlAs Photoconductors** **H2D-2**
Björn Globisch; Roman J. B. Dietz; Andreas Steiger; Werner Bohmeyer; Thorsten Göbel; Martin Schell
We present the first absolute power measurement of a photoconductive terahertz (THz) emitter developed for time domain spectroscopy. The broadband THz radiation is generated by a high mobility InGaAs/InAlAs multilayer heterostructure photoconductive emitter packaged into a fiber-coupled housing. For detection a recently developed ultrathin pyroelectric thin-film detector with special conductive electrodes is employed. The detector signal is traceable to the International System of Units since the power responsivity of the detector was calibrated with a standard detector at the German national metrology Institute (PTB). Absolute THz power exceeding 0.1 mW was detected.

14:45 **Nanovircator: Promising THz Electromagnetic Radiation Source** **H2D-3**
Nikita Frolov; Semen Kurkin; Alexey Koronovskii; Alexander Hramov
We suggest the new approach of sub-THz and THz signals generation based on intense electron beams containing oscillating virtual cathode. In this work we discuss the results of numerical simulation and optimization of the novel device called "nanovircator" that have been carried out. The results of the numerical study show the possibility of ``nanovircator'' operation at 0.1-0.4 THz frequency range.

15:00 **Nanostructured Interdigitated Electrodes For Microlensless Photoconductive Terahertz Emitters** **H2D-4**
Abhishek Singh; S. S. Prabhu
A new design for interdigitated photoconductive antenna (iPCA) has been studied. Using the plasmonic electrode techniques for photoconductive THz sources, we were able to design this new electrode designs for iPCA, which does not require microlens focusing and is much easier to fabricate in comparison to other alternatives of microlensless iPCAs. It is more than 3 order more efficient than usual PCA and almost an order more efficient than plasmonic PCA at 750 mW optical excitation.

15:15 **High Quality Beams Of MV/cm THz Pulses Generated From DSTMS** **H2D-5**
Pernille Klarskov; Peter Uhd Jepsen
The recent development of THz sources has led to studies of nonlinear effects induced by intense THz pulses. Organic crystals such as DSTMS have been demonstrated to produce very high pulse energies of more than 100 μJ, which, with the advantage of a collinear phase matching geometry, easily can be focused to achieve tens of MV/cm. For most experiments within spectroscopy, imaging and z-scan techniques, the beam profile of the incident beam plays an important role. For visible and NIR beams this is typically characterized by a beam scan where a CCD or CMOS camera is scanned through the focal plane and the beam shape and radius is measured as function of z distance. However, due to the limited availability of cameras sensitive to THz radiation, the number of full beam characterizations in the THz range has been limited. Now, the recent development of THz cameras has opened the possibilities for beam characterization in the same way as what is typically performed with visible and NIR beams. Here, a characterization of a THz beam profile generated from a DSTMS crystal is presented, where a M2 values less than 1.5 are achieved.

14:00 - 15:30 **H2E - 19 - Laser Driven THz Sources II** **Lecture Theatre 7**

Chairpersons: Richard J. Temkin;

14:00 **Coherent Radiation Sources Based On Laser Driven Plasma Waves** **H2E-1**
Dino Jaroszynski
In this talk we will explore ways of converting laser radiation to coherent electromagnetic radiation using laser-driven plasma waves. Several schemes will be explored, including colliding laser pulses in magnetized plasma and utilizing ultra-short electron bunches from laser wakefield accelerators to produce intense single-cycle pulses through coherent transition radiation and few-cycle coherent synchrotron radiation in undulators and plasma channels. These sources rely on high current electron bunches with femtosecond durations, which result in radiation over a broad range of frequencies from 1 to 10^5 THz.

14:30 **Tunability Enhancement Of Injection-seeded THz Parametric Generator** **H2E-2**
Kosuke Murate; Kazuki Imayama; Shin'ichiro Hayashi; Kodo Kawase
Recently, the output power of injection-seeded THz-wave parametric generator (is-TPG) was improved drastically. It already reached few tens of kW@peak. However, the tuning range was limited. In this paper, we report the improvement of the is-TPG tuning range. Suppression of THz-wave absorption in the crystal by total reflection of a portion of the pump beam at the crystal surface increased the upper limit of the tunable range from 3.0 to 4.7 THz.

14:45 **Terahertz Wave Emission From Dual Color Laser-Induced Microplasma** **H2E-3**
Fabrizio Buccheri; Xi-Cheng Zhang
We investigated the THz emission from a microplasma induced by a dual color laser field. The addition of the second color significantly enhances the generated terahertz (THz) radiation up to directions perpendicular to the laser propagation axis. Unlike with elongated plasmas, we were able to observe the interplay between two THz generation driving mechanisms: ponderomotive force and AC biasing of the plasma.

08:45 - 09:15 **Welcome and Opening Remarks** — **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

15:00 **Studies Of Powerful Terahertz Radiation From Laser-Produced Plasmas** — **H2E-4**

Yutong Li; Guoqian Liao

Recently Terahertz radiation from laser-produced plasmas has attracted much interest since plasmas can work at arbitrarily high laser intensity. We will present the generation of strong THz radiation from femtosecond and picoseconds relativistic laser-plasma interactions. THz pulses with energies up to >200 microJ/sr have been demonstrated. The temporal waveform, polarization, and angular distribution are measured. We find that the radiation depends on the preplasma density scale length. The THz radiation is probably attributed to the self-organized transient fast electron currents formed along the target surface when the plasma density profile is steep, while, the linear mode conversion when a large preplasma is formed.

15:15 **Study Of THz Emission From Ring-Airy Beam Induced Plasma** — **H2E-5**

Kang Liu; Dimitrios Papazoglou; Anastasios Koulouklidis; Stelios Tzortzakis; Xi-Cheng Zhang

We experimentally investigated the THz emission from two-color ring-Airy beam induced plasma in the ambient air. The results show that this exotic autofocusing beam tends to form an elongated weak filamentation with a main peak at the front and a 'tail' with certain oscillations following, which leads to a higher THz yield and a slightly narrower THz spectrum than the emission from a Gaussian beam plasma under the same circumstances.

16:00 - 17:30 **H3A - 19 - Laser Driven THz Sources III** — **Lecture Theatre 2**

Chairpersons: George Neil;

16:00 **THz Emission From Graphene Induced By Dynamical Photon Drag** — **H3A-1**

Juliette Mangeney; Jean Maysonnave; Simon Huppert; Feihu Wang; Claire Berger; de Heer Walt; Ted Norris; Louis-Anne De Vaulchier; Sukhdeep Dhillon; Jerome Tignon; Robson Ferreira

We demonstrate broadband coherent THz emission at room temperature from epitaxial graphene under femtosecond optical excitation induced by photon drag effect. We interpret the emitted THz radiation characteristics with a model describing the electron and hole states beyond the usual massless relativistic scheme. This second-order nonlinear effect relies on the dynamical transfer of light momentum to the carriers by the ponderomotive electric and magnetic forces. Finally, our results indicate that optical rectification in graphene can provide emission up to 60 THz, opening new routes for the generation of ultra-broadband THz pulses at room temperature.

16:30 **Ultra-intense Laser-Driven Target Normal Sheath Radiation In The Terahertz Region** — **H3A-2**

Zhan Jin; HongBin Zhuo; Junghun Shin; Noburo Yugami; MingYang Yu; ZhengMing Sheng; Ryosuke Kodama

Ultra-intense radiation in the terahertz (THz) regime emitted from the rear side of laser-irradiated solid target is experimentally investigated using a 20 TW fs laser system. The THz radiation emitted in a conical angle around 45 degrees is of radially polarized and has its duration of tens of ps. The waveform, angular distribution, polarization and laser intensity dependence of the observed radiation are in good agreement with those predicted for the radiation from deceleration of >sub-MeV electrons passing through the sheath electric field behind the target.

16:45 **Optical Generation Of Terahertz Based On All Fiber Highly Coherent Optical Parametric Light Source** — **H3A-3**

Sigang Yang; Xiaojian Wang; Chen Jin; Donghui Jin; Hongwei Chen; Minghua Chen; Shizhong Xie; Sigang Yang

Narrow band Terahertz generation based on an all fiber, highly coherent pump light source derived from fiber optical parametric process is reported. A pair of phase conjugated beams with high coherence and narrow bandwidth are generated via all fiber parametric process as the seed light. The amplified highly coherent light beam is injected into DSTMS to stimulate the emission of Terahertz radiation. A terahertz wave with the frequency of 1.25 THz and linewidth less than 512 MHz is generated.

17:00 **Simulation Of Laser Pulse Driven Terahertz Generation In Corrugated Plasma Channels** — **H3A-4**

Chenlong Miao; John Palastro; Andrew Pearson; Thomas Antonsen

Intense, short laser pulses propagating through inhomogeneous plasma generate THz radiation. Full format PIC simulations and theoretical analysis are conducted to investigate two mechanisms of ponderomotively driven THz radiation: a transition radiation mechanism (TRM) occurring as a laser pulse crosses a plasma boundary, and a slow wave phase matching mechanism (SWPM) that occurs in corrugated plasma channels. TRM is generated at vacuum plasma boundary and SWPM occurs in corrugated channels. Terahertz radiation from SWPM generally increases with channel length and by reducing density. In contrast, THz energy from TRM is insensitive to the plasma length and density above 1.5*10^18/cm^3 and and can be further modified by adding a density upward or downward ramp. One can see both ponderomotively driven THz generation can be enhanced by increasing the laser intensity in our results. We've achieved an energy conversion efficiency of approximate 6% for the THz generation and this could be further modified by varying density profiles of the plasma channel. As an example, a fixed driver pulse (1.66 J) in a short 500-micrometer-long modulated channel, the THz radiation is 33.6 μJ and 83.7 μJ from TRM and SWPM, respectively. THz generated from SWPM in centimeter-long channels typically created in the experiment will be simulated.

17:15 **Spectrum And Polarization Of THz Radiation From Two-color Femtosecond Laser Breakdown: Theory And Experiment** — **H3A-5**

Mikhail Esaulkov; Vera Andreeva; Vladimir Makarov; Petr Solyankin; Alexander Shkurinov; Olga Kosareva; Nikolay Panov; Daniil Shipilo

We present a comprehensive experimental and numerical study of spectral, spatial and polarization features of the widely used THz source -- plasma of optical breakdown by a two-color femtosecond laser. We show experimentally presence of high-frequency component of THz radiation related to response of neutral gas molecules. Taking into account evolution of phase and polarization of optical pulses propagating through plasma allows to account for the experimentally observed polarization and spectrum of the emitted pulse.

16:00 - 17:30 **H3B - 05 - Spectroscopy and Material Properties VI** — **Lecture Theatre 3**

Chairpersons: Vincent Wallace;

16:00 **Magnon Polariton And Psudo-Magnon-Polariton** — **H3B-1**

Can-Ming Hu; Bimu Yao; Sandeep Kaur; Yongshen Gui; Wei Lu

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Experimental realization of magnon-photon coupling in microwave cavity is leading to a new field of cavity spintronics, which paves new ways for microwaves and materials applications utilizing magnon polariton and pseudo-magnonpolariton. In this paper, we will briefly review our recent work in this frontier of condensed matter and wave physics by addressing the following topics: (1) cavity magnon-polariton, (2) voltagecontrolled pseudo-magnon-polariton for creating tunable electromagnetically induced transparency (EIT) and (3) characterization of magnetic nanoparticles (MNP) by using magnonphoton coupling effect. These results will be presented and demonstrate how the research of the fundamental physics can pave new ways for practical applications. For more information and references, please check our group website at: http://www.physics.umanitoba.ca/~hu/

16:30 **THz Emission From InP And InGaAs Nanowires Fabricated Using Electron Beam Lithography** **H3B-2**

Soner Balci; Ju-Hyung Kim; David Czaplewski; Il Woong Jung; Fariba Hatami; Patrick Kung; Seongsin Margaret Kim

THz emission from semiconductor nanowires has been an emerging trend since nanowires exhibit an increase in optical absorption by having a much larger effective surface area than films. The efficient THz emission is related with strong local field enhancement by coherent surface plasmons. In this work, we investigated THz generation from nanowires fabricated through a process that includes e-beam lithography and plasma etching, fully control on structural geometry such as the diameter, length, excellent-vertical alignment, and perfectly-uniform distribution.

16:45 **THz Near-field Nanoscopy Of Graphene Layers** **H3B-3**

Damien Ducatteau; Jean-Francois Lampin; Dominique Vignaud; Geetanjali Deokar; Antoine Pagies

Far-field terahertz imaging is limited by diffraction to low resolutions in the 50 μm range. On the other hand, near-field optical nanoscopy is a recent technique that shows permittivity contrasts at the nanoscale. We present here images of graphene layers on SiO2 obtained by scattering scanning near-field nanoscopy at 2.5 THz that show high contrasts.

17:00 **Charge Carrier Dynamics In Benzoporphyrin Thin Films Investigated By Time-Resolved THz Spectroscopy** **H3B-4**

Kaoru Ohta; Sho Hiraoka; Yuto Tamura; Hiroko Yamada; Keisuke Tominaga

Conjugated organic semiconductors have been extensively studied because of promising applications for bulk heterojunction solar cells. In order to improve a power conversion efficiency of such materials, it is indispensable to understand the detailed mechanism of charge generation, recombination, and charge carrier mobilities. In this study, we performed optical pump-terahertz (THz) probe measurements to investigate the charged carrier dynamics of benzoporphyrin (BP) thin films. For measuring the dynamics in a broad THz range, the THz probe pulses were generated by a laser-induced plasma and sampled by an air-biased coherent detection. From analysis of the transient spectra in THz region, it is possible to obtain information on the degree of localization of photo-generated charge carriers. We measured the photo-induced change of THz electric field amplitude as a function of pump-probe delay with excitation at 400 nm. The transient signal has an instantaneous rise due to the formation of mobile charges (polarons). The signal decays within a few picosecond and a small long-lived component remains. This result suggests that most of mobile charges recombine on this time scale. From analysis of the transient complex conductivity spectra, we found that the conductivity spectra can be well reproduced by Drude-Smith model. This means that generated charged carriers are rapidly localized by preferential backscattering.

17:15 **Magnetic Field Induced Spin Reorientation Transition In YFeO3 Probed With THz Spectroscopy** **H3B-5**

GuoHong Ma; Junjie Jiang

By using terahertz time-domain spectroscopy (TDS), we systematically investigate the spin reorientation transition (SRT), a switching of macroscopic magnetization rotated by 90º, in YFeO3 single crystal triggered by magnetic field. Our results suggest that the chosen of R would tailor the dynamical rotation properties of Fe ions, leading to the designable spin switching in the orthoferrite antiferromagnetic systems.

16:00 - 17:30 **H3C - 03 - Applications in Security and Defense - 24 - Applications in Art Conservation studies** **Lecture Theatre 4**

Chairpersons: Zengxiu Zhao;

16:00 **Terahertz Time-domain Imaging Of A 17th Century Lacquered Cabinet: A Contribution To European Lacquerwares Characterization** **H3C-1**

Corinna Ludovica Koch Dandolo; Vincent Cattersel; Peter Uhd Jepsen

A late 17th century white European lacquered cabinet, stylistically attributed to the Gérard Dagly workshop and belonging to the Barbara Piert-Borgers private collection of Far-East and European lacquerware, has been investigated by means of terahertz time domain imaging (THz-TDI), giving new insights into its composition. The peak-to-peak THz image highlights certain heterogeneity within the area (dark greyish areas), not connected to the decoration apparatus of the art-piece. A frequency analysis of the THz image confirms that these stains have a different behavior compared to the adjacent areas. To gain a better understanding of the true nature of the stains appearing in the terahertz images, and relate and localize them within the lacquerware stratigraphy, B-scans have been realized after signal deconvolution. B-scans of interest show no significant changes in the cabinet stratigraphy where the stains are located, compared to that of the adjacent areas. The THz signals arising from the reflection at the air/cabinet interface are often observed to split at the locations of the stains. This suggests the presence of an additional surface material in those areas. Additionally, changes in the moisture content within the wooden panel cannot be excluded. Finally, the THz image of the wooden support located underneath the lead-white ground layer has been clearly imaged. This confirms the capability of THz-TDI in imaging subsurface features behind lead white layers, differently than X-radiography, where the lead-white efficiently shields X-rays because of high Pb stopping power.

16:15 **Cyclododecane As A Reversible Contrast Enhancer For The Terahertz Imaging Of Frescos** **H3C-2**

J. Bianca Jackson; Tom Owen; Gillian Walker; John Bowen; David Giovannacci; Dominique Martos-Levif; Vincent Detalle

CYCLODODECANE (CDD) is a wax-like cyclic hexane (C12H24) commonly used by art conservators as a volatile binding medium to consolidate and protect works of art with delicate, porous or friable surfaces during their transportation or cleaning [1]. It is particularly useful for this purpose because--in addition to being easily applicable, durable and water resistant--it is completely reversible and sublimates away at room temperature over the course of some weeks or months, leaving no residues or need for mechanical or chemical removal. A region of a fresco was scanned twice; the first time, fine, human, facial features were subtly revealed; the second, 3 months later, only coarse, nebulous features could be detected. We postulate that the visible presence of cyclododecane (CDD, a consolidant used as a part of the cleaning process to protect the pigment from the white spirit) during the first experiment improved the transmission of terahertz radiation through the plaster top layer and enhanced the contrast between the plaster and the pigment. Follow-up work includes an extensive study of traditional plasters and pigments treated with different CDD preparations), using terahertz dispersive Fourier-transform spectroscopy (THz-DFTS). It is

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Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

believed that the CDD serves as an index-matching medium, replacing air in the porous plaster-matrix, thus reducing scattering and improving signal to noise. As a well-characterised, non-destructive, volatile medium, this application of CDD could significantly progress the THz imaging of covered wall paintings.

16:30 **Terahertz Time Of Flight Imaging Of Hidden Layers In Oleo Paintings** **H3C-3**

A. M. Gomez-Sepulveda; A. I. Hernandez-Serrano; E. Castro-Camus

In this work we use the echoes of THz radiation pulses reflected from multilayer systems in order to find hidden layers in an oleo on canvas painting. We fit the reflected waveforms to a superposition of various echoes using a least square algorithm in order to separate overlapping pulses owing to reflections in sub wavelength layers.

16:45 **Non-destructive Inspection Of Chemicals In Mail Envelopes Using An Injection-seeded Terahertz-wave Parametric Generator** **H3C-4**

Ryo Yamazaki; Mikiya Kato; Kosuke Murate; Kazuki Imayama; Kodo Kawase

The injection-seeded terahertz parametric generator (is-TPG) is suitable for the non-destructive inspection of illicit drugs and explosives concealed in mail because of its high power generation and sensitive detectors. This study examined a terahertz (THz) spectrometry method suitable for the non-destructive detection of chemicals concealed in mail envelopes. We compared the transmission spectra of three saccharides in different covering materials using is-TPG and terahertz time-domain spectroscopy (THz-TDS)

17:00 **On The Development Of A Quasi-optical System For Short And Long Range Standoff Imagers** **H3C-5**

Erio Gandini; Jan Svedin; Tomas Bryllert; Nuria Llombart

The design of the opto-mechanical system for standoff security imagers is driven by different constraints depending on the chosen frequency and imaging distance. THz frequencies are often chosen because they can penetrate the cloths and the size of the optic system is smaller compared to lower frequency solutions. A given linear field of view (FOV) corresponds to a relatively small angular FOV for large ranges and a large angular FOV for short ranges. Since large apertures are required to achieve a satisfactory resolution in long range systems, a scanner is typically placed before the main reflector and a large optical magnification is necessary. This implies additional scan loss due to the scanner rotation. In a short range system, good resolution can be achieved with a relatively small primary aperture, and the scanner can be placed after the main reflector, without introducing additional beam aberrations. In both short and long range systems, the use of a focal plane array (FPA) can drastically improve the frame rate if compared to single pixel solutions. The issue is to illuminate the optics with low scan loss for off-focus feeds.

In this contribution, an optical system that can operate at both short and long ranges is presented. The short range system is based on a Dragonian dual-reflector architecture and the scanner is placed after the main aperture. A linear sparse FPA of 8 active transceivers is used to feed the reflectors. The same Dragonian system is used to illuminate a confocal dual-reflector architecture. The latter has a larger main aperture allowing good resolution at a larger focal distance.

16:00 - 17:30 **H3D - 12 - Devices, Components, and Systems V** **Lecture Theatre 6**

Chairpersons: Gun-Sik Park;

16:00 **Rapid Prototyping Lightweight Millimeter Wave Antenna And Waveguide With Copper Plating** **H3D-1**

Ruoyu Zhu; Danial Marks

We present a novel method of rapid prototyping waveguide and antenna using plating on plastic technique. The part is created by high precision 3D printing and plated with copper using both electroless plating and electroplating. The performance is comparable with industry made waveguides and antennas but the time and cost for creating these parts are largely reduced.

16:15 **High Efficiency Superconducting Nanowire Single Photon Detector At Wavelength 940 Nm** **H3D-2**

Yajun Chen; Min Gu; Labao Zhang; Lin Kang; Peiheng Wu

Superconducting nanowire single photon detectors with an optical resonant cavity structure are fabricated directly on the single crystal substrate. In order to enhance the photons absorption of incident light and improve system detection efficiency (SDE) efficiently, the structure of SNSPD was designed and optimized using the finite-difference time-domain analysis for different kinds of substrates. The NbN-SNSPDs fabricated on different substrates are measured and compared. The SDE of NbN-SNSPD on MgO substrate reaches 66 % at the wavelength of 940nm at a dark count rate of 100 cps by illuminating from the back of the device through single mode optical fiber.

16:30 **An Active Terahertz Magneto-plasmonic Device Based On A Cobalt Aperture Array** **H3D-3**

Barun Gupta; Shashank Pandey; Ajay Nahata

Within the field of plasmonics, there has been significant work in demonstrating that the structure imparted to an otherwise planar metal film can give rise to a broad range of different responses. However, once such a structure has been fabricated, the response is typically fixed. One approach to allowing for allowing control over the response after the structure has been fabricated involves the use of ferromagnetic materials in the structure, which correspond to the excitation of magneto-plasmons. Until now, the bulk of the experimental work in this area has focused on developing devices that have been interrogated at optical frequencies [1]. In the presence of the external applied magnetic field, the propagation properties of the surface plasmons are altered such that an isotropic response, for example, becomes anisotropic. In the presence of a longitudinal magnetic field, this response is typically linear in the applied magnetic field. However, when the magnetic field is transverse to the propagation direction of the interrogating radiation, the response is typically quadratic. In this submission, we demonstrate that although we use a transverse magnetic field, the variation in transmission using a periodic aperture array is dramatically larger than equivalent studies at optical frequencies in any geometry. To demonstrate this, we fabricated a periodic aperture array in a free-standing stainless steel metal foil. We then uniformly coat the structure with a ~1μm thick gold film on all sides. The array consists of 750 μm diameter apertures periodically spaced by 1.5 mm on a square lattice fabricated in a 75 μm thick metal foil. Since the skin depth of gold is ~150 nm, the gold film is much thicker than two skin depths, such that surface plasmons do not see the underlying medium (stainless steel). We use a commercial cw THz spectroscopy system that can scan from 0.05 -- 1.5 THz. Given that the lowest order transmission resonance has a peak at 0.174 THz, independent of the metal coating, we only scan in a + 20 GHz range about that peak as a function of the applied magnetic field. The observed transmission properties are shown in Figure 1 below. In both sets of data, the percent amplitude change is given by (Emagnetic -- E0)/E0, where Emagnetic is the transmitted THz radiation in the presence of the magnetic field and E0 is the transmitted THz radiation in the absence of magnetic field. In the case of the gold array, we observed a maximum change of ~0.21 %, but there

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Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

was no clear trend and no observed no hysteresis. However, we observed a large (~5%) change when the array was coated with cobalt. We discuss the variation in the response and potential applications that may arise from such structures.

16:45 **Ultra-high Extinction Tri-layer Thin-film Wire-grid THz Polarizer** **H3D-4**

Zhe Huang; Hau Ping Chan; Edward Philip John Parrott; Yuk Tak Chow; Emma Pickwell-MacPherson

The terahertz (THz) waves generated by time-domain spectroscopy (TDS) usually have mixed polarizations. Thus, a THz polarizer can be used to remove unwanted minor polarizations [1] and facilitate the characterization of birefringent materials and devices in THz spectrum. Currently, there are two major issues challenging the development of THz polarizers. The first is the multi-reflection issue which occurs when the THz wave passes through THz polarizers with a thick supporting substrate: this eventually induces signal interference in the THz spectrum. The second challenge is that it is difficult to achieve a high extinction ratio while keep a low transmission loss. To tackle both these issues, a THz polarizer (SLP) with a single-layer aluminum (Al) grid on a thin-film silica substrate [2] was proposed firstly -- it achieved no multi-reflections (up to 20 THz) and low transmission loss (below 0.8 dB for 0.2-2.0 THz). However, its extinction ratio was limited and comparable with the commercial products (about 30 dB at 1 THz). Then, a THz thin-film polarizer (BLP) with a bilayer Al grid structure [3] was recently reported. This achieved a much higher extinction ratio (above 50 dB for 0.2-1.1 THz). In this paper, a thin-film THz polarizer based on a tri-layer wire-grid structure is studied to further increase the extinction ratio. An ultra-high extinction THz polarizer with a tri-layer wire-grid structure was proposed here. The performance of the THz polarizer was theoretically evaluated through FEM software (HFSS). The designed tri-layer polarizer has an extinction ratio greater than 90 dB at 1 THz, which is the highest as far as the authors' knowledge. Moreover, the polarizer performance tuned by the lateral phase shift is studied. The polarizer is currently in the progress of fabricating. This work was supported by the Strategic Research Grant (SRG NO. 7004055) of the City University of Hong Kong. References: [1]. H. Park, E. P. J. Parrott, Z. Huang, H. P. Chan, and E. Pickwell-MacPherson, "Accurate photoconductive antenna characterization using a thin film polarizer," Appl. Phys. Lett., vol. 101, 121108 2012. [2]. Z. Huang, H. Park, E. P. J. Parrott, H. P. Chan, and E. Pickwell-MacPherson, "Robust Thin-Film Wire-Grid THz Polarizer Fabricated Via a Low-Cost Approach," IEEE Photon. Techn. Lett., vol. 25, pp. 81--84, 2013. [3]. Z. Huang, E. P. J. Parrott, H. Park, H. P. Chan, and E. Pickwell-MacPherson, "High extinction ratio and low transmission loss thin-film terahertz polarizer with a tunable bilayer metal wire-grid structure", Opt. Lett., vol. 39, pp. 793--796, 2014.

17:00 **Passive Electric Monopole Array For Terahertz Surface Wave Launcher** **H3D-5**

Daniel Headland; Mohammad Taha; Philipp Gutruf; Withawat Withayachumnankul; Madhu Bhaskaran; Christophe Fumeaux; Derek Abbott; Sharath Sriram

Micron-scale passive grounded quarter-wave electric monopole antennas can be constructed by direct-drawing a polymer into micropillars, followed by metallization. This technique is proposed for the realization of a homogeneous 2D array of passive electric monopoles, with an operating frequency of 500 GHz. The array utilizes grating lobes, as opposed to phased array techniques, to couple obliquely incident radiation to a surface wave in the transverse plane. Numerical simulations verify the operation of the antenna array as a surface wave launcher.

17:15 **A 4-Way 0.11THz Power Synthesizer Based On IMPATT Source** **H3D-6**

Zhongbo Zhu; Xiaojun Li; Qinggui Tan; Wei Jiang; Dong Liang; Shuantao Li

The lack of high frequency source with a simple structure and enough power output at THz band limits the development of tera-hertz technology. As a result achieving high-power THz radiation has attracted many efforts. In this paper, we investigate the possibility of power synthesis at 0.11THz based on discrete sources. The simulation and test results show that with a precision digital phase control, A power synthesizer at 0.11THz can be achieved. For demonstration, we implement a 0.11THz prototype system employing solid-state impact avalanche and transit time (IMPATT) diodes. Maybe the method has a wide foreground in THz at higher frequency by increasing the digital bit width.

16:00 - 17:30 **H3E - 01 - Astronomy and Environmental Science - 23 - Planetary and Earth Science Applications** **Lecture Theatre 7**

Chairpersons: Kiyomi Sakai;

16:00 **The Development Of Infrared Remote Sensors For Chinese Meteorological Satellites** **H3E-1**

Lei Ding; Wei Lu

Meteorological satellites have become an irreplaceable weather and ocean observing tool. There are totally 13 meteorological satellites that were launched into both sun-synchronous and geostationary orbit in China. All the satellites have been incorporated into the global constellations of operational meteorological satellites within the WMO framework. More satellites are under construction to be the second generation ones. Infrared remote sensors are the main payloads on-board each satellite. Recently, there are four type of infrared sensors which are carried aboard each platform of the second generation polar orbiting meteorological satellite (FY-3): the Visible and Infrared Radiometer (VIRR), Medium Resolution Spectral Imager (MERSI), Infrared Atmospheric Sounder (IRAS), Earth Radiation Measurer (ERM). As the results of the three launches of FY-3A, FY-3B and FY-3C satellites, three groups of these four sensors are currently operating on-orbit and providing not only the imaging data, but also the sounding data and Earth radiance budget data at the same time. MERSI surveys the earth with a ground pixel resolution of 250-metre and a swath width over 2900 km, that could get the global TIR (thermal infrared) image of 250-metre resolution twice each 24 hours. This specification improves the continuous global imaging capability from kilometer resolution to hundred-meter resolution. This improvement is distinctive in the world and very useful for the environmental monitoring. In order to enhance our understanding of the Earth system, the upgrading sensors of MERSI and IRAS, MERSI-2 and High-spectral Infrared Atmospheric Sounder (HIRAS), focusing on imaging and sounding mission separately, are developed and will be launched with FY-3D in 2016.Moreover, two type of infrared sensors, Advanced Geostationary Radiometric Imager (AGRI) and Geostationary Interfering InfraRed Sounder (GIIRS), are under construction for the new generation of the geostationary-orbit meteorological satellite (FY-4). HIRAS and GIIRS are nadir and limb viewing infrared Fourier transform spectrometers (FTS), which could be able to provide sounding data with 0.625 cm^-1 spectral resolution covering wavelengths in the midwave infrared and longwave infrared to users. While these two infrared sensors are put into operation in 2016, China may be the first country that could get high spectral infrared data from both geostationary and polar-orbiting satellites. Some tradeoffs have been made to build the infrared sensors. In accordance with specification and designing strategy, the following choices of single-pixel detector, linear detector and focal plane detectors, thermal cooler and mechanical cooler, different type of telescope, double-axis gimbaled mirror and single-axis scanning mirror, have been selected respectively. The characteristics of these infrared sensors, design overview conjoined with detector are introduced in this paper.

Monday, August 24, 2015

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

16:30 **SPACEKIDS: Kinetic Inductance Detector Arrays For Space Applications** **H3E-2**

Matt Griffin; Jochem Baselmans; Andrey Baryshev; Simon Doyle; Martin Grim; Peter Hargrave; Teun Klapwijk; Jesus Martin-Pintado; Alessandro Monfardini; Andrea Neto; Henk Steenbeck; Ian Walker; Ken Wood; Antonio D'Addabbo; Pete Barry; Aurelien Bideaud; Beatriz Blázquez; Juan Bueno; Jose-Luis Costa-Kramer; Lerenza Ferrari; Alicia Gómez-Gutiérrez; Johannes Goupy; Nuria Llombart; Stephen Yates

Kinetic Inductance Detectors (KIDs) offer excellent sensitivity in the THz region combined with ease of operation. The SPACEKIDS project is working on developments needed to enable this technology for space. It includes development of antenna-coupled and lumped-element KIDS, and of the necessary readout electronics. KID arrays have been developed for both low-background (astrophysical) and high-background (Earth-observing) applications. Two laboratory demonstrator systems are now being used to evaluate kilo-pixel array characteristics and performance in an environment representative of both astronomy (low background) and Earth observing (high-background) applications.

16:45 **10 Meter Sub-Orbital Large Balloon Reflector (LBR)** **H3E-3**

David Lesser; Chris Walker; Stefan O'Dougherty; Brandon Swift; Paul Goldsmith; I. Steve Smith; Casey Honniball; Jenna Kloosterman; Abram Young; Bill Peters; Craig Kulesa; Bill Perry; James Noll; Pietro Bernasconi; Chris Groppi; Hamdi Mani; Brian Duffy

Now in Phase II of the NASA Innovative Advanced Concepts (NIAC) Program, our team is working to use half-aluminized balloons to provide lightweight deployable optics for orbital and suborbital applications. Our primary goal is to design a ten meter class telescope for flight on one of NASA's super-pressure high-altitude balloons, thus combining the high resolving power and sensitivity of modern ground-based telescopes with the exemplary atmospheric transmission at such high altitudes. This best-of-both-worlds instrument would provide the needed means of follow-up to successful orbital missions such as Spitzer, Herschel, and SOFIA. In addition to star formation and exoplanet studies with the LBR design, we anticipate exciting applications in communications and earth sciences for smaller variants of this design, such as in a cubesat form factor.

17:00 **Terahertz Limb Sounder To Measure Winds And Temperature Above 100 Km** **H3E-4**

Erich Schlecht; Jose Siles; Jeanne Treuttel; Robert Lin; Jeng-Hwa Yee; Dong Wu; Bertrand Thomas; Imran Mehdi

We describe a new instrument, the Terahertz Limb Sounder (TLS) designed to measure upper atmospheric winds and temperature in the altitude regime between 100 and 150 km. It is based on Doppler measurements of the line of neutral atomic oxygen, OI, at 2.06 THz. This measurement takes advantage of a Schottky diode based all solid state receiver.

Friday, August 28, 2015

08:45 - 09:00 **Morning Announcements and Closing Ceremony** **Lecture Theatre 1**

09:00 - 10:30 **FP - Friday Plenary** **Lecture Theatre 1**

Chairpersons: Peter H. Siegel;

09:00 **Terahertz Communications: Past, Present And Future** **P9**

Tadao Nagatsuma

It has been about 15 years, since the first demonstration of terahertz (THz) communications using both impulse and continuous waves. To meet an ever-increasing demand for the speed of wireless communications, THz communications have recently gained lots of interest and expectation. This paper overviews a latest trend of THz communications research, and discusses the future perspective with respect to technologies, applications and standardization.

09:45 **Terahertz Materials Discovery And Integration: The Search For Novel Functionality** **P10**

Huseyin Seren; George Keiser; Jingdi Zhang; Scott Maddox; Xiaoguang Zhao; Kebin Fan; Seth Bank; Xin Zhang; Richard Averitt

The functionality of terahertz metamaterials can be dramatically increased through judicious materials integration. In addition to semiconductors, materials ranging from graphene to superconductors can enhance or enable new functionality. Following a brief review, we present recent results creating nonlinear metamaterials using InAs and YBa2Cu3O7, and discuss the broad range of possibilities to explore using transition metal oxides in the design of metamaterials.

11:00 - 12:30 **F1A - Applications in Industry II** **Lecture Theatre 2**

Chairpersons: J. Bianca Jackson;

11:00 **Laser Terahertz Emission Microscope And Its Application** **F1A-1**

Masayoshi Tonouchi

One can observe terahertz (THz) emission upon femtosecond (fs) optical pulse illumination from various materials. Scanning fs laser beam on the materials gives us an image to visualize its dynamic optical response to generate rapid generation of photocurrent. We named the system as laser THz emission microscope (LTEM). In the present work, recent progress of LTEM and its application will be reviewed.

11:30 **Curing Monitoring Of Two-Component Epoxy Adhesives At THz Frequencies** **F1A-2**

Amin Soltani; Thorsten Probst; Stefan Sommer; Martin Koch

We demonstrate real time monitoring of the curing of two-component epoxy adhesives at THz frequencies. Our method is based on THz time domain spectroscopy (TDS) in reflection geometry. We monitor the curing of two-component adhesive over ten hours and extract refractive index, absorption and thickness.

11:45 **Rapid Control Of Machined Glass Fiber Reinforced Plastics By Single Shot Terahertz Time Domain Spectroscopy** **F1A-3**

Uli Schmidhammer; Xavier Neiers; Pierre Jeunesse

We apply single shot THz Time Domain Spectroscopy to control glass fiber reinforced plastics that were machined during their production. The THz imaging reveals that the mechanical processing as hole punching introduced significant modifications to the composite structures, also beyond the directly impacted region. These changes can be precisely localized and further

08:45 - 09:15	**Welcome and Opening Remarks** **Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;**	**Lecture Theatre 1**

characterized in order to classify the types of defect. The results show that the time of flight information is particularly sensitive to changes in the complex fiber and polymer matrix network. They can be visualized and quantified with B- and C-scans. Thanks to the ultrashort duration and high repetition rate of acquisition, the single shot technology is suited for the control of composites within cycle time of industrial production.

12:00 **Impact Damage Characterization In Hybrid Fiber Composites Using Terahertz Imaging In The Time And Frequency Domains** **F1A-4**

Junliang Dong; David Citrin; Nico Declercq; Alexandre Locquet

A hybrid fiber composite laminate with impact damage has been studied via terahertz imaging. Terahertz C-scan and B-scan images are obtained in both the time and frequency domains. Factors including the terahertz polarization, fiber orientation and arrangement are considered to compare and analyze the images in an impact-damaged sample.

12:15 **Transfer Matrix Method For Precise Determination Of Thicknesses In A 150-ply Polyethylene Composite Material** **F1A-5**

Norbert Palka; Soufiene Krimi; Frank Ospald; Rene Beigang; Danuta Miedzinska

The multilayer structure of an ultra-high molecular weight polyethylene composite material was investigated in the terahertz (THz) spectral range by means of time domain spectroscopy (TDS) technique. Such structures consist of many alternating layers of fibres (~150), each being perpendicular to the other and each having a thickness of about 50 µm. A transfer matrix method and a time-domain fitting procedure were used to determine thicknesses of all layers of the composite material with high accuracy.

11:00 - 12:30	**F1B - High-Field THz Wave Generation & Nonlinear THz Physics IV** **Chairpersons: Angelo Tuccillo;**	**Lecture Theatre 3**

11:00 **Revision Of Photo-current Model Of Terahertz Wave Generation By Two-color Femtosecond Laser Filamentation In Air** **F1B-1**

Jiayu Zhao; Yizhu Zhang; Weiwei Liu

The conventional photo-current model of terahertz wave generation by femtosecond laser filamentation has been improved with taking into account the interaction between the THz pulse and the plasma inside the filament. The results given by this revised model are consistent with the macroscopic four wave mixing mode.

11:30 **Colossal Terahertz Nonlinearity Of Angstrom-sized Infinite Gaps** **F1B-2**

Young-Mi Bahk; Bong Joo Kang; Yong Seung Kim; Joon-Yeon Kim; Won Tae Kim; Tae Yun Kim; Jiyeah Rhie; Sanghoon Han; Cheol-Hwan Park; Fabian Rotermund; Dai-Sik Kim

Metal-graphene-metal hybrid structures provide the smallest possible optical gaps, through which quantum tunneling routinely occurs, making this system an ideal platform for quantum plasmonics. In this work, we manufactured angstrom sized infinite gaps of copper-graphene-copper using chemical vapor deposition system and simple adhesive tape based planarization. The angstrom gaps with a few millimeter length are applicable in broadest spectrum domain. We performed terahertz time domain spectroscopy using both oscillator- and amplifier-based terahertz system, in which the incident electric field is changed from 30 V/cm to 200 kV/cm at the focus. We observed funneling of terahertz waves through the angstrom gaps in low-field regime, which is almost completely blocked in high-field regime. The unprecedented transmission nonlinearity of 97% was induced by the electron tunneling across the angstrom gap, which modifies the effective dielectric constant of the fictitious material inside the gap. Our work opens up long wavelength quantum plasmonics and angstrom optics.

11:45 **Extreme Terahertz Brightness By Focusing To A Lambda-cubic Volume** **F1B-3**

Mostafa Shalaby; Christoph. P. Hauri

We demonstrate bright low-frequency terahertz (<5 THz) radiation confined to a diffraction-limited spot size by wavefront manipulation. Focusing to a lambda-cubic volume provides bright THz radiation at the PW/m2 level.

12:00 **High Power Terahertz Induced Carrier Multiplication In Silicon** **F1B-4**

Abebe Tilahun Tarekegne; Pernille Klarskov; Krzysztof Iwaszczuk; Peter Uhd Jepsen

Recently we reported THz induced nonlinear carrier generation in high resistivity silicon through impact ionization. The THz field energizes conduction band electrons which impact bound electrons in the valence band. If the conduction band electron gains sufficient kinetic energy, the impact event lifts the bound electron into the conduction band generating a new electron-hole pair. The process continues in cascaded manner in the time span of the THz transient, thus generating a large number of free carriers. Silicon, which is an indirect semiconductor, requires stronger field strength to initiate significant impact ionization on a subpicosecond time scale. Previously we used an antenna array to enhance the field strength of THz pulses from lithium niobate to several MV/cm. In that case the impact ionization is limited only to small region of the substrate near the antenna tips where field enhancement is largest. It is therefore difficult to observe a change in overall transmission amplitude between high and low THz fields, and quantitative spectroscopy investigation of the effect is challenging. Here we report on strong transmission modulation through bare, intrinsic silicon by application of a THz field of several MV/cm generated from an organic crystal (DSTMS, pumped with femtosecond pulses at 1300 nm). When high resistivity silicon with an array of metal antennas for field enhancement is illuminated with LiNbO3-based source and with peak field strength of about 265 kV/cm, impact ionization in the silicon near the antenna tips leads to the generation of carriers which in turn change the local dielectric properties of the substrate. This results in a significant redshift of the resonance frequency of the antenna array. THz generation from DSTMS enables us to access several MV/cm electric field strength. This field strength is sufficient for impact ionization to occur without additional local field enhancement which makes it easier to probe the carrier scattering dynamics. A single --pulse THz transmission measurement shows a decrease transmission through the silicon wafer as the incident field strength is increased. At low field the amplitude transmission is about 70%, as expected for undoped silicon due to Fresnel losses. As the field strength increases, the transmission decreases to about 62%. The decrease in transmission is due to absorption of THz field by free carriers generated by THz induced impact ionization with saturation at field strengths of above 80% of the highest field strength available. This decrease in transmission is due to absorption of the THz field by free carriers generated by THz-induced impact ionization. We tentatively attribute the saturation of the nonlinear transmission to a combination of saturation of conduction band electronic states and increase of effective mass of electrons at high THz fields which will be discussed in the conference in detail.

12:15 **Air Nonlinearity Triggered By An Ultra-intense Sub-5 THz Light Bullet** **F1B-5**

Mostafa Shalaby; Christoph P. Hauri

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Air turns into a nonlinear medium for electromagnetic waves under exceptionally strong fields [1]. However up to present, its minuscule nonlinear response has limited the exploration to the optical frequency regime owing to the availability of intense near-infrared lasers. Here, we report on the observation of large-amplitude nonlinearity in air induced by an extremely intense light bullet [2] at THz frequencies provoking strong air birefringence [3]. The observed nonlinearity manifests itself as third order susceptibility. The presented nonlinear observations break the barrier for the entire exciting THz-induced nonlinear phenomena in air ranging from THz-induced self-focusing and self-phase modulation to THz solitons and filamentation. Our pulse was 3.9 THz-centered and its peak field and intensity were 3.3 GV/m and 14.4 PW/m2, respectively.

11:00 - 12:30 **F1C - Metamaterial Structures & Applications VII** **Lecture Theatre 4**

Chairpersons: Peter Uhd Jepsen;

11:00 **Experimental Realization Of Double-sided Perfect Metamaterial Absorber Through Stochastic Design Process At Terahertz Gap** **F1C-1**

Ting-Tso Yeh; Tsung-Yu Huang; Ta-Jen Yen; Akalin Tahsin

We have stochastically developed metamaterial patterns to successfully demonstrate a double-sided perfect absorber at 2.4 THz to trap light at the two opposite directions with the absorbance of up to 0.917 by matching the impedance between free space and the device and providing equivalent great imaginary part of index, respectively. The double-sided is with the thickness of λ0/6 that can be further reduced by employing thinner rigid substrate such as a silicon thin film.

11:15 **Design Study Of Low Loss Single-Mode Hollow Core Photonic Crystal Terahertz Waveguide With Support Bridges** **F1C-2**

Binbin Hong; Nutapong Somjit; John Cunningham; Ian Robertson

We present a design study of an all-polymer low loss single-mode hollow-core photonic crystal (HCPC) terahertz (THz) waveguide with dielectric bridges used as mechanical supports. By exploiting a modal-filtering effect and Brewster phenomenon, we maximize the loss discrimination between the fundamental and other higher order modes resulting in an effectively single-mode operation, though the HCPC THz waveguide is ostensibly multi-mode. Owing to the use of support bridges, which increase the propagation loss, the non-ideal HCPC THz waveguide has higher loss than an ideal one. Nonetheless, the propagation loss of the fundamental HE11 mode can still be minimized, to lower than 5 dB/m over the frequency range from 0.75 to 1.1 THz. In addition, the group velocity dispersion of the HE11 mode is less than -0.5 ps/THz/cm.

11:30 **Zoning Technique For A Broadband Fishnet Metamaterial Lens** **F1C-3**

Miguel Navarro-Cia; Bakhtiyar Orazbayev; Victor Pacheco-Peña; Victor Torres; Miguel Beruete

The profile of any lens can be reduced by applying a zoning technique, at the expense of narrower frequency range. Here, using an optimized zoning technique, a slim broadband zoned fishnet metamaterial lens with fractional bandwidth of 8.5% is designed, fabricated and measured at millimeter waves. Measurements are in good accordance with simulation results and demonstrate good performance of the zoned fishnet metamaterial lens. A high directivity of 16.6 dBi is experimentally achieved in the lens antenna system.

11:45 **Terahertz Rectification By Noncentrosymmetric Plasmonic Metasurface** **F1C-4**

Viacheslav Popov

The plasmon modes lacking the inversion symmetry can be excited by terahertz radiation on a noncentrosymmetric plasmonic metasurface formed by a two-dimensional electron system gated by a metal grating with an asymmetric unit cell. Excitation of the noncentrosymmetric plasmon mode leads to the terahertz rectification by generating a plasmon-photogalvanic current in the two-dimensional electron system. Strong terahertz photogalvanic response of the noncentrosymmetric plasmonic metasurface was predicted theoretically and demonstrated experimentally.

12:00 **Silver And Carbon Ink-Jet Printing To Create An Amplitude And Phase Controlled THz Metasurface** **F1C-5**

Andrew Paulsen

Controlling the amplitude and phase response of an optical device was once thought to be constrained by the bulk material properties of that device. Demonstrations of metamaterials and metasurfaces have shifted this paradigm. We show that the amplitude and phase of a transmitted THz signal through an array of V-shaped antennas can be controlled by varying the conductivity and geometry of the V-shaped structures. These structures are created using conductive silver and resistive carbon ink deposited by a consumer ink-jet printer.

11:00 - 12:30 **F1D - Sources, Detectors & Receivers IX** **Lecture Theatre 6**

Chairpersons: Martin Koch;

11:00 **Fiber Coupled Terahertz Time Domain Spectroscopy System Based On InGaAs/InAlAs Photoconductors With 100 DB Dynamic Range** **F1D-1**

Roman J.B. Dietz; Björn Globisch; Helmut Roehle; Thorsten Göbel; Martin Schell

We present an all fiber coupled terahertz (THz) time domain spectroscopy (THz-TDS) system operating at 1.5 µm wavelength with very high dynamic range. The broadband THz radiation is generated by a high mobility InGaAs/InAlAs heterostructure photoconductive emitter. For the detection a low temperature grown (LTG) Be-doped InGaAs/InAlAs heterostructure is employed. Both, detector and emitter, are packaged into fiber-coupled housings. The system reaches a dynamic range in excess of 100 dB and a spectral bandwidth of 6.5 THz..

11:30 **Cryogenic Amplifier Based Sideband Separating Receivers** **F1D-2**

Goutam Chattopadhyay; Theodore Reck; Erich Schlecht; Imran Mehdi; William Deal

MMIC based radiometers are very attractive for radio astronomy and Earth science applications since their limited cooling requirements and front-end gain simplifies instrument design compared to SIS-junction mixers. For space-borne instruments 20 K cooling is much lower risk because 4 K closed-cycle coolers have limited flight heritage. Moreover, the MMIC's sensitivity degrades gracefully as temperature increases whereas SIS receivers do not operate at all above their critical temperature, generally around 10 K. The emergence of the Northrop Grumman's 30nm gate InP HEMT process has enabled MMIC technology above 300 GHz. These devices have fT > 1000 GHz, enabling amplifiers up to 750 GHz [1]. These new devices also offer higher performance at lower frequencies, such as the amplifier used in this work, which offers 40% bandwidth centered at 225 GHz. This paper presents the development of cryogenically cooled MMIC-based single-sideband receivers

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

operating from 180 to 270 GHz and 620 to 660 GHz.

11:45 **A Dual-Pass High Current Density Resonant Tunnelling Diode Terahertz Emitter** **F1D-3**

Kristof Jacobs; Benjamin Stevens; Osamu Wada; Toshikazu Mukai; Dai Ohnishi; Richard Hogg

We reported an InGaAs/AlAs/InP resonant tunnelling diode terahertz emitter fabricated using a dual-pass technique. Using this technique we achieved a final device area accuracy of < 1 % for a 3.3 μm2 device, and fabricated reproducible low resistance ohmic contacts of 2 ohms for the emitter and the collector. The RTD devices were monolithically integrated with slot antennas on an InP substrate and fundamental room temperature emission at 0.35 THz was demonstrated.

12:00 **High-TC THz HEB Mixers: Progress And Prospects** **F1D-4**

Boris Karasik; Daniel Cunnane; Andrei Sergeev

We analyze the pathways for achieving the THz hot-electron bolometer (HEB) mixers using high-TC superconductors. Requirements to the material in order to obtain large (up to 10 GHz) intermediate frequency bandwidth as well as recent results on MgB2 HEB mixer devices are discussed. Based on a thermal model of the energy relaxation in a thin film, we explain the difference between the mixing behaviors in previously studied HEB materials. We also introduce the concept of the HEB mixer based on the low electron density MBE-grown quasi-2DEG LaCuO/LaSrCuO superconductors with tunable critical temperature.

12:15 **Bandwidth Measurement Of Terahertz Detector Using High Electron Mobility Transistor By Heterodyne Mixing** **F1D-5**

Safumi Suzuki; Takuro Nukariya; Yugo Ueda; Masahiro Asada

We measured the bandwidth of a terahertz detector using an InAlAs/InGaAs high-electron--mobility-transistor by heterodyne mixing with UTC-PD and a frequency multiplier as a radio frequency (RF) and local oscillator (LO), respectively. The intensity of the intermediate signal was measured by changing the frequency of UTC-PD, and a very high bandwidth of up to 26 GHz was obtained.

11:00 - 12:30 **F1E - Applications in Biology & Medicine** **Lecture Theatre 7**

Chairpersons: Fritz Keilmann;

11:00 **Compact Non-Invasive Millimeter-Wave Glucose Sensor** **F1E-1**

Peter Siegel; Adrian Tang; Gabriel Virbila; Yanghyo Kim; Frank Chang; Victor Pikov

The authors present a design for a compact non-invasive CMOS-circuit-based glucose monitor using millimeter-wave transmission for use on animal and human subjects. In vivo measurements have been performed through the ear in anesthetized animals and correlated with blood glucose concentration. In addition, millimeter wave absorption through glucose-containing solutions was measured in specialized liquid transmission cells and compared to similar data from literature.

11:30 **Terahertz Reflection Imaging Of Hypertrophic Scar Tissue In Vivo** **F1E-2**

Shuting Fan; Benjamin Ung; CheukTing Li; Emma Pickwell-MacPherson

We use terahertz reflection imaging to measure hypertrophic scar tissue in vivo. The reflected terahertz wave from the scar tissue is significantly different from the reflected wave from surrounding healthy tissue. The absorption coefficient of both areas is calculated and shows that the absorption coefficient of the scar tissue is much lower than the healthy tissue. These data suggest that it could be possible to use in vivo terahertz imaging to quantitatively monitor the effectiveness of wound healing treatments.

11:45 **Exploration Of The Rayleigh Roughness In THz Medical Imaging** **F1E-3**

Shijun Sung; Neha Bajwa; Warren Grundfest; Zachary Taylor

The effect of rough surface scattering on the contrast observed in THz medical imaging is explored. A Frequency Modulated Continuous Wave (FMCW) THz imaging system operating at a center frequency of 650 GHz with a time averaged bandwidth varied between ~ 0.01% and 1% bandwidth was used to image rough surface targets to explore the effect of rough surface scattering on the contrast observed in THz medical imaging. In addition to the commonly characterized expected power reflected in the specular direction we also ascertained the variance (second moment) of the power and computed the observed signal to clutter ratio (SCR). The results fit well to standard Rayleigh roughness theory and confirm that operating THz imaging systems at moderate incidence angles offer a significant increase in SCR at the minimal cost of spatial resolution.

In our work we are pursuing windowless THz imaging where imaging systems comprised primarily of reflective optics are used to acquire non-contact images of the tissue of interest. We have observed in previous results that the SCR of the resulting images is much lower than the SNR and CNR and thus forms the performance limit of the system. We constructed a THz imaging system based on a narrow band amplified multiplier chain and performed imaging of rough targets with varying, characterized surface characteristics. The mean and variance of the signal was ascertained form the resulting image series and trends in SCR were computed and compared to theory.

12:00 **The Investigation Of Blood And Skin THz Response At High Glucose Concentration** **F1E-4**

Olga Cherkasova; Maxim Nazarov; Alexander Shkurinov

Studies of a rat blood and skin were carried out using THz-TDs. The transmission and the attenuated total internal reflection geometries have been used for measuring the dielectric properties of the water solutions and biological samples with high glucose concentration. We discuss the reasons for the observed THz sensitivity to diabetes mellitus in the context of changes in the bounded water caused by glucose.

12:30 - 14:00 **FS - Friday Poster** **YIA Lobby**

Chairpersons: Gian-Piero Gallerano;

Fourfold Azimuthal Dependence Of Terahertz Radiation From (100) Silicon **FS-1**

Quan Guo; Lei Chen; Dongwen Zhang; Xiaowei Wang; Zhi-hui Lv; Chao Meng; Yindong Huang; Yilei Ge; Jianmin Yuan

A fourfold azimuthal dependence of terahertz radiation from (100) silicon surfaces is shown in Fig. 2. It is obvious that this azimuthal dependence is very similar with that of second harmonic generation (SHG), which displays the lattice symmetry of silicon. As far as we know, it's the first time that the silicon symmetry was detected in this way. Comparing THz and SHG from (100) silicon, we can conclude that the azimuthal dependence we found should be attributed to the electric quadrupole-magnetic dipole (EQMD) of (100) silicon.

High Power Coupled Ridge Waveguide Quantum Cascade Laser Arrays **FS-2**

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

JinChuan Zhang; Junqi Liu; Jinchuan Zhang; Jinchuan Zhang
We have described a fifteen-unity couple ridge waveguide DFB QCL arrays with coherent emission. Phase-locking and the fundamental supermode emission have been obtained leading to beam close to diffraction limited operation in lateral direction.

Dielectric Constants Of Ferroelectric PZT At THz Frequencies **FS-3**
Mira Naftaly; Markys Cain; Serban Lepadatu; Till Buchacher; Jeremy Allam; John Molloy
The complex dielectric constant of bulk ceramic ferroelectric PbZr0.4Ti0.6O3 was measured in the range 0.2-2 THz using transmission time-domain spectroscopy. The material shows strong absorption and high refractive index with large dispersion. The results are compared to equivalent thin film data in the literature.

Optically Tunable THz Frequency Metamaterial Absorber **FS-4**
Fangjing Hu; William Otter; Stepan Lucyszyn
In this paper, we propose a metamaterial-based terahertz (THz) absorber with optically tunable absorbance. The unit cell of the structure consists of a cross-shaped resonator, a dielectric spacing layer for wave impedance matching and a high-resistivity silicon (HRS) substrate. Without illumination, the structure acts as a capacitive metal mesh filter that has minimum transmittance and maximum reflectance at its resonance frequency. When the HRS substrate is optically illuminated, its conductivity increases, effectively blocking transmission through the structure. Therefore, this device will have a low reflectance if the impedance is matched. The optimized structure shows a high absorbance of 98% at 0.25 THz in simulations. This concept can be used for the realization of dynamic control of absorbance and emissivity for applications in the THz and infrared (IR) range.

Optical Measurements Of Heat Treated Silica Samples **FS-5**
Francesco Mazzocchi; Theo Andreas Scherer; Rafael Saavedra; Piedad Martin Martinez
In the following article the measurements performed at CIEMAT on several silica samples are described. The samples were treated in both N2 and O2 atmosphere, in a temperature range from 500 to 1000 °C. The measurements include UV -- VIS -- NIR absorption spectroscopy, FT-IR transmission and reflectance spectroscopy, and visual inspection of the treated samples with a confocal microscope.

Terahertz Spectroscopic Characterization Of Naphthalene And 1-Nitronaphthalene **FS-6**
Yong Du; Hongxia Fang; Qi Zhang; Zhi Hong
Terahertz absorption spectra of parent polycyclic aromatic hydrocarbon (naphthalene) and its nitropolycyclic aromatic hydrocarbon (1-nitronaphthalene) have been investigated using terahertz time-domain spectroscopy (THz-TDS) technique. The results show large difference in 0.1~2.2 THz region, which probably originated from the difference of molecular structure and lattice vibrational modes. The study indicates that THz-TDS technology can offer a new experimental method to identify and analyse such kinds of environmental pollutants.

Project Of CW High Harmonics Double-Beam Gyrotrons With Operating Frequencies In The Range 0.7-1.0 THz **FS-7**
Irina Zotova; Mikhail Glyavin; Vladimir Manuilov; Naum Ginzburg; Andrey Malkin; Vladislav Zaslavsky; Mikhail Proyavin; Roman Rozental; Anton Sedov; Aleksander Sergeev; Vladimir Zapevalov; Toshitaka Idehara
The concept of a CW THz range gyrotrons operated at the second or third cyclotron harmonic is presented. To suppress the mode competition effects a double beams scheme is applied. The helical electron beams are formed in a double-beam triode magnetron-injection gun (MIG), where both emitters of the electron beams are located on a common cathode of the conventional MIG. Results of numerical simulation of electron beams formation and mode excitation have been presented. The concept makes possible high power (several hundred Watts) single-mode gyrotron operation at 0.7-1.0 THz frequency range at high harmonics.

Determination Of Automobile Paint Thickness Using Non-contact THz-TDS Technique **FS-8**
A. I. Hernandez-Serrano; E. Castro-Camus
We use pulsed THz-TDS as a non-contact method for the measurement of thickness in automobile paint on a non- metallic substrate. We use a least square algorithm in order to fit the reflected pulses of each layer. Extracting the delay of each from the theoretical function allows us to know the thickness of each layer present in the system.

Particle-in-Cell Simulation And Optimization For A 108GHz Folded Waveguide Traveling-wave Oscillator **FS-9**
Ke Li; Wenxin Liu; Yong Wang; Miaomiao Cao
In this paper, a 108GHz FW traveling-wave oscillator is designed and optimized. The PIC simulation is applied to simulate the FW oscillator. The operating parameters are optimized by the PIC simulation. The optimized oscillator obtains 527W at 108GHz. The research of this paper makes contributions to the maching of 108GHz FW oscillator.

Passive Subsystem Antenna Array Design For TeraSCREEN Security Screening System **FS-10**
Itziar Maestrojuan; Aitor Martinez; Asier Ibañez
The FP7 project TeraSCREEN is focused on the development of a multi-frequency multi-mode Terahertz (THz) detection prototype for security screening. In this paper the passive subsystem antenna array is presented which consists of standard gain horn antennas, a waveguide manifold in order to reduce the antenna separation and improve the array resolution and compact waveguide twists required to change the polarization between the mixers and the antenna manifold.

High Power RF Radiation At W-band Based On Wakefield Excited By Intense Electron Beam **FS-11**
Dan Wang; Sergey Antipov; Manoel Conde; Scott Doran; Wei Gai; Chunguang Jing; Wanming Liu; John Power; Jiaqi Qiu; Chuanxiang Tang; Eric Wisniewski
We report the experimental design and initial experimental results on high power RF generation at W-band based on coherent wakefield from the metallic periodic structure of 91 GHz, excited by intense electron beam at the Argonne Wakefield Accelerator (AWA) facility. The recently output RF power is 0.7 MW, with 67 MeV, 1.4 nano-column (nC) single electron beam go through the 12cm structure. The RF pulse is 3.4 nano-second (ns). We measure the energy loss of electron beam in the experiment. Next run is to increase the output RF power with higher charge in the driven beam and to excite higher gradient of wakefield with electron bunch train.

Preparation Of Nanostructured NiCr Film As A Terahertz Absorption Layer By Magnetron Sputtering And RIE **FS-12**
Jun Gou; Jun Wang; Xing Zheng; Deen Gu; Yadong Jiang
Nanostructured NiCr thin film was prepared by a combination of magnetron sputtering and reactive ion etching (RIE) in 80 × 60 uncooled infrared focal plane arrays (IRFPA). The surface morphologies and THz absorption characteristics of the IRFPAs were tested with NiCr absorption layers prepared by magnetron sputtering and the combined process respectively. The tests suggested that THz absorption could be effectively enhanced by RIE processes applied to the dielectric substrate and NiCr film,

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

which increased the specific surface area of NiCr absorption film by generating nano -- scale structures on upper and lower surfaces.

A THz Measurement Platform Design For 0.2- 1.1THz **FS-13**

Haotian Zhu; Quan Xue

A precise and stable THz Measurement Platform is proposed in this paper. The displacement precision and angle precision of the platform are 0.02mm and 1° respectively. With OML or VDI extension module and Agilent N5245A PNA-X network analyzer, the THz Measurement Platform can measure waveguide components and antennas precisely in 0.2-1.1THz.

Silicon Junctionless Field Effect Transistors As Low Noise THz Detectors **FS-14**

Przemyslaw Zagrajek; Jacek Marczewski; Michal Zaborowski; Marek Piszczek

This paper describes metal-oxide-semiconductor junctionless field effect transistors working as detectors of THz radiation. The exceptionally high signal to noise ratio has been achieved. These devices may operate as two terminal detectors without any gate bias.

A Method For Sorting Of Electrons In Gyrotron Multistage Depressed Collectors **FS-18**

Oleg Louksha; Pavel Trofimov

A new method of spatial separation of electrons with different initial energies in the helical electron beams of gyrotrons, based on the radial drift in the presence of crossed azimuthal magnetic and axial electric fields is reported. The possibility of application of this method of electron sorting for effective multistage depressed collectors in gyrodevices is shown through analytical assessment and numerical simulation of electron trajectories.

Design Of The Radial Divergent Sheet Beam Electron Optical System With Cylindrical Emission Surface **FS-20**

Xinyi Li; Xianbao Shi; Zhanliang Wang; Zhaoyun Duan; Huarong Gong; Yanyu Wei; Jinjun Feng; Yubin Gong

The radial sheet beam traveling wave tubes can work at the frequency of millimeter wave band, have the properties of high efficiency, broad bandwidth, miniaturized dimensions, and easily to be integrated and so on. The radial divergent sheet beam electron optical system with cylindrical emission surface is designed for the Ka band radial sheet beam traveling wave tubes in this paper. The radial divergent sheet beam with the open angle of 8 deg and the thickness of 0.28 mm, generated by the electron gun with 1800V, 84.9 mA, can achieve 100% transmission efficiency in a 20 mm length radial direction drift tunnel with the open angle of 10 deg and the height of 0.36 mm.

Efficient THz Signal Generation Via Optical Frequency 24-Tupling Without Optical Filter **FS-21**

Dong Liang; Qinggui Tan; Wei Jiang; Zhonbo Zhu; Xiaojun Li; Jinfang Dou

In this paper, a novel optical frequency 24-tupling scheme for THz signal generation is proposed and demonstrated. Based on two cascaded Dual-Parallel Mach-Zehnder Modulators (DPMZM) and three phase shifters, optical signal with only ±12th-order sidebands is achieved without optical filter. Theoretical analysis and simulation results show that the scheme can generate 0.12THz signal from a 5GHz radio frequency local oscillator (LO), and the harmonic distortion suppression ratio is more than 55 dB.

Temperature Dependence Of Terahertz Spectra Of Chlorophyll A And B **FS-23**

Ling Jiang; Jiangping Yu; Chun Li; Yutian Xu; Biaobin Jin; Li Xu; Haijun Sun; Yunfei Liu

We employed THz-TDS spectroscopy to investigate the broad-band terahertz spectrum in the frequency range of 0.1-4 THz for chlorophyll a and b at different temperatures. The absorption frequencies of the chlorophyll a and b do not change with temperature. And there is no new absorption peak while the temperature was cooled down to helium temperature. Since the simulated results for single molecule do not consider the intermolecular interactions, the simulated and measured absorption spectra are not consistent.

Anisotropy Of Electrical Properties Of Rocks At THz Frequency Range **FS-24**

Grigorii Dunaevskii; Alexander Badin; Igor Dorofeev

I. INTRODUCTION Now the short-wave part of gigahertz and the terahertz waverange are intensively developed and investigated. A new element base is appeared, properties of materials are investigated. All this allows to hope that in the near future the devices and the methods using these frequencies will go beyond research laboratories and will find the application in the industry [1]. Application in the field of radiowave nondestructive contactless control of parameters of materials can be one of such applications. Using of more short waves can significantly increase locality and resolution of supervising devices. In geology to determine he lamination and porosity of rocks the optical refractometers and x-ray methods of diagnostics are traditionally applied, such as electronic microscopy. They are very labor-consuming and need in precise preparing of samples. By means of these methods the anisotropy of material is investigated with which the definite parameters of rock are connected [2]. II. RESULTS For research 9 samples of the rocks in the form of plane-parallel polished plates 3.1 -- 7.2 mm thick were selected. As experimental equipment the interferometer of the Mach-Zehnder working in the range of frequencies of 0.034 -- 1.2 THz was used. The measurement showed that transmittance of samples with increasing of frequency was decreased (Figure 1). Therefore the possibility of schemes, which are used for raying of samples, is limited by low-frequency part of the range. The coefficient of reflection is in limits 0.05 -- 0.4 in all band of frequencies. Therefore schemes on reflection will give more possibilities in variation of frequency, in search of optimum values, and in using of samples with only one surface. The dependences of transmission and reflection coefficients at various orientations of samples relative to polarization of incident field were also investigated. The analyzer on an input of the receiving detector was set up on polarization of an input signal of radiation in wideband of frequencies [3]. The analysis of the obtained data and their comparison with the results received by optical methods showed correlation of angle dependence of reflection coefficient and anisotropy of permittivity of samples with their geological parameters, such as porosity, direction of distribution of minerals in rock. However this correlation has complicated character and is different in various parts of investigating frequency range (Figure 2). III. SUMMARY Thus, the dependence of anisotropy of electric parameters in the submillimeter waverange on geological properties of studied samples can be based on the development of nondestructive contactless radiowave control methods of natural materials with use of terahertz radiation in wideband of frequencies.

Design And Analysis Of A Waveguide Window Of W-Band TWT **FS-25**

Xiaofang Zhu; Quan Hu; Yulu Hu; Li Xu; Bin Li

A waveguide window is designed for W-Band folded waveguide TWT. The window is initially designed by the transmission line theory and then optimized by 3D EM simulation code CST MWS, HFSS and MTSS. The results of these codes are in agreement and all show us that the waveguide window has excellent transmission performance from 90GHz to 102GHz with VSWR less than 1.1 and S11 less than -30dB.

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Ga2S3: Optical Properties And Perspectives For THz Applications **FS-28**

Zhiming Huang

To the best of our knowledge, nonlinear 3-d crystal Ga2S3 is considered for THz application for the first time. Single Ga2S3 crystals were grown by the Bridgman and flux method using three kinds of solvents. XRD-patterns confirmed its Cc monoclinic structure. The entire (visible-THz) transmission spectrum is recorded for the first time. It is established that maximal transparency range (from 0.48 to 25 μm) is the widest among known anisotropic nonlinear crystals. Multiphonon absorption peak is recorded at about 24 μm. On the other hand, it is found that long-wave THz range is free from phonon absorption peaks. Raman scattering spectra confirm it once more time. Damage threshold for a single crystal was also measured for the first time. Under the expose to ns Nd:YAG laser pulses at 1.064 μm it is at least from 20 to 30 times higher than that for mostly used 2-d anisotropic GaSe crystal. Optical anisotropy was verified by demonstration of SHG phase matching. Developed properties render Ga2S3 as a serious competitor to pure and doped GaSe in THz application. In difference to pure and doped GaSe, Ga2S3 is useful for out-of-lab application due to bulk structure.

Infrared Ellipsometric Spectroscopy Of Mn1.56Co0.96Ni0.48O4 Thin Films With Different Layers **FS-31**

Yanqing Gao; Zhiming Huang; Yun Hou; Jing Wu; Wei Zhou

Different layers of Mn1.56Co0.96Ni0.48O4 (MCN) films have been prepared on Pt/Ti/SiO2/Si substrate by chemical solution deposition method. Infrared optical properties of MCN films have been investigated using infrared spectroscopic ellipsometry. The optical constants and thickness of the thin films have been obtained by fitting the measured ellipsometric parameter data with classical infrared model. The refractive index n of the MCN films decreases as the wavelength increases, but the extinction coefficient k monotonously increases in the wavelength range of 2-13 um. For the 20 layers MCN film, the minimal n value is only 2.07, and the maximal k value is 0.18.

Analysis Of Terahertz Spectral Variations In Porcine Dermis **FS-32**

Maya Mizuno; Kensuke Sasaki; Soichi Watanabe; Kaori Fukunaga

The absorption spectra of dried porcine dermis were measured under different sample handling conditions in a terahertz band from 0.3 to 12 THz. The spectral shapes and polarization properties depended on the drying and impurity conditions at approximately 3 THz. We inferred that the configuration changes of collagen fibers inside the dermis caused the spectral variations.

Harmonic Generation By A Terahertz Pulse In A Thin Nonlinear Layer On A Metal Mirror **FS-33**

Elizaveta Buyanovskaya; Sergei Kozlov; Andrey Sukhorukov

Recent development of powerful single cycle waves in terahertz range generation systems has brought immediate interest to the effects of medium nonlinearity on their propagation. The concept of a slowly-varying envelope is not valid for such pulses and new features of nonlinear effects can be identified by modeling the evolution of the light pulse field itself. In this paper we investigate the third harmonic generation by a terahertz pulse in a thin layer of nonlinear dielectric media on top of a metal mirror. Due to the lack of destruction of optical media in the field of intense pulses such generation can be significant and has practical application. We perform theoretical analysis based on a second order wave equation formulated directly for the electric field of a few cycle electro-magnetic pulse with a broad spectrum. We assume the pulse spectrum lies in the transparency range of nonlinear dielectric media. We apply method of successive approximations and derive asymptotic expression for the field of the wave reflected from metal mirror with nonlinear dielectric layer, in the absence of dispersion. Based on the analytical and numerical analysis we calculated the transformations of the optical electric field profiles, optical spectra and phase at the output of the layer. It was shown that due to self-action of a single cycle wave and its nonlinear interaction with radiation reflected from the mirror we observe increased spectral broadening. We find that the nonlinear layer thickness can be chosen to either suppress or enhance third harmonic generation, whereas the generation of spectral components around the third harmonic frequency is always present.

Dispersion Characteristics Of Double-Corrugated Rectangular Waveguide For Terahertz Vacuum Devices **FS-35**

Yulu Hu; Quan Hu; Mauro Mineo; Li Li; Francesco Napoli; Bin Li; Xiaofang Zhu; Jianqing Li; Li Xu; Tao Huang; Xiaolin Jin; Claudio Paoloni

An analytical study on the dispersion of the double-corrugated waveguide for THz vacuum devices is presented. The boundary element method (BEM) is introduced to improve the accuracy of the dispersion. The results are compared with the 3D electromagnetic simulations.

Tunable Terahertz Radiation From Graphene Surface Plasmon Polaritons Excited By Parallel Moving Electron Beam **FS-36**

Min Hu; Sen Gong; Tao Zhao; Renbin Zhong; Xiaoxing Chen; Ping Zhang; Xinran Wang; Chao Zhang; Huabing Wang; Biaobing Jin; Jian Chen; Peiheng Wu; Shenggang Liu

We propose a novel kind of terahertz radiation source utilizing grapheme surface plasmon polaritons (GSPPs) excited by parallel moving electron beam. Theoretical analyses show that terahertz radiation can generate from graphene sheet on a periodic grating structure. The intensity of the radiation are greatly enhanced due to GSPPs and the frequency of the radiation can be widely tuned by both of the electron beam energy and chemical potential of graphene. The experiment based on this mechanism are in progress.

Antireflective Broadband Micro Structure At Terahertz Range By A Hot Deformation **FS-37**

Yunzhou Li; Bin Cai; Yiming Zhu

In conclusion, Chinese acupuncture needles were utilized for a metallic mold, and hot embossing was applied to form a gradient refractive index profile for antireflection in the THz region. Using this very-low-cost equipment and simple process, we increased the transmittance from 50%, for a bare silicon substrate, to approximately 75%, which is ~20% higher than that of single antireflective layer. The proposed structure provides a far broader bandwidth (0.1--1.5 THz) than the single-layer antireflective structure and can decrease the Fabry-Perot resonance effectively. In contrast with other surface relief structure fabrication methods, hot embossing imposes lesser substrate limiting and can therefore be applied onto various THz substrates and devices. By optimizing the mold structure, coating material, and other design parameters, the antireflective effect can be further enhanced.

Long-Distance Enhanced Fourier Transform By Hyperbolic Gradient-Index Metalens **FS-38**

Heng-He Tang; Pu-Kun Liu

Fourier transform can be achieved by a various kind of lenses or metalenses. However, it is difficult especially in the terahertz frequency range to extend the spatial frequency bandwidth of Fourier lenses. A lens with extraordinary spatial frequency bandwidth can allow the light to be manipulated in the subwavelength scale, which is significant for the optical information

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

processing. In this paper,a new hyperbolic metalens is demonstrated at terahertz (THz) frequency to realize enhanced Fourier transform with extended spatial frequency bandwidth. By using an anisotropic metamaterial with hyperbolic dispersion, evanescent wave in free space with high transverse wave-vector can be transformed into propagating wave and gradually focused in the metamaterial. And because of negative-refraction, the emerging wave outside the metamaterial will refocus in the far-field. The bandwidth can be extended to 2.5k0 (k0 is the wave-vector in air), which is 2 to 3 times of conventional lens. Furthermore, the working distance can be larger than one wavelength, which is in the far-field region. The metalens has potential applications on super-resolution imaging working over long distances.

Terahertz Superradiation From Cylindrical Surface Wave-Annular Electron Beam Interaction Within A 3-Mirror Quasi-Optical Cavity **FS-40**

Yucong Zhou; Yaxin Zhang; Shenggang Liu

A cylindrical surface wave-annular electron beam interaction in a special 3-mirror quasi-optical cavity is presented and explored. The study demonstrates THz free electron superradiation from the interaction of cylindrical surface wave and annular electron beam that forms a resonance within the structure, with the 3-mirror quasi-optical cavity enhancing the intensity of superradiation by more than one order of magnitude. Moreover, this system can work with 2nd harmonic superradiation at 0.607 THz with only about 30 A/cm^2 which is a relatively low value.

Characterization Of Terahertz Generation Based On The Different Structures Of Lithium Tantalate Crystals **FS-41**

Kyu-Sup Lee; Shunji Takekawa; Kenji Kitamura; Do-Kyeong Ko; Nan Ei Yu

Difference in the terahertz generations using three types of 1 mol % MgO-doped stoichiometric LiTaO3 crystals were analyzed. Weak single-cycle, multi-cycles, and strong single-cycle terahertz pulses were radiated at bulk, periodically poled, and angle-cut structures, respectively. The three different types of terahertz generation depend on the phase-matching process.

A Solid-State Electronic Millimeter And Terahertz Imaging System **FS-42**

Ken Smart; Jia Du; Li Li; David Wang; Keith Leslie; Fan Ji; Xiandong Li; D.Z Zeng

A practical millimeter and terahertz multi-spectral imaging system based on commercially available components is presented. The advantages of its robust low cost design and the convenience of switching between transmission and reflection mode are explored. The system is then used to undertake a study of imaging at millimeter and terahertz wave frequencies with results compared.

RF Behavior Of A 42/84 GHz, 0.5 MW, Dual Frequency Gyrotron **FS-43**

Gaurav Singh Baghel; Kartikeyan Machavaram

In this paper, the RF behavior studies of a 500 kW 42/84 GHz dual frequency gyrotron is presented. The operating modes selected for 42/84 GHz dual regime operation are TE6,3 and TE15,4 respectively. The present study includes the mode competition, cold cavity design, single-mode and time dependent multi-mode self-consistent computations.

Non-destructive Characterization Of Automobile Car Paints Using Terahertz Pulsed Imaging And Infrared Optical Coherence Tomography **FS-44**

Yue Dong; Jinke Zhang; Yao-chun Shen; Ke Su; Axel Zeitler

Terahertz pulsed imaging (TPI) and Optical Coherence Tomography (OCT) are two powerful techniques that can be used to non-destructively acquire high quality three-dimensional images from within scattering media. In this paper, we report experimental results of using TPI and infrared OCT for characterizing automobile car paints. We found that the individual layer thickness of all four layers of real-world car paint samples could be determined from TPI measurements whilst OCT measurements can only image the top two layers of the car paints albeit with a better image resolution. OCT is able to reveal additional information such as the shape and orientation of metallic flakes in the base coat of the car paints.

A 0.22-THz Sine Waveguide Traveling-wave Tube **FS-45**

Luqi Zhang; Yanyu Wei; Jin Xu; Wenxiang Wang; Yubin Gong; Jinjun Feng

A 0.22THz sine waveguide TWT is designed to develop the high power terahertz radio source. The simulation results reveal that with the sheet electron beam parameters of 20.8-kV and 100mA, the maximum output power and interaction efficiency can reach 90.59W and 4.36% , respectively.

Optically Tunable Metamaterials On Lattice-Matched InGaAs/InP **FS-46**

Dalius Seliuta; Dovilė Zimkaitė; Gediminas Slekas; Andzej Urbanovič; Jan Devenson; Ramūnas Adomavičius; Zilvinas Kancleris

Optically controlled mode switching in the split-ring resonators deposited on the lattice-matched InGaAs/InP was demonstrated at excitation wavelengths 900-1200 nm. Using tunable excitation wavelength as well as split-ring resonators of different configurations attempts were made to optimize the mode switching conditions for application of tunable metamaterial for high-speed narrow-band THz modulation

<tilde>A Ka-band Relativistic Sheet Electron Beam Traveling Wave Tube Using Electric Coupling Input Structure **FS-47**

Yabin Zhang; Zhanliang Wang; Yubin Gong; Jinjun Feng; Yabin Zhang

In this paper, an electric coupling input structure has been designed which is proved to be suitable for high power relativistic sheet electron beam TWT. Using this input structure a 1.07MW radiation is obtained at 35GHz.

A Wide-band HE11 Mode Window For Millimeter Wave Gyro-TWAs **FS-48**

Craig Donaldson; Liang Zhang; Adrian Cross; Paul McElhinney; Helen Yin; Wenlong He

Broadband windows are critical components in gyro-TWAs and pose a great challenge to manufacture. They are required to have very low reflection whilst coupling in microwave power. Presented in this paper is the design, simulation and measurement of a wide-band (90 to 100 GHz) multilayer microwave window using the HE11 mode as the input microwave mode. The simulated performance shows a better than -30 dB reflection over a 10% bandwidth of 90-100 GHz. The measured window is in very good agreement with simulations.

Terahertz Imaging Of Carcinoma-affected Colon Tissues Fixed In Paraffin **FS-49**

Rimvydas Venckevicius; Irmantas Kasalynas; Faustino Wahaia; Andzej Urbanovic; Gediminas Molis; Dalius Seliuta; Gintaras Valusis; Fatima Carneiro; Catia D. Carvalho Silva; Janez Trontelj

A compact THz imaging system was developed for the adenocarcinoma-affected human colon tissues measurement simultaneously in transmission and reflection geometry. The contrast between the cancer and control tissues fixed in paraffin at 0.6 THz frequency was up to 23%.

3D Polymer Structures With Variable Permittivity At Terahertz Frequencies **FS-50**

Jonathan Hammler; Yi Pan; Andrew Gallant; Claudio Balocco

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

Titanium dioxide (TiO2) powder has been blended with polydimethylsiloxane (PDMS) to manufacture a composite polymer with variable permittivity. Vector network analyser measurements taken between 0.75--1.1 THz quantify the relationship between TiO2 concentration and complex permittivity of the resultant material. Complex 3D structures have been produced with a casting process. Applications for the tunable-permittivity polymer include dielectric regions in photonic and plasmonic devices operating at terahertz frequencies as well as single pixel imaging systems.

Design And Experiments Of A Five-fold Helically Corrugated Waveguide For Microwave Pulse Compression **FS-51**

Liang Zhang; Sergey V. Mishakin; Wenlong He; Sergey V. Samsonov; Adrian W. Cross; Gregory G. Denisov; Michael McStravick; Vladimir L. Bratman; Colin G. Whyte; Craig W. Robertson; Alan R. Young; Huabi Yin; Kevin Ronald; Philip MacInnes; Alan D.R. Phelps

Metal waveguide can be used as a dispersive medium to convert long duration, lower power pulses into short, higher peak power pulses. This provides an advanced method to generate radiation with gigawatts power in the millimeter and sub-millimeter wavelength range by compressing a megawatt level long duration pulse. In this paper, a five-fold helically corrugated waveguide operating in X-band was designed and constructed. The experiments conducted show that a 5.75 kW average power microwave pulse with a 6% bandwidth and duration of 80 ns can be compressed into a 144.8 kW, 1.6 ns pulse with a power compression factor of 25.2.

Diffraction Properties Of Binary-type Liquid Crystal Gratings In The Terahertz Region: Numerical Investigation **FS-52**

Michinori Honma; Ryota Ito; Toshiaki Nose

We performed a numerical evaluation of the diffraction efficiency of a liquid crystal (LC) grating with binary phase and amplitude distribution profiles based on the Jones calculus of a terahertz wave transmitted through the LC layer. The optimum LC layer thickness for maximum diffraction efficiency was revealed to be much shorter than the LC layer thickness for a π phase difference in the binary phase distribution profile, indicating that the absorption anisotropy of the LC material has a major influence on the diffraction properties, as is true of birefringence.

Infrared Absorption At The LO Phonon Energy Of Metal/ Semiconductor/metal Composite Materials **FS-53**

Yoshihiro Ishitani; Eito Takeuchi; Bei Ma; Ken Morita

The interaction between infrared light and phonon-plasmon systems has been discussed in many articles. Since Berreman has found a sharp drop in the p-polarized IR reflectance (IRR) spectrum of a LiF film backed by silver around the LO phonon energy, IR absorption, reflectance loss by interface polariton generation, and so forth were discussed as the possible sources. One of the present author clarified the respective contribution of these factors using attenuated total reflectance method. Thus far, metal/dielectric composite structured materials have been investigated to control the permittivity and permeability. These studies analyzed the coupling of the electronic plasmon but not that of the phonon. Many articles have discussed emission of electromagnetic waves related to the LO phonon. Although these radiations were induced by short pulse excitation, the long coherence of several ps demands further mechanism. Thus the generation mechanism of the LO-resonant electric dipolemoment surviving over several ps or continuously is of great interest. In this article, we report a strong IR absorption at the LO phonon energy in a metal/semiconductor composite materials based on theoretical function of permittivity. The mesa-stripe structures of GaN and GaAs were fabricated. Undoped GaN thin layers on sapphire (0001) substrates and undoped GaAs (001) substrates were etched as mesa stripe structure with 6μm width of etched regions and a period of 14 μm. Ti metal was deposited in the etched regions. IRR measurements were performed by the incidence angle of 30° from the surface normal. Raman spectra were obtained by the back scattering geometry using a 532-nm laser beam. For IRR spectra, when the incidence direction is parallel to the stripes, the electric field E of the s-polarized light is perpendicular to the stripes, while for p-polarized light the E has no such a component. For the incidence of perpendicular to the stripes, E of the p-polarized light has a component perpendicular to E. We have found that the optical absorption takes place for E perpendicular to the metal/semiconductor interfaces. This is the same for GaN case. For Raman spectra, when the incident spot covers both of the two interfaces of Ti/GaN, an additional peak is found at the higher energy side of the LO peak. When we calculate the dielectric function by taking account of the polarization charges at the interfaces, an additional peak in the imaginary part at the resonant energy to the LO phonon and a new zero point in the real part are found. These characteristic energy positions agree with the observed respective energies of reflectance loss and the new Raman peak. Thus The generation of the lateral dipolemoment in the LO phonon energy region is found. This dipolemoment is significant for the surface emission in THz region.

Study Of Broadband Quasi-Optical Mode Convertor For THz Gyrotron **FS-54**

Chao-Hai Du; Xiang-Bo Qi; Pu-Kun Liu

This paper presents the design of a broadband quasi-optical mode converter for a 330 GHz TE62 mode tunable gyrotron. It consists of a Vlasov launcher and three reflector mirrors. A series of important considerations, including Vlasov launcher of reasonable radius, robust and simple system configuration, are the keys to realize stable and broadband mode converting. The optimized internal converter achieves well compatibility with the gyrotron electron-optical system and generates high-purity gaussian beam between 320 GHz ~ 340 GHz.

Spectral Characterization Of Planar Resonators By Terahertz Josephson Spectroscopy **FS-55**

Alexander Snezhko; Yuri Divin; Vladimir Gubankov; Irina Gundareva; Valery Pavlovskiy; Vadim Pokalyakin; Oleg Volkov; Alexander Snezhko

Here, we report the results of spectral analysis of planar open ring resonators by Josephson spectroscopy. Square shape resonators on separate wafers were positioned in the vicinity of YBa2Cu3O7-x bicrystal Josephson junction (JJ). DC characteristics of JJ demonstrated specific features related to resonant modes excitation. Resonators of various sizes were analyzed, and excitation of LC modes at frequencies from 80 GHz to 700 GHz were observed. Resonator quality factors were estimated using resistively shunted model of JJ and resonator equivalent circuit.

Terahertz Superradiance Of An Extended Electron Bunch Moving In An Oversized Corrugated Cylindrical Waveguide **FS-56**

Naum Ginzburg; Ilya Zheleznov; Andrey Malkin; Alexander Sergeev; Irina Zotova; Michael Yalandin

We consider superradiance from an extended relativistic electron bunch moving in a periodically corrugated cylindrical waveguide for the generation of multi-megawatt terahertz pulses. To study this process, we have developed a self-consistent, quasi-optical theory which includes a description of the formation of evanescent wave near a corrugated surface and its excitation by RF current induced in the electron bunch.

Dynamic Measurements At THz Frequencies With A Fast Rotary Delay Line **FS-57**

Hichem Guerboukha; Andrey Markov; Hang Qu; Maksim Skorobogatiy

08:45 - 09:15 **Welcome and Opening Remarks** **Lecture Theatre 1**

Chairpersons: Gun-Sik Park, Emma MacPherson and Benjamin Wah;

A fast rotary delay line is fabricated and characterized for terahertz (THz) frequencies. With this new device, we present dynamic measurements of spray painting process and fast moving objects detection along with thickness determination.

High-harmonic Large Orbit Gyrotrons In IAP RAS **FS-58**

Ilya Bandurkin; Vladimir Bratman; Yuri Kalynov; Ivan Osharin; Andrei Savilov

A series of experiments with Large Orbit Gyrotrons has been carried out in the IAP over years. The experience gained during this time allowed creating efficient electron-optical systems capable of providing high-density axial-encircling beams, which were used for selective gyrotron operation at up to 4th cyclotron harmonic and at the frequencies of up to 1 THz. Novel projects include further optimization of the existing 3rd cyclotron harmonic 1 THz moderately-relativistic gyrotron scheme, as well as creating of a new CW 4th harmonic weakly-relativistic gyrotron for DNP.

Accurate Material Parameter Extraction From Broadband Terahertz Spectroscopy **FS-60**

Nicholas Greenall; Chris Wood; Christopher Russell; Lianhe Li; Edmund Linfield; Giles Davies; John Cunningham; Andrew Burnett

We demonstrate how a transfer function model based parameter extraction method, combined with total variance analysis, allows the extraction of both the complex refractive index and thickness of a sample over a bandwidth of > 6 THz from THz time-domain spectroscopy measurements.

Terahertz Light Bullet-induced Nonlinearity In A Gold Thin Film **FS-61**

Mostafa Shalaby; Carlo Vicario; Christoph. P. Hauri

The concept of metamaterials is of growing importance for manipulating THz pulse characteristics. In nonlinear science, metamaterials have been successfully used to locally enhance the THz field intensity [1], thus overcoming the technological challenge in intense generation. In such structures, local field intensities up to 2.6 GV/m have been demonstrated [2]. These structures are made mainly from gold. However, so far the linear response of gold has been taken for granted in the design and measurements interpretation of such structures. Here, using an intense THz bullet (3.3 GV/m) [3], we show that the dielectric constant of gold is changed under high THz field. We performed our experiment on a thin gold sheet in a THz pump-optical Kerr rotation probe in reflection.

Ultrabroadband Spectroscopy Of Explosives **FS-62**

Sebastian Engelbrecht; Luc Berge; Stefan Skupin; T Wang; Peter Jepsen; Bernd Michael Fischer

This poster will present ultrabroadband spectra of explosives. Plasma based terahertz spectroscopy is used to obtain fingerprints of TNT, TNB, ANTA, HMX and RDX. Due to the enhanced bandwidth much more characteristic features can be observed compared to conventional time domain data.

Terahertz Spectroscopy Used To Distinguish Breast Epithelial Cell Lines **FS-63**

Ju-Hyung Kim; Elizabath Philip; Ursula Triantafillu; Yonghyun Kim; Seongsin Margaret Kim

THz spectroscopy has the potential to be used in identifying and characterizing cell types. In this study, normal 184A1 and metastatic MDA-MB-231 breast epithelial cell lines were characterized using THz spectroscopy as they transitioned from their active to in-active state. A frequency domain scan was performed at set time intervals on both cell lines and the result showed that there is a time domain variation between the scans of the two cell lines that can be used to identify each cell type.

Non-contact Carrier Density Measurement Of Semiconductor Wafers By Terahertz Spectroscopic Ellipsometry **FS-65**

Tomoyu Yamashita; Masayuki Suga; Takanori Okada; Akiyoshi Irisawa; Motoki Imamura

We developed a terahertz ellipsometry system that can measure the complex dielectric characteristics of doped semiconductors and evaluate the carrier density and mobility in a non-destructive, non-contact way. The system is constructed of optical-fiber pigtail-coupled terahertz emitter and detector, and delivers high measurement precision and stability. We demonstrated carrier-density measurement of n-type GaAs wafer and n-type SiC epitaxial film using this system, and confirmed a good agreement with conventional measurement methods.