PROGRAM SCHEDULE

Monday, August 31, 2015

9:20-10:50 Session MoA1 (Advances in THz spectroscopies)
Chair : TOMINAGA Keisuke and NAHATA Ajay Room: 41

9:20-9:45
MoA1.1

A first principle study of THz spectroscopy of molecular crystals

ZHANG Feng [a]; WANG Houng-Wei [b]; TOMINAGA Keisuke [a]; HAYASHI Michitoshi [b]
a)Molecular Photoscience Research Center, Kobe University, Japan, b)Center for Condensed Matter Sciences, National Taiwan University, Taiwan

Terahertz spectroscopy has been a powerful tool of studying lattice vibrations of various systems, in particular, molecular crystals. Molecular crystals consist of molecules being bounded together via a weak coupling, and thus, THz spectroscopy shed the light on the role of the weak coupling on the orientational configuration of each molecule in the crystal. C60, for example, crystal shows complete separation of intramolecular vibration and intermolecular vibration. As the strength of the weak coupling increases such as anthracene, amino acids and etc, we find that the mixing of the intramolecular vibration and intermolecular vibration in the THz region. In this talk, we will discuss recent progress of computational simulation and its applications to molecular crystals and address the relationship between the strength of the weak coupling and the orientational ordering in the crystals.

9:45-10:10
MoA1.2

Polymer Morphology Studied by Terahertz Spectroscopy

HOSHINA Hiromichi; SUZUKI Hal; OTANI Chiko; YAMAMOTO Shigeki; SATO Harumi; OZAKI Yukihiro
RIKEN, Center for Advanced Photonics Terahertzwave Research Group, Japan

In the terahertz (THz) frequency region, absorption spectra of polymer reflect their higher-order conformation and intermolecular interaction. Recent development of THz technology enables rapid and precise spectral measurement, which provides information about polymer crystallization, degradation and water adsorption. We have succeeded to develop method for the assignment of low-frequency vibrational modes of polymers and obtained information of their higher-order conformations. By the temperature dependent THz spectra, the change of the hydrogen-bond interaction and the structure of the polymers during the phase transition were observed. In this talk, potential of terahertz spectroscopy as a new tool for the research of soft materials will be discussed.

10:10-10:35
MoA1.3

Terahertz Measurements of Correlated Motions in Proteins

NIESSEN Katherine [a]; XU Mengyang [a]; MICHKI Nigel [a]; DENG Yanting [a]; SCHMIDT Marius [b]; CODY Vivian [c]; SNELL Edward [c]; MARKELZ A. G. [a];
a)Department of Physics, University at Buffalo, United States, b)Department of Physics, University of Wisconsin, Milwaukee,United States, c)Hauptman Woodward Medical Research Institute, Buffalo, United States

By using near field THz anisotropic absorption measurements on protein crystals we measure long range vibrational motions in proteins. Protein crystals provide an ideal aligned protein sample which is fully hydrated. The crystal anisotropy terahertz microscopy (CATM) measurements are made on lysozyme, dihydrofolate reductase and photoactive yellow protein crystals. We find that the observed absorption bands are dependent on functional state, species and temperature. The measurements establish that the bands arise from the intramolecular vibrations, as opposed to lattice phonons. We will discuss how terahertz measurements of these motions can shed light on long standing questions as to the relevance of such motions in biological function, and allosteric control. In addition, we will discuss how it is possible that such absorption bands can be measured in spite of a rugged energy landscape. We suggest that the existence of the absorption bands indicates preferred directions of motion for a given backbone conformational state. This biasing of sampling of configurations may enable proteins to efficiently access conformational changes necessary to function.

10:35-10:50
MoA1.4st

Sensing the Oxidative Stress in HeLa Cells by using Terahertz Complementary Split-Ring Resonators

HORI Ayaka [a]; SHIRAGA Keiichiro [a]; MIYAMARU Fumiaki [b]; SUZUKI Tetsuhito [a]; KONDO Naoshi [a]; OGAWA Yuichi [a] *a)Graduated school of Agriculture, Kyoto University, Japan, b)Department of Physics, Faculty of Science, Shinshu University, Japan*

Complementary Split-Ring Resonators (CSRRs) are a type of metamaterial with a periodic metal structure. CSRRs have electromagnetic responses, dependent on their structure, that unusually transmit incident waves at a specific resonant frequency. With CSRRs small changes in the imaginary part of the complex dielectric constant of a sample can be detected as a big change in reflectance and thus have attracted recent attention as a potential sensitive bio-sensor. We investigated the potential of CSRRs in the terahertz (THz) region to detect oxidative stress in HeLa cells by directly culturing these cells on CSRRs, and then measuring reflectance every hour after hydrogen peroxide (H_2O_2) stress was applied. The results showed CSRR resonance, measured using reflectance spectroscopy, was attenuated after adding H_2O_2. In the THz region complex dielectric constant reflects water dynamics. We hypothesize that the properties of intracellular water change as a result of the expression or denaturing of some proteins within the cell when oxidative stress is applied to the cells, this in turn modifies the hydrogen-bond network structure of intracellular water. Thus, our results demonstrate that THz-CSRRs can be sensitive sensors of oxidative stress in living cells.

11:10-12:40 Session MoA2 (THz imaging and spectroscopy)
Chair : SASAKI Tetsuo and MARKELZ Andrea G. Room: 41

11:10-11:35
MoA2.1

Terahertz real-time imaging based on uncooled antenna-coupled bolometer arrays developed at CEA-LETI: review and perspectives

SIMOENS Francois ; MEILHAN Jérôme
CEA Leti-MINATEC, France

Uncooled microbolometer focal plane arrays (FPAs) that are tailored specifically for terahertz (THz) sensing are increasingly recognized as a relevant technology for fast, compact and hand-held imaging cameras. Owing to its advanced know-how in thermal infrared bolometer sensors, CEA-Leti has designed and prototyped proprietary QVGA THz bolometer array architectures. In particular, the use of antennas and a thick resonant cavity for optical radiation coupling provides high versatility - in frequency and polarization sensing - as well state-of-the art sensitivity in real-time video operation mode. The technological approach and the performances of the cameras will be reviewed. The capabilities of these THz arrays to be applied to real applications will also be illustrated as well as future perspectives of this promising THz technology.

11:35-12:00
MoA2.2

Plasmonics-Enabled Advancements in Terahertz Imaging and Spectroscopy Systems

JARRAHI Mona
Electrical Engineering Department, University of California Los Angeles, United States

In this talk I will describe some of our recent results on developing new terahertz imaging and spectroscopy systems based on plasmonic terahertz radiation sources and detectors, which offer orders of magnitude higher signal-to-noise ratio levels compared to existing terahertz imaging and spectroscopy systems. In specific, I will introduce new designs of high-performance photoconductive terahertz sources and detectors that utilize plasmonic electrodes to offer significantly higher terahertz radiation powers and detection sensitivities compared to the state of the art. Utilizing plasmonic nanostructures in a photoconductive source and detector allows concentrating a larger fraction of the incident pump photons within nanoscale distances from the contact electrodes. By reducing the average transport path of photocarriers to the contact electrodes, the device ultrafast photocurrent is significantly enhanced and the optical-to-terahertz power conversion efficiency of photoconductive sources and detection sensitivity of photoconductive detectors are increased considerably. This enhancement mechanism is universal and has been widely used in various photoconductive terahertz sources and detectors with a variety of device architectures and in various operational settings, demonstrating significant optical-to-terahertz conversion efficiency and terahertz detection sensitivity enhancements.

12:00-12:25
MoA2.3

Challenges in Terahertz Cancer Imaging

SON Joo-Hiuk
University of Seoul, Korea

Terahertz (THz) radiation has unique characteristics for cancer imaging. Most significant properties are the non-ionization due to low photon energy, the high sensitivity to water molecules, and the capability of spectroscopic analysis. Except the radiation safety, these advantages are not fully utilized in cancer imaging. The sensitivity to water molecules helps probe the dynamics of biological samples but also limits the penetration depth of THz radiation into water-abundant tissues. This difficulty can be overcome by using several techniques such as paraffin-embedding, freezing, and the use of penetration enhancing gels. The spectral fingerprints have been measured with nucleobases, which are components of DNAs and RNAs, but the resonant features of DNAs and RNAs are hardly discovered. However, the resonances of such macromolecules can be measured during the progress of biochemical changes such as getting diseased with cancer. The mechanisms of showing fingerprints are to be discussed and the examples with several cancer DNAs will be shown in the presentation. The contrast enhancing techniques for cancer imaging will also be explained. In conclusion, the author believes that there are some points where terahertz imaging can contribute to the real-world cancer diagnosis.

12:25-12:40
MoA2.4

Terahertz spectroscopy of biochars and related aromatic compounds

LEPODISE Lucia [a]; HORVAT Joseph [b]; LEWIS Roger A. [b]
a)Department of Physics and Astronomy, Botswana International University of Science and Technology, Botswana, b)Institute of Superconducting and Electronic Materials and School of Physics, University of Wollongong, Australia

Soils are complex mixtures. Nonetheless, a range of soils are now beginning to be probed using terahertz spectroscopy. For example, the fertile soil of the Amazon Basin known as terra preta is characterized by a high content of charcoal. Various chemical and physical analytical methods have been directed to determining the origin of the high fertility but with little success to date. Recently, we have demonstrated that differently sourced biochars may be distinguished using terahertz spectroscopy. Both terahertz time domain spectroscopy and conventional Fourier-transform interferometry have been employed. To determine the origin of the absorption features that appear in the complex spectra, we have investigated in detail two related carbon-based systems, namely benzoic acid and two derivatives and 2,4-dinitrotoluene. To provide additional information we have cooled the samples from room temperature to 7 K. Reducing the temperature results in the sharpening of lines, the appearance of new lines, usually and increase in absorption strength, and both red and blue shifts. Our various experimental data have been numerically modeled by density functional theory employing several functionals. Many of the absorption modes have been successfully identified, but further work is needed to make the identification of all modes unambiguous.

15:40-17:10 Session MoP1 (Cutting edge THz sources and devices)
Chair : NAKAJIMA Makoto and HESLER Jeffrey L. Room: 41

15:40-16:05
MoP1.1

Room-temperature oscillation of resonant tunneling diodes close to 2 THz and their functions for various applications

ASADA Masahiro; SUZUKI Safum
Dept of Electrons and Applied Physics, Tokyo Institute of Technology, Japan

Compact and coherent source is a key component for various applications of the terahertz wave. We report on our recent results of terahertz oscillators using resonant tunneling diodes (RTDs). The RTD is an InGaAs/AlAs double-barrier structure integrated with a micro-slot antenna. To achieve high-frequency oscillation, the electron delay time in RTD, which degrades the negative differential conductance, was reduced with a narrow quantum well and an optimized collector spacer thickness. The former reduces the electron dwell time in the resonant tunneling region, and the latter simultaneously minimizes the electron transit time and the capacitance in the collector depletion region. The conduction loss of the resonance circuit was also reduced with a wide air-bridge between the RTD and slot antenna. By these structures, a fundamental oscillation up to 1.92 THz was obtained at room temperature. We also fabricated an oscillator with reduced parasitic elements around the RTD for high-speed direct modulation, and obtained direct intensity modulation up to 30 GHz. This result is useful for high-speed wireless data transmission. By integrating a varactor, wide frequency sweep of 580-700 GHz in a single device and 580-900 GHz in a 4-element array were also demonstrated, which expands possible applications of RTD oscillators.

16:05-16:30
MoP1.2

Efficient terahertz-wave generation in mid-infrared quantum cascade lasers with a dual-upper-state active region

FUJITA Kazuue; HITAKA Masahiro; ITO Akio; DOUGAKIUCHI Tatsuo; EDAMURA Tadataka
Central Research Laboratories, Hamamatsu Photonics K.K., Japan

The 1-6 THz spectral range still lacks high performance compact semiconductor sources operable at room temperature. Recently, THz sources based on intracavity difference-frequency generation (DFG) in dual-wavelength mid-infrared (mid-IR) quantum cascade lasers (QCLs) have been demonstrated. These devices, known as THz DFG-QCLs, have their active region engineered to have giant intersubband nonlinear susceptibility $\chi^{(2)}$ for THz DFG. Upon application of bias current they generate two mid-IR pump frequencies that are converted via DFG into THz frequency in the same laser cavity. Such approach does not require maintaining population inversion in a QCL and these devices can operate at and above room temperature. Currently, only active region designs with single upper laser state and a multitude of the lower laser states were utilized for the THz DFG-QCLs. Here we report THz DFG-QCL devices based on a principally-different active region design with the anti-crossed dual-upper-state (DAU) concept. Our calculations indicate that DAU active region design may offer higher nonlinearity for THz DFG compared to the active region designs used previously. Experimentally, proof-of-concept devices demonstrate single-mode THz emission at ~2.9 THz at room temperature with mid-IR-to-THz conversion efficiency of 0.8 mW/W2, which is a record-high number for THz DFG-QCLs operating below 3 THz.

16:30-16:55
MoP1.3

Graphene electronics and integrated III-V diode circuits for terahertz applications

STAKE Jan

Department of Microtechnology and Nanoscience, Chalmers University of Technology, Sweden

Compact heterodyne receivers operating in the terahertz range are needed for earth observation instruments, space science missions (e.g. ESA's "Jupiter icy moons explorer - JUICE") and in the millimeter wave region for ground-based applications such as security scanners. Existing terahertz heterodyne receivers are usually bulky due to complex hybrid integration and there is a strong need for a terahertz monolithic integration circuit ("TMIC") platform that allows for higher circuit functionality, ease of assembly, and low loss at terahertz frequencies. Moreover, this part of the electromagnetic spectrum, where optical and microwave techniques meet, call for an integration scheme that can support both active THz electronics & photonics. A possible solution is heterogeneous integration of THz devices (III-V, graphene) on a silicon carrier, which also allows for advanced micromaching of passive components and interconnects such as waveguides and antennas. Progress on graphene THz detectors and integrated diode circuits for terahertz applications will be presented.

16:55-17:10
MoP1.4

Multi-Extreme THz ESR: Its Developments and Applications

OHTA Hitoshi [a, b]; OKUBO Susumu [a]; OHMICHI Eiji [b]; SAKURAI Takahiro [c]

a)Molecular Photoscience Research Center, Kobe University, Japan, b)Graduate School of Science, Kobe University, Japan, c)Center for Supports to Research and Education Activities, Kobe Unversity, Japan

Recent developments and applications of our multi-extreme THz electron spin resonance (ESR) in Kobe will be presented. Our system can cover the wide frequency region between 0.03 to 7 THz using Gunn oscillators, multipliers, backward wave oscillators (BWO) and optically pumped far-infrared (FIR) laser. Transmitted light is detected by liq. He cooled InSb hot electron bolometer. We can combine the multi-extreme conditions, such as low temperature, high magnetic filed, and high pressure, with this THz ESR system. The temperature can go down to 1.8 K. The magnetic field can go up to 55 T using the pulsed magnetic field. The pressure can be applied up to 2.1 GPa using the transmission-type pressure cell. Moreover, we have also developed micro-cantilever ESR, which enables the detection of micrometer size crystal using the micrometer size cantilever. We name these combined system as the multi-extreme THz ESR. As an application, high pressure THz ESR measurement of Shastry-Sutherland model substance $SrCu_2(BO_3)_2$ will be presented. Our high pressure THz ESR measurement at 2 K in the frequency region up to 0.645 THz revealed the linear decrease of the excitation gap up to 1.51 GPa. Proposed pressure induced phase transition at 2 GPa will be discussed.

17:30-18:50 Session MoP2 (THz metamaterials and their applications)
Chair : KADOYA Yutaka and ESTACIO Elmer S. Room: 41

17:30-17:55
MoP2.1

THz time-domain spectroscopy using an achromatic wave plate based on the stacked parallel metal plates

NAGAI Masaya

Graduate School of Engineering Science, Osaka University, Japan

We proposed an achromatic terahertz wave plate composed of stacked parallel metal plates. It is an effective medium with the controllable birefringence, and has the advantages of cost, size, versatility, and available bandwidth. We fabricated parallel plate waveguides with a through-hole array and that with a pillar array on the surface of the metal sheets. The center available frequencies of achromatic wave plates were tuned from 0.5 THz to 2.5 THz. Using them, we performed THz time-domain spectroscopy for an InSb wafer in the reflection geometry to evaluate the reflection coefficient for the circular polarization. The field amplitude and the phase of the detected THz pulses modulated by the magnetic field directly reflect the circular dichroism and the optical rotation, respectively, which are critical for the magneto-optical Kerr spectroscopy.

17:55-18:20
MoP2.2

Terahertz Plasmonics and Metamaterials Using Unconventional Metals

GUPTA Barun; PANDEY Shashank; PAULSEN Andrew; NAHATA Ajay
University of Utah, United States

The field of plasmonics has developed rapidly over the last decade, in large part, because the use of metals allow for unique capabilities in controlling and manipulating the propagation properties of electromagnetic radiation. The overwhelming fraction of work in these two areas has relied on the use of conventional metals, such as gold, silver and aluminum. While the materials work extremely well, their structure and physical properties constrain the range of allowable applications. A much broader array of materials (i.e. exotic metals) also work well for these applications, since they exhibit electrical conductivities that are sufficiently high. The primary rationale for using such materials is that they can allow for added functionality or spur the development of new fabrication techniques. In this talk, we briefly describe the dielectric properties of conventional metals in the THz spectral range using a new characterization approach, along with several recent demonstrations of THz plasmonics structures using materials that are unconventional for this application.

18:20-18:35
MoP2.3

Terahertz Single Pixel Imaging with Metamaterials

PADILLA Willie J. [a,b]; WATTS Claire [b]; MONTOYA John [a,c]; KRISHNA Sanjay [c]; NADELL Christian C. [a]
a)Department of Electrical and Computer Engineering, Duke University, United States, b)Department of Physics, Boston College, United States, c)Department of Electrical and Computer Engineering, University of New Mexico, United States

Imaging is a critical technology enabled by numerous devices that has shaped our modern world. Although significant worldwide efforts continually strive to make long wavelength imaging a commercial reality, terahertz imaging is ultimately restricted by a fundamental limit related to noise. Recent work in compressive sensing demonstrated that signals and images can be acquired with far fewer measurements than that previously believed necessary, thus making terahertz imaging potentially more viable. Compressive imaging, however, requires much post processing and there is ambiguity in the final recovered images. Here we demonstrate an alternative approach to increase imaging rates using metamaterials. We experimentally demonstrate an all-electronic metamaterial spatial light modulator capable of significant gains in the channel efficiency of a single-pixel, metamaterial-based imaging system. Our imaging technique is deterministic and demonstrates a new path forward for terahertz imaging.

18:35-18:50
MoP2.4

Magnification of sub-wavelength images to far-field images with hyperbolic metamaterials in terahertz region

MIYAMARU Fumiaki [a, b]; MURAI Kotaro [a]; FURUIE Tetsuro [a]; NISHIDA Tsubasa [a]; NAKATA Yosuke [b]; HAYASHI Shinichiro [c]; NAWATA Kouji [c]; MINAMIDE Hiroaki [c]; TANI Masahiko [d]; TAKEDA Mitsuo [a]
a)Department of Physics, Faculty of Science, Shinshu University, Japan, b)Center for Energy and Environmental Science, Shinshu University, Japan, c)Tera-photonics Research Team, RIKEN, Japan, d)Research Center for Development of Far-Infrared Region, University of Fukui, Japan

The magnification of a sub-wavelength image to a far-field image was demonstrated in terahertz (THz) region by using hyperbolic magnifying lens. Our hyperbolic magnifying lens consists of a metallic wire array arranged periodically. The period of the metallic wires is about 10 μm at the input side while the period of the metallic wires is expanded to be about 60 μm, which indicates that the image at the input surface is magnified 6 times at the output surface. When the double metallic slit (slit width 200 μm, slits pitch 400 μm) is attached on the input surface, we observe the THz intensity distribution (at 0.5 THz) of the two peaks with about 2400 μm pitch. This result indicates that the sub-wavelength image created at the input side can be magnified to the far-field image transferred at the output side.

Tuesday, September 01, 2015

9:00-10:30 Session TuA1 (THz sources and spectroscopies)
Chair : UZAWA Yoshinori and STAKE Jan Room: 41

9:00-9:25
TuA1.1

Terahertz spectroscopy with a single frequency comb

BAKUNOV Michael I.; SKRYL Anton S.; PAVELYEV Dmitry G.
University of Nizhny Novgorod, Russia

We report a new spectroscopic technique based on heterodyne detection of a photonically generated terahertz frequency comb via its nonlinear mixing with a harmonic of a CW signal from a microwave frequency synthesizer. The comb is generated in a photoconductive antenna by a femtosecond laser pulse train. A superlattice diode is used as a nonlinear mixer. The spectral resolution of the technique is determined by the repetition rate of the pump laser (100 MHz) and exceeds the resolution of THz-TDS by an order of magnitude. By using a laser with a tunable repetition rate, the resolution can be further increased by several orders of magnitude. For example, in measuring the absorption profile of a rotational transition of OCS, we achieved the spectral resolution as high as ~50 kHz. The spectral coverage of the technique is determined by the nonlinear properties of the mixer and in our experiments was as large as several hundred gigahertz.

9:25-9:50
TuA1.2

Development of DESHIMA: Superconducting On-chip Spectrometer for Submillimeter Wave Cosmology

ENDO Akira [a,b]; YATES Stephen [c]; BUENO Juan [d]; THOEN David [b]; MURUGESAN Vignesh [c]; ISHII Shun [e]; BARYSHEV Andrey M. [C, f]; KLAPWIJK Teun M.K. [b, g]; WERF Paul P. van der [h]; BASELMANS Jochem J.A. [a, c]
a) Department of Electrical Engineering, Faculty of Mathematics and Computer Science (EEMCS), Delft University of Technology, The Netherlands, b) Delft University of Technology, Kavli Institute of Nanoscience, Department of Quantum Nanoscience, The Netherlands, c) SRON Netherlands Institute for Space Research, The Netherlands, d) SRON Netherlands Institute for Space Research, The Netherlands, e) Institute of Astronomy, University of Tokyo, Japan, f) Kapteyn Astronomical Institute, University of Groningen, The Netherlands, g) Physics Department, Moscow State Pedagogical University, Russia, h) Leiden Observatory, Leiden University, The Netherlands

The advent of Kinetic Inductance Detectors (KIDs) has enabled millimeter-submillimeter wave instruments with >10,000 detector elements. This has opened up the possibility to simultaneously sample data over very large ranges, either spatially, or spectroscopically, or an (arbitrary) mixture of both. We are developing a new instrument DESHIMA (Deep Spectroscopic High-redshift Mapper), which takes advantage of the multiplexability of KIDs to realize an ultra-wideband spectrometer to cover the entire submillimeter band (326-905 GHz), with a frequency resolution of f/df = 500 and up to 7 spatial pixels. DESHIMA is remarkably compact, thanks to the on-chip filterbank spectrometer design, and also the adoption of an adiabatic demagnetization refrigerator (ADR) to operate the KIDs at 150 mK. The filterbank spectrometer chip consists of the following components: (1) a leaky-lens antenna to couple a linearly polarized beam to a coplanar waveguide (CPW) over the wide DESHIMA band, (2) an array of superconducting narrow band filters, each being a quarter-wavelength CPW resonator made of superconducting NbTiN, and (3) NbTiN/Al hybrid CPW KIDs. In the conference we will give an overview on the recent progress of DESHIMA, focusing especially on the development of the on-chip filterbank.

9:50-10:15
TuA1.3

Broadband THz spectroscopy of semiconductors using laser-induced plasma as a THz source

YAMAGUCHI Masashi
Department of Physics, Applied Physics, & Astronomy, Rensselaer Polytechnic Institute, United States

THz spectroscopy has been playing a crucial role in materials studies. However, the bandwidth of THz pulses generated in solid state sources such as EO crystals and antenna devices are often limited by the phonon absorptions of the THz source itself, and the benefits of THz spectroscopy is often not fully utilized. In this talk, we present the broadband THz pulses from laser-induced plasma in nitrogen gas which covers over 20 THz bandwidth. We will present coherent phonon excitation by broadband THz pulses in GaAs and InSb. Excited coherent phonons are monitored by optical probe through the induced reflectivity change and the EO detection. A single and double THz pump excitation were used. We observed oscillations in (110) GaAs wafer while no oscillation in (100) wafer contrast to the optical excitation case. We have observed two phonon modes at TO and LO phonon frequency, while LO phonon is infrared inactive in normal incident condition. From the orientation dependence, the oscillation at LO frequency was assigned to the phonon-polariton mode in the upper branch. With double THz pulse excitation, we have observed the constructive and destructive interference of coherently excited phonon modes at 8.0 THz and 8.7THz.

10:15-10:30
TuA1.4

Terahertz diagnostics of ultra-short pulses at high repetition rates fromrelativistic electron sources

BRÜNDERMANN Erik [a,b]; MÜLLE Anke-Susanne [c]; HIROMOTO Norihisa [d]; INOKAWA Hiroshi [e]
a) Accelerator Research, *Institute for Photon Science and Synchrotron Radiation (IPS), Karlsruhe Institute of Technology (KIT), Germany, b)Nanovison Technology, Graduate School of Science and Technology, Shizuoka University, Japan, c)Institute for Photon Science and Synchrotron Radiation (IPS), Karlsruhe Institute of Technology (KIT), Germany, d)Terahertz Vision Laboratory, Mechanical Engineering, Graduate School of Engineering, Shizuoka University, Japan, e)Research Institute of Electronics, Shizuoka University, Japan*

Optimization of current and the development of future light sources based on electron accelerators and storage rings is closely intertwined with advances in terahertz techniques and short pulse diagnostics. Electron beam diagnostics currently includes various types of electrooptic sampling, streaking techniques, terahertz spectroscopy, imaging, and time domain analysis. Storage rings can provide terahertz radiation in short pulses at high repetition rates in the MHz to GHz range. This challenges current data acquisition, data processing, and data storage methods, but also enables to monitor electron beams on short time scales and with large statistics. Terahertz technologies are also explored to detect single short electron bunches consisting of relativistic electrons by direct diagnostics or, indirectly, via the short emitted photon pulses consisting of terahertz transients in the sub-ps to fs time scale, which drives various concepts to reach such extreme-performance diagnostics, mainly, array technology.

13:30-14:15 Special Session SP1.1 (International Year of Light 2015)
Chair : HIROMOTO Norihisa Room: 41

13:30-14:15
SP1.1

Semiconductor Lasers for Optical Fiber Communications and Evolving Society

SUEMATSU Yasuharu
Honorary Professor of Tokyo Institute of Technology

Progress of dynamic single mode Lasers (DSM lasers), semiconductor lasers for ultrahigh-capacity and long-distance optical fiber communication, is reviewed with the social impact.

14:15-15:45 Session TuA2 (New THz sources)
Chair : NAGAI Masaya and SON Joo-Hiuk Room: 41

14:15-14:40
TuA2.1

Terahertz emission characteristics of MBE-grown GaAs and InAs-based film and nanostructures:interface and surface modification effects

ESTACIO Elmer S. [a]; SOMINTAC Armando [a]; SALVADOR Arnel [a]; YAMAMOTO Kohji [b]; TANI Masahiko [b]
a) National Institute of Physics, University of the Philippines-Diliman, Philippines, b) Research Center for Development of Far Infrared Region, Unversirsity of Fukui, Japan,

Current research being undertaken at the National Institute of Physics, University of the Philippines on the terahertz (THz) radiation characteristics of GaAs- and InAs-based thin films grown via molecular beam epitaxy (MBE) will be presented. Firstly, we will report on the MBE growth of GaAs and InAs thin films on GaSb substrates. The films are characterized using standard techniques and their THz emission properties were compared with a bulk p-InAs surface emitter. Secondly, a novel MBE-growth design involving the inclusion of a thin n-type GaAs buffer layer in a low-temperature-grown GaAs film to enhance the THz emission, will be presented. The surface modification of GaAs and InAs with the deposition of wide bandgap aluminum nitride leading to enhanced THz emission will then be discussed. These research activities are carried out with the goal of eventually designing a surface-modified and novel MBE-grown semiconductor film for device fabrication as a THZ photoconductive antenna. Finally, very recent results on the experimental observation of THz emission in InAs pyramidal quantum dots on GaAs substrates, via surge current mechanism will be reported. The results lend proof to the existence of a strain-induced permanent dipole in InAs/GaAs quantum dots. "

14:40-15:05
TuA2.2

Antennas for Terahertz Applications

RAHARDJO Eko Tjipto [a]; APRIONO Catur [a,b]; HIROMOTO Norihisa [b]
a) Department Electrical Engineering, Universitas Indonesia, Indonesia, b) Graduate School of Science and Technology, Shizuoka University, Japan

Terahertz (THz) technology is now becoming attract more interest for various applications. Antenna is a device that play an important role in this area. This paper present an overview of the development THz antennas. Two types THz antennas have been developed i.e. conventional or traditional antenna and photoconductive antenna. Highlight including discussion of the earlier up to recently antenna types use in THz is presented.

15:05-15:30
TuA2.3

Bright terahertz-wave generation and real-time imaging using nonlinear optical effect

MINAMIDE Hiroaki
Tera-Photonics Research Team, RIKEN Center for Advanced Photonics, Japan

Recently, a remarkable breakthrough related to radiation peak-power over ten kilowatt or broad-band frequency-tunability covering tens of THz frequency were achieved using nonlinear optical wavelength-conversion in a MgO doped $LiNbO_3$ or organic nonlinear crystals of DAST and BNA. Moreover, highly sensitive detection of terahertz-waves with wide dynamic range using frequency up-conversion at room temperature was obtained. In nondestructive sensing applications, THz imaging has attracted a lot of interests for more than 10 years. But real time, high sensitive, low cost THz imaging in room temperature, which is widely needed by fields such as biology, biomedicine and homeland security, has not been fully developed yet. A lot of approaches have been reported on the raster scanning imaging technologies or using THz cameras with photoconductive antenna or microbolometer integrated. But they still have much limitation.
Our current research has proved that THz detection by nonlinear frequency up-conversion offers fast response up to nanosecond scale, and very high sensitivity with orders higher than Bolometer, attributed to the high nonlinear coefficient of the 4-Dimethylamino-N-Methyl-4-Stilbazolium Tosylate (DAST) crystal. This talk describes advanced studies of intense THz-wave generation, the sensitive detection, and the real-time THz-wave imaging.

15:30-15:45
TuA2.4

Terahertz radiation from gold nanorod arrays excited by femtosecond laser pulses

TAKANO Keisuke [a]; KOMIYAMA Hideaki [b]; ASAI Motoki [a]; KATO Kosaku [a]; IYODA Tomokazu [b,c]; TADOKORO Yuzuru [a]; NAKAJIMA Makoto [a]; HANGYO Masanori [a]
a)Institute of Laser Engineering, Osaka University, Japan, b)JST-ERATO Iyoda Supra-Integrated Material Project, Japan, c) Chemical Resources Laboratory, Tokyo Institute of Technology, Japan

Surface of metals exhibits a nonlinear optical response. By irradiation of femtosecond laser pulses, the wavelength of the laser can be converted to that of the terahertz waves via the nonlinearity of the metallic surfaces. The nonlinearity of the metallic surface is attributed to the modulation of the electron density owing to the incident electric fields. The electric fields can be enhanced and designed by nanostructures. In this work, we demonstrate the radiation of the terahertz waves from vertically standing gold nanorod arrays excited by femtosecond laser pulses. The terahertz radiation is generated by the second-order nonlinear optical effect enhanced by the plasmon resonance of the gold nanorod arrays. The conversion efficiency is compared to the conventional nonlinear optical crystals.

16:00-17:15 Session TuP1 (Applications of THz radiation)
Chair : HOSHINA Hiromichi and RAHARDJO Eko Tjipto Room: 41

16:00-16:25
TuP1.1

Non-destructive thickness measurement system for paint multilayer based on femtosecond fiber laser technologies

SUDO Masaaki; TAKAYANAGI Jun; OTAKE Hideyuki
Aisin Seiki Co., Ltd., JAPAN, Aisin Seiki Co., Ltd., Innovation Center, Japan

Optical systems based on optical fiber devices are generally robust from external interference. So, they can be applied industrially for reliable systems in various fields. In this paper, we describe fiber lasers generating femtosecond pulses that use optical fibers as gain media and optical path. We also represent examples of application for non-destructive paint multilayer thickness measurement of automotive parts using terahertz wave generated and detected by femtosecond fiber laser systems

16:25-16:50
TuP1.2

Terahertz MMICs and Antenna-in-package Technology at 300 GHz for KIOSK

Download System
TAJIMA Takuro; SONG Ho-jin; KOSUGI Toshihiko; HAMADA Hiroshi; MOUTAOUAKIL Amine El ; SUGIYAMA Hiroki; MATSUZAKI Hideaki ; YAITA Makoto ; KODAMA Satoshi ; KAGAMI Osamu
NTT Science and Core Technology Laboratory Group, NTT Device Technology Laboratories, Japan
Toward the realization of ultra-fast wireless communications systems, terahertz (THz) waves are attracting great interest, especially for short-distance applications. In this talk, we will present the recent progress in InP MMICs and packaging techniques based on LTCC technology. In addition, we will demonstrate wireless data transmission at 20 Gbps with the simple ASK modulation scheme for KIOSK data downloading.

16:50-17:15
TuP1.3 **Development of THz Test & Measurement Instrumentation to 1.6 THz**
HESLER Jeffrey L. ; BRYERTON Eric W. ; KOLLER Daniel
Virginia Diodes Inc., United States
In recent years commonly available microwave test & measurement capabilities such as signal generators, spectrum analyzers, and network analyzers have been extended up to 1.1 THz. For example, a VNA extender to 0.75-1.1 THz has been developed with 65 dB dynamic range and -35 dBm test port power [1]. The availability of these instruments has helped enable the development of new THz components and devices, e.g. the first transistor with gain above 1 THz [2]. This article will discuss the extension of these test capabilities to 1.6 THz. The technologies that will be discussed include: - The development of waveguide interfaces in the WM-164 (1.1-1.7 THz) frequency band. The design of this interface and its measured performance will be discussed. A frequency multiplier based source covering 1.1-1.5 THz with a typical measured output power of 1 uW A heterodyne receiver with conversion loss of 20-25 dB typical over the frequency range 1.1-1.6 THz - Initial vector S-parameter measurements in the 1.1-1.5 THz band

---

17:30-19:10 Session TuP2 (Electromagnetic metamaterials: Memorial session for Prof. Hangyo)
Chair : TANI Masahiko and BAKUNOV Michael I. Room: 41

17:30-17:55
TuP2.1 **Polarization property of terahertz wave emission from gammadion-type photoconductive antennas revisited**
ISHIHARA Teruya
Solid State Photo-Physics Froup, Department of Physics, Tohoku University, Japan
In order to commemorate the deceased Professor Hangyo, I review our collaboration work on terahertz wave emission from gammadion-shaped photoconductive antennas. Terahertz emission from gammadion-shaped photoconductive antennas prepared with a superfine ink-jet printer was experimentally investigated. Finite difference time domain simulation reproduces the observation fairly well.

17:55-18:20
TuP2.2 **Application of Terahertz field enhancement effect in metal microstructures**
NAKAJIMA Makoto [a]; TADOKORO Y [a].; TAKANO K. [a]; KURIHARA T.[b]; YAMAGUCHI K. [b]; WATANABE H.[b]; OTO K.[c]; SUEMOTO T.[b]; HANGYO M.[a]
a)Institute of Laser Engineering, Osaka University, Japan, b)ISSP, the University of Tokyo, Japan, c)*Department of Physics, Chiba University, Japan*
Nonlinear phenomena induced by high intensity Terahertz pulse irradiation have attracted much attention recently. In this study, the phenomena induced by the enhanced electric or magnetic Terahertz field in the metal microstructures are demonstrated. Subwavelength metallic structures have the ability to create a strongly enhanced field in the vicinity of the structures. First, the enhanced electric Terahertz field in metal particles induces an irreversible electric conductivity change. The electrical resistance falls down several orders for packed aluminum or copper particles whose diameters are as large as 30 micrometers by single-shot terahertz intense pulse irradiation. It is confirmed that the electron conduction paths are induced in a direction parallel to polarization of incident THz pulse. This phenomenon is induced by strongly enhanced electric field in the nanometers gap between the metal particles. Second, the enhanced magnetic Terahertz field induces the spin precession with large amplitude in magnetic material. The metallic split ring resonator was fabricated on a surface of orthoferrite $ErFeO_3$. The irradiated THz electric field induces the enhanced magnetic near-field in the direction perpendicular to surface. We succeeded in enhancing the spin precession amplitude by ~ 8 times using by split ring resonator metamaterial.

18:20-18:45

TuP2.3

Transmission Line Metamaterials for Transformation Electromagnetics

SANADA Atsushi; NAGAYAMA Tsutomu

Graduate School of Science and Engineering, Yamaguchi University, Japan

Transmission line approach has been presented to realize wideband and low loss operation of metamaterials. The approach is based on an equivalent circuit model with circuit elements that is directly determined by the physical material parameters, and therefore, the parameters can be controlled individually. This is especially useful for designing a material based on the transformation electromagnetics in which full control of anisotropy of permittivity and/or permeability is required. In this paper, the transmission line metamaterials is presented. A carpet cloak of invisibility is designed and its operation of invisibility is demonstrated by the circuit simulation.

18:45-19:10

TuP2.4

Frequency-independent transmission characteristic of self-complementary checkerboard-like screens

KITANO Masao; URADE Y; NAKATA Y.; NAKANISHI T

Graduate School of Engineering, Kyoto University, Japan

According to Babinet's principle, it has been shown that self-complementary metallic screens such as checkerboards show a frequency-independent response due to their self-complementary symmetry. However, this property had never been observed before because the ideal checkerboard geometry contains singular metallic point contacts, which cannot be realized. In this paper, we propose to replace these singular point contacts with resistive patches with appropriate sheet impedance. By controlling the sheet impedance, we can realize the intermediate states between the connected state and the disconnected one of the metallic parts. The self-complementary condition on the resistive checkerboard-like structure is theoretically formulated by Babinet's principle extended to the screens composed of resistive element. Then, the resistive checkerboard-like structure is fabricated and experimentally characterized by the terahertz time-domain spectroscopy. It is confirmed that the screen exhibits a nearly frequency-independent transmission spectrum. This phenomenon is universal because it is based on the symmetry of structures. Therefore, this knowledge plays important roles not only in the terahertz regime but also in the other regions of electromagnetic spectra.