14:00-15:40 Poster Session Pos1

Room ; 43, 44

Pos1.01 **THz Wave Absorbance Properties of $YBa_2Cu_3O_{7-\delta}$ Systems Superconductor**

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We report an investigation of the THz wave absorbance properties of Y-Ba-Cu-O (YBCO) superconductor systems. $YBa_2Cu_3O_{7-\delta}$ samples were baked at 900ºC and then mixed with polyethylene powder. Portions of 6 mg of the mixed samples were molded into pellets. Using a THz spectroscopy system, the frequency could be tuned from 0.5 to 6.0 THz. Samples were measured at 70 K (below the YBCO superconducting transition temperature) and 300 K, and the respective THz absorbance spectra of $YBa_2Cu_3O_{7-\delta}$ were compared. The 300 K spectrum featured several absorbance peaks, for instance, at around 3.0 and 4.2 THz. However, these peaks were absent in the 70 K spectrum. We assume that these THz absorbance peaks arose from defects or structural vibrations in the YBCO crystals, which would influence the superconductive mechanism. On the basis of the results obtained in this study, we propose that THz spectroscopy offers a novel and suitable analysis system for superconductor materials.

Pos1.02st **Carrier Lifetime Evaluation for Low Temperature-Grown GaAs Using Terahertz Emission by Double Optical Pump**

MAG-USARA Valynn Katrine [a]; FUNKNER Stefan [a]; NIEHUES Gudrun [a]; PRIETO Elizabeth Ann [b]; SOMINTAC Armando [b]; ESTACIO Elmer [b]; SALVADOR Arnel [b]; YAMAMOTO Kohjo [a]; KITAHARA Hideaki [a]; HASE Muneaki [c]; TANI Masahiko [a]
a)University of Fukui , b)Univercity of the Philippines, c)University of Tsukuba

We propose and demonstrate the use of a "double optical pump" technique in terahertz time-domain spectroscopy (THz-TDS) as an alternative method to obtain information on the lifetime of photo-excited carriers in semiconductors. In a "double optical pump" THz-TDS configuration, photo-excited carriers are generated on a semiconductor sample by a carrier injection pump pulse and the terahertz emission generated by a signal generation or reference pump pulse is observed. Since the surface electric field is screened by optical carriers, the THz emission amplitude is expected to change with the relative time delay between the two optical pump pulses due to carrier decay. We applied this technique for evaluation of the carrier lifetime in low temperature-grown gallium arsenide (LT-GaAs). The carrier lifetime values deduced from "double optical pump" THz emission decay curves show good agreement with data obtained from transient photo-reflectance measurements done on the same LT-GaAs samples grown at 200ºC-310ºC.

Pos1.03 **Minute-sample terahertz spectroscopy using a metal parallel-plate waveguide with tapered-structure**

YAMAMOTO Kohji [a]; KURIHARA Kazuyoshi [b]; KUWASHIMA Fumiyoshi [c]; MORIKAWA Osamu [d]; TANI Masahiko [a]
a)Research Center for Development of Far-Infrared Region, University of Fukui, Japan, b)Department of Physics, Faculty of Education and Regional Studies, University of Fukui,Japan, c)Department of Electrical, Electronics and Computer Engineering, Fukui University of Technology, Japan, d)Japan Coast Guard Academy, Japan

We have investigated the feasibility of minute-sample terahertz spectroscopy using a metal parallel-plate waveguide with tapered-structure. We carried out terahertz time-domain spectroscopy of L-cystine, powdered samples of which were diluted with hydrocarbon-based grease. These mixed samples were sandwiched between metal parallel plates with 200 micrometer gap in the THz transmission measurements. We observed both of the sharp absorption peak and the dispersion feature of the refractive index of L-cystine at 24 cm^{-1}. We found that background feature of powdered samples in THz absorption spectra possibly due to THz wave scattering was reduced by diluting the samples with the grease. We also obtained the quantitative THz spectra of L-cystine in both of the absorption coefficient and the refractive index through spectra analysis based on the effective medium theory. We succeeded in THz measurements of one-order of magnitude smaller sample of L-cystine relative to the sample amount necessary for the traditional terahertz measurements.

Pos1.04 **Terahertz intersublevel transitions in single self-assembled InAs quantum dots with variable electron numbers**

ZHANG Ya [a]; SHIBATA Kenji [ab]; NAGAI Naomi [a]; NDEBEKA-BANDOU Camille [ac]; BASTARD Gerald [ac]; HIRAKAWA Kazuhiko [ab];
a)Center for Photonics Electronics Convergence, Institute of Industrial Science, University of Tokyo, Japan, b)Institute for Nano Quantum Information Electronics, University of Tokyo, Japan, c)Laboratoire Pierre Aigrain, Ecole Normale Superieure, France

Probing nanostructure electronics by using long-wavelength terahertz(THz) wave has been considered as one of the big challenges in the THz technologies. In this work, We propose a method for performing THz spectroscopy on nanometer (nm)-scale systems by using metal nanogap electrodes. We used a single electron transistor (SET) geometry that consists of a self-assembled InAs quantum dot (QD) and nanogap metal electrodes as a terahertz detector, and we measured the intersublevel transition spectra of single QDs by detecting the THz induced photocurrent through the SET. We have provided, for the first time, an experimental method to perform THz spectroscopy on nm-scale systems with a good S/N ratio, which can be applied to THz spectroscopy on various kinds of nm-scale systems, such as carbon nanotubes, nanowires, and even single molecules.

Pos1.05st **Terahertz Absorption of Polyethylene Naphthalate and Its Relation to Crystallinity**

ODAKA Daisuke [a]; IZUTSU Tomoyuki [a]; KOMATSU Marina [a]; OHKI Yoshimichi [ab]; MIZUNO Maya [c]

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Polyethylene naphthalate (PEN) is a kind of crystalline engineering polymer that can be used in adverse environments such as those at high temperatures. Its rystallinity is an important factor controlling its material properties. Regarding this, the present work examines the possibility of using terahertz (THz) absorption spectroscopy as a tool to evaluate the crystallinity of PEN. Sheet samples of PEN were first melted at 300 ºC, and then they were either quenched by immersing them into liquid nitrogen or held at various temperatures between 180 and 250 ºC for about 10 min in a 1.0-atm nitrogen gas. With this procedure, samples with various degrees of crystallinity were obtained. In some samples, X-ray diffraction (XRD) patterns appear at 2θ= 15.6, 23.4, and 27.1º, while others exhibit an XRD halo. The former samples exhibiting the XRD patterns show a THz absorption peak at 2.15 THz, but the latter samples with the halo do not absorb THz waves at that frequency. By analyzing the intensities of these XRD patterns, we found that the 2.15-THz absorption has a close relation with the crystallinity of PEN. Therefore, there is a high feasibility of using THz absorption spectroscopy for estimating the crystallinity of PEN.

Pos1.06 **Characterization of GaN single crystals using THz ellipsometry**

TACHI Kouhei [a]; FUJII Takashi [a]; ARAKI Tsutomu [a]; NANISHI Yasushi [a]; NAGASHIMA Takeshi [b]; IWAMOTO Toshiyuki [c]; SATO Yukinori [c]; MORITA Naotake [d]; SUGIE Ryuichi [d]; KAMIYAMA Satoshi [a]*a)Department of Electrical and Electronic Engineering, Ritsumeikan University, Japan, b)Faculty of Science and Engineering, Setsunan University, Osaka, Japan, c)Nippo Precision Co., Ltd, Japan, d)Toray Research Center, Inc, Japan, e)Faculty of Science and Technology, Meijo University, Japan*

Contactless evaluation methods for electrical properties of wide gap semiconductors that is promising material for efficient power devices are needed because of difficulties in fabricating ohmic electrodes on those materials used in conventional techniques. Time domain spectroscopic ellipsometry at terahertz frequencies (THz-TDSE) is one of the strong candidates for contactless characterization of semiconductors. In order to examine the accuracy of the electrical properties obtained by THz-TDSE, the comparison of the results between THz-TDSE and conventional evaluation techniques is needed. In this study, GaN bulk wafers were measured by THz-TDSE first. From the obtained ellipsometric parameters, the mobility and density of the free carriers and DC resistivity were deduced using Drude model. Then, CV measurements to evaluate n and sheet resistance measurements based on eddy current technique were carried out. Lastly, Hall mobility and carrier concentration were obtained by conventional Hall measurements with van der Pauw configuration. As a result, the values of the mobility and carrier density obtained by THz-TDSE show good agreements with those by Hall measurements.

Pos1.07 **Self-association of Propionaldehyde and Dimethyl Sulfoxide through Weak Hydrogen Bonds, C-H···O, Studied by Mid-IR and THz-TD Spectroscopies, and DFT Calculations**

MIZUNO Kazuko [a]; KIKUCHI Takuya [a]; MURAKAMI Kohsuke [a]; AOIKE Yuuki [b]; FUKUI Kazutoshi [a]; YAMAMOTO Kohji [c]; TANI Masahiko [c]

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Self-association of organic compounds with both a hydrogen bond donor and an accepter can make variety of molecular structures. Since 1980s, CH groups in hydrophobic solutes with a polar group, such as C=O and S=O, have been known to possess potential to act as hydrogen bond donors of C-H···O/N. These interactions have become to be noted as weak hydrogen bonds. Here we report that we observed red shifts of (C=O) and (S=O) stretching vibration bands in mid IR spectra of propionaldehyde(PA) and dimethyl sulfoxide (DMSO) in solutions of cyclohexane. We observed broad absorption bands in their THz TD spectra also, the frequencies of which coincided with those of the bands for intermolecular vibration modes calculated by means of DFT method. Our observations of

these mid-IR and THz spectra show that weak H-bonds, C-H···O=C and C-H···O=S, are formed in self-associated dimers of PA and DMSO. DMSO is one of typical aprotic solvents, and several molecular interaction schemes in pure liquid have been reported, where ionic or dipolar interactions were involved. Our results show that DMSO has possibility to form variety types of intermolecular interactions in which both C-H groups as H-bond donors and an accepter, S=O, are involved.

Pos1.08 **Study of photoexcited *d*-electron dynamic in transition metal oxide MnO by optical pump-THz probe measurements**

NISHITANI Junichi [a]; KURIHARA Takayuki [a]; ASAHARA Akifumi [a]; NAGASHIMA Takeshi [b]; LIPPMAA Mikk [a]; SUEMOTO Tohru [a]

a)Institute for Solid State Physics, The University of Tokyo, Japan, b)Faculty of Science and Engineering, Setsunan University, Japan

Optical pump-THz probe (OPTP) measurements allow us to get the dynamical response of the photoconductivity in materials by observing the transient change of THz transmittance after optical excitation. In this study, THz responses to *d*-electrons at various photoexcited states in MnO were investigated by pump-energy-tunable OPTP measurements to lucidate the photoexcited *d*-electron dynamics in a transition metal oxide. At room temperature, photoexcited *d*-electrons induced by a *d*-*d* transition to the lowest excited *d*-state showed the longest relaxation time. The relaxation time decreased drastically below the Neel temperature (~120 K). Accompanied with this decrease, the magnetic-excitation-assisted photoluminescence from the self-trapped exciton (STE) state emerged. This suggests that photoexcited *d*-electrons relax to the STE state below the Neel temperature. These findings shed new light on the photoexcited *d*-electron dynamics, contrasting with the behavior of the photoexcited carriers generated in the upper excited *d*-states that showed the relaxation to trap states through phonon and magnon scatterings in previous study.

Pos1.09st **High Frequency Accuracy CW THz Spectroscopy System using External Cavity Feedback**

ANDO Keiichi [a]; IIZUKA Yuma [a]; OTO Kenichi [a]; MURO Kiyofumi [ab]; NAKAJIMA Makoto [c]

a)Chiba University, Japan, b)Spectra Quest Lab. Inc,Japan, c)Osaka University, Japan

We have constructed the CW THz spectroscopy system with narrow spectrum width (~1.85 MHz) and broad tunable range (~3 THz), using two tunable diode lasers developed originally as mixing laser sources and a photoconductive antenna based on InGaAs as a THz emitter. Laser sources and the emitter are connected by optical fiber for flexible set up. The frequency feedback system with a thermally stabilized external cavity (FSR: 484 MHz) realized that the absolute frequency accuracy is sub GHz by the measurement of water vapor absorption around 0.55 THz. The frequency stabilization of two laser's beat signal is ~10 MHz in 10 minutes. We have also measured the comb-like methanol absorption spectrum from 0.7 THz to 1.2 THz, supporting high reproducibility of this system. We are trying to adapt this system to the cryogenic temperatures in high magnetic field, such as the quantum Hall condition measured in two-dimensional electron systems. We will report the details of this spectroscopy system and some results of gas spectroscopy such as water vapor and methanol.

Pos1.10 **Design of a 300GHz band TWT with a Folded Waveguide fabricated by Micro Electro Mechanical Systems**

TSUTAKI Kunio [a]; NEO Yoichiro [a]; MIMURA Hidenori [a]; FUJISHITA Yusuke [b]; YOSHIDA Mitsuru [b]; MATSUOKA Junichi [b]

a)Research Institute, Sizuoka University, Japan, b)Microwave Tubes Division, NEC Network and Sensor Systems, Ltd., Japan

The national project of development of a 300GHz band folded waveguide traveling wave tube (FWG-TWT) for broad band communications has started last year. We will present the outline of the development program and summary design of the FWG-TWT. Major targets of the 300GHz FWG-TWT are the output power more than 1 W and the gain over 20dB in the wider frequency range from 280GHz to 300GHz. In order to study the optimum design of the FWG-TWT, some simple calculation formulas for the design of a folded waveguide slow wave circuit (FWG-SWC) were introduced, and calculation results were compared with that of the CST microwave studio. The Design to achieve the wider bandwidth at 300GHz band TWT was discussed by using omega-beta diagram. For a compact and light weight TWT, the periodic permanent magnet (PPM) was employed for electron beam focusing in the slow wave circuit. For stable beam transmission, lower beam perveance design was adopted, i.e. a beam voltage was 12kV and a cathode current was 8.3mA. To fabricate the 300GHz FWG-SWC, micro electro mechanical systems (MEMS) technology such as X-ray LIGA was employed. Finally, numerical simulation was carried out by using the CST particle studio. The output power of 4.5W (beam efficiency of 4.6%) and small signal gain of 25dB at the frequency of 290GHz were predicted, and also trial FWG-SWC by LIGA was manufactured with desired dimensional accuracy.

Pos1.11 **Frequency modulation and stabilization for sub-THz DNP-NMR spectroscopy**

IDEHARA Toshitaka [ab]; KHUTORYAN Eduard M. [ac]; TATEMATSU Yoshinori [a]; YAMAGUCHI Yuusuke [a]; KULESHOV Aleksei N. [ac]; MATSUKI Yoh [d]; FUJIWARA Toshimichi [d]

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The high speed frequency modulation of a 460 GHz Gyrotron applied for DNP-NMR spectroscopy was achieved by modulation of acceleration voltage of beam electrons. Because the sensitivity of NMR is inversely proportional to the frequency, high-speed frequency modulation can compensate the decreasing the enhancement factor in high frequency DNP-NMR spectroscopy and keep the factor at high value. Also, in this gyrotron, the stabilization of the output frequency was achieved by use of PID feedback control of acceleration voltage. The frequency stabilization in long time is also useful for application of DNP-NMR spectroscopy to analysis of complicated protein molecules. In this gyrotron the cavity (body) is isolated from the collector and modulation voltage is applied between gyrotron body and collector. For frequency stabilization we compare the measured demodulated intermediate frequency with the set value and apply voltage defined by PID algorithm to gyrotron body. Aspects of both frequency modulation and stabilizing of slow frequency fluctuations (mainly caused by cavity temperature drift) have been analyzed.

Pos1.12 **Tunable sub-THz wave source from DAST-DFG pumped by a dual-wavelength, injection-seeded BBO OPG system**

TOKIZANE Yu [a]; MIYAKE Yoshiki [ab]; NAWATA Kouji [a]; FAN Shuzhen [a]; HAYASHI Shin'ichiro [a]; NOTAKE Takashi [a]; SATO Atsushi [b]; TAKIDA Yuma [a]; MINAMIDE Hiroaki [a]

a)Tera-Photonics team, RIKEN, Japan, b)Tohoku Institute of Technology, Japan

Tunable sub-THz wavegeneration was demonstrated in DAST-DFG pumped by output of the dual wavelength injection-seeded BBO-OPG (is-BBO-OPG). The multiple wavelength output around 1300 nm region were obtained by cascaded process of BBO-OPG and peaks in the spectrum were tunable from 1323.2 nm to 1325.1 nm. The multiple wavelength outputs efficiently pumped DAST crystal to generate tunable sub-THz wave from 0.3 THz to 1.0 THz by the difference frequency generation (DFG).

Pos1.13 **THz Wave Generation by a UTC-PD using 1μm Band Tunable Diode Lasers**

MURO Kiyofumi [a]; NODA Kazufusa [b]

a)Spectra Quest Lab. Inc.,Japan, b)Oshima Prototype Engineering Co.Japan

A compact coherent THz light source is developed by a photo-mixing of 1um band tunable diode lasers using a UTC-PD. UTC-PD enables a very efficient photo-mixing, and several tens of microwatts output is generated in the sub-THz frequency region using waveguide structure. Free space device on a Si hemi-sphere enables higher frequency and broad band operation of photo-mixing. Employment of 1um tunable lasers helps to make the system simple and efficient, because Si hemi-sphere blocks the mixing light and extra filtering is not necessary. The employed tunable lasers, lambda Master 1040, Spectra Quest Lab. Inc. realize a continuously tunable ASE-free output based on a patented extra-cavity configuration. ASE-free nature of mixing light predicts a generation of low noise coherent THz wave, which is favorable for the THz local oscillator in the heterodyne detection. The frequency of tunable laser is digitally controlled with a resolution of 3MHz, and the athermal cavity structure with Invar frame enables a high frequency-stability. Detailed performance of the tunable coherent light source will be presented at the meeting.

Pos1.14 **Sub-terahertz-wave generation based on nonlinear wavelength-conversion in a $MgO:LiNbO_3$**

HAYASHI Shin'ichiro [a]; NAWATA Kouji [a]; TAKIDA Yuma [a]; KAWASE Kodo [ba]; MINAMIDE Hiroaki [a]

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We demonstrated the generation of narrowband and continuously tunable sub-terahertz-waves (< 1 THz) using parametric wavelength conversion in a Magnesium Oxide doped Lithium Niobate ($MgO:LiNbO_3$) crystal. Nonlinear optical parametric conversion between infrared and sub-terahertz-waves are realized by a subnanosecond, passively Q-switched, microchip Nd:YAG laser as a pumping source. This pump source allows high-intensity pumping without damage to the nonlinear crystal and generates a narrow linewidth and continuously tunable subterahertz wave with injection seeding by an external cavity diode laser for the idler wave. The high-intensity pumping causes a gain curve broadening of the terahertz-wave parametric generation. We obtained an output terahertz wave with a tuning range of 0.4 - 1.8 THz (750 - 167 microm). These results are very promising for extending applied research into the terahertz region, and we expect that this source will open up new research fields.

Pos1.15st **Intense laser interaction with a thin foil and its induced surface wave along a neighbor metal wire**

TERAMOTO Kensuke [ab]; INOUE Shunsuke [ab]; TOKITA Shigeki [c]; YASUHARA Ryo [d]; HASHIDA Masaki [ab]; SAKABE Shuji [ab]

a)GSS Kyoto University, Japan, b)ICR Kyoto University, Japan, c)ILE Osaka University, Japan, d)NIFS, Japan

Laser plasma has high potential for strong terahertz wave sources. In the plasmas, generation of higher energy terahertz wave would be possible by simply increasing laser intensity. In particular, solid targets have high conversion efficiency from laser to terahertz wave. We have reported strong sub-terahertz surface wave generation by the interaction of intense laser pulses with a metal wire. The peak electric field strength and pulse duration are estimated to be 200 MV/m and 7 ps at near the wire surface respectively. However, repetitive generation of such strong surface wave on a metal wire remains a challenge, because it is difficult for the wire target to be supplied for each shot. We have demonstrated that surface wave are propagated on a metal wire placed near the laser-plasma. The wire is not damaged by the laser, therefore repetitive generation of the surface wave is possible. Intense laser pulses are focused on a thin aluminum foil. A tungsten wire is placed perpendicularly to the foil. The foil and the wire are not contact with each other, keeping a spatial gap. The electric field is measured electro-optically. For the hybrid targets, surface wave has been observed as well as for wire targets.

Pos1.16 **Terahertz generation from nano-metal ink irradiated by femtosecond laser pulses**

KATO Kosaku; TAKANO Keisuke; TADOKORO Yuzuru; NAKAJIMA Makoto

Institute of Laser Engineering, Osaka University, Japan

Recent progress in printing technology enables us to draw various terahertz metamaterials with nano-metal ink. The structure made of the nano-metal ink is also considered to be an interesting terahertz emitter. In this work, we report the generation of terahertz pulses by irradiating nano-metal ink with femtosecond laser pulses. We used silver nano-metal ink pasted on a fused-silica substrate as a sample. After baked at about 490 K for 1 hour, this sample was pumped by a Ti:sapphire regenerative amplifier (800 nm center wavelength, 50 fs pulse duration, 1 kHz repetition rate) at an angle of incidence of 45 degrees. The terahertz signal radiated from the sample surface is p-polarized, and is larger when pump pulses are p-polarized than when they are s-polarized. We discuss the role of sintering process of the nano-metal particles on the terahertz generation process. The flexibility of the nano-metal ink has a potential to realize a structure that efficiently converts the pump pulse to the terahertz wave.

Pos1.17 **Refractive indexes of KTP and KTA crystals in the terahertz spectral range**

CONG Zhenhua; LIU Zhaojun; CHEN Xiaohan; QIN Zengguang; WANG Weitao; TANG Guanqi; FU Qiang ; JIANG Shiqi; WU Dong; ZANG Jie; ZHANG Xingyu

School of Information Science and Engineering, and Shandong Provincial Key Laboratory of Laser Technology and Application, Shandong University, P. R. China

The potassium titanyl phosphate ($KTiOPO_4$, KTP) and the potassium titanyl arsenate ($KTiOAsO_4$, KTA) are excellent nonlinear crystals. They have been widely used in second harmonic generation, sum and difference frequency generation, optical parametric oscillation, and Raman conversion. Recently it is shown that they can be used to generate terahertz wave by simulated polariton scattering. For the theoretical analysis and design of KTP and KTA terahertz generators, their crystal properties such as refractive indexes in the terahertz spectral range are necessary. In this paper, a method for measuring the refractive indexes of KTP and KTA crystals at 3-6 THz is given. The Stokes light with a wide spectral range was obtained by using a Q-switched Nd:YAG 1064 nm laser as the pump source and the KTP (KTA) crystal as the nonlinear medium in the terahertz parametric oscillator. The Stokes wavelengths and the corresponding angles between the pump and Stokes beams were measured. The refractive index was calculated by using the energy conservation and the momentum conservation. The refractive index of KTP crystal was measured to be 2.74-5.10 at 3.07-6.12 THz, and the refractive index of KTA crystal was 3.19-5.26 at 3.17-6.39 THz.

Pos1.18 **Over *10*-THz broadband *TDS*-system using *LT*-GaAs on Si photoconductive antennas by *1560*-nm excitation**

KOIZUMI Takayuki; SATO Takahiro; OUCHI Toshihiko

Corporate R&D, Canon Inc., Japan

A compact terahertz time domain spectroscopy (THz-TDS) system exhibiting over 10-THz bandwidth was demonstrated with a 30-fs pulse duration fiber laser and low-temperature-grown (LT)-GaAs photoconductive antennas (PCAs) grown on Si substrate. The system was composed of two LT-GaAs on Si PCAs without any nonlinear crystals such as periodically poled lithium niobate because THz radiation was emitted and detected by nonlinear excitation of LT-GaAs layer by 1560-nm laser light. A structure of 6-μm gap and 20-μm dipole antenna with 3-mm length bias line was used as the PCA. The adoption of the LT-GaAs on Si for both emitter and detector drastically reduced the phonon based absorption of GaAs substrate, resulted in THz pulse duration of less than 150 fs and small dip around

8 THz. High optical power of 170 mW and 30-fs laser light can raise the nonlinear effect such as two step excitation and two photon absorption, which led to large signal-to-noise ratio of over 70 dB and detection current of 60 nA. This TDS apparatus as well as LT-GaAs on Si PCAs can enable us to provide low cost and stable system and are promising to apply a lot of applications such as medical imaging, process control.

Pos1.19 **Arbitrary shifting of carrier envelope phase of broadband terahertz pulses**

KAWADA Yoichi; YASUDA Takashi; TAKAHASHI Hironori
Central Research Laboratory, Hamamatsu Photonics K.K. Japan

Femtosecond laser technology enables us to obtain ultrashort terahertz (THz) pulses. The electric field profile of such THz pulses is the same for each shot. In other words, the carrier envelope phase (CEP) of each pulse is locked. We have shifted CEP arbitrarily using several prism-type wave plates. CEP is an important parameter for ultra-short pulses, especially in interactions of intense light pulses with matter. Our CEP shifter is composed by arranging a first quarter-wave plate, a half-wave plate, and a second quarter-wave plate in order. The second quarter-wave plate can be substituted with a wire-grid polarizer. The prism-type wave plates give the same amount of phase changes to whole spectrum components of THz pulses. By rotating the half-wave plate, we can shift the CEP of the THz pulses depending on the angle of the plate. Shifting of the CEP was observed using THz time domain spectroscopy. Measured temporal waveforms clearly showed changes in the CEP. Nevertheless, the relative relationships obtained by the Fourier transformation of each temporal waveform were the same over the whole spectrum phase. These results represent that only the CEP has been shifted without temporal delay and spectrum dispersion.

Pos1.20 **Ray tracing method with Fresnel's transmission for a Silicon lens antenna irradiated with linearly polarized THz wave**

APRIONO Catur [ab]; RAHARDJO Eko Tjipto [b]; HIROMOTO Norihisa [a]
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An extended hemispherical Silicon lens antenna is an attractive and practical element to focus and collimate beams of THz radiation in THz systems. By adjusting the extension length to the focal point and placing a detector or an emitter at around the focus, we can improve coupling efficiency of the THz system. Because linearly polarized radiation is ordinary in the THz systems, a practical method to calculate a precise profile of power-flow density distribution of the polarized THz wave radiation is important to design a Silicon lens antenna. In this study, we propose a ray-tracing method combined with Fresnel's transmission to calculate the power-flow density distribution in a Silicon lens antenna irradiated with linearly polarized THz wave. The result calculated by the proposed method is compared with the simulation by the CST Microwave Studio, and they were consistent with each other, though the EM simulation included the effect of interference and diffraction which are not considered in our proposed method.

Pos1.21 **Terahertz Field Enhancement and Photon-Assisted Tunneling through Single Molecules**

YOSHIDA Kenji [a]; SHIBATA Kenji [c]; HIRAKAWA Kazuhiko [ab]
a)Center for Photonics Electronics Convergence, IIS, University of Tokyo, Japan, b)Institute for Nano Quantum Information Electronics, University of Tokyo, Japan, c)Tohoku Institute of Technology, Japan

Characteristic energy scales in single molecule transistors lie mostly in the terahertz (THz) range and the interaction between THz fields and single molecules results in intriguing transport phenomena. We have investigated electron transport in single C_{60} molecule transistors under the illumination of monochromatic THz radiation at 2.5 THz with an intensity of a few tens mW. By using the electrical break junction method, we have fabricated a sample structure that can focus the THz radiation onto a single molecule trapped in the nanogap electrodes. When the samples are illuminated with the THz radiation, they 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 nearly 10^5.

Pos1.22 **Optical Phase Modulator based on Mechanically Reconfigurable Metamaterial**

IWAMI Kentaro; KINOSHITA Takuya; SHIMURA Takashi; NAGASAKI Hideaki; UMEDA Norihiro
Department of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology, Japan

An optical phase modulator based on plasmonic reconfigurable grating was designed, developed and evaluated. Plasmonic grating shows giant birefringence at the visible range, because propagation constants for TE and TM modes in grating gaps shift in the opposite direction from that for vacuum. The grating consists of interleaved fixed and movable beams, which are electrostatically actuated with a facing transparent electrode. Since the gap length is changed by mechanical motion, retardation of

the grating is modulated. The grating was fabricated with the period of 2μm and the thickness of 400 nm. The fabricated grating was evaluated by polarization microscopy. Retardation was modulated about 10º by applying voltage for electrostatic motion. Application of this principle to THz region will be discussed.

Pos1.23 **High extinction ratio double-layered free-standing wire-grid polarizer**

NASHIMA Shigeki; HANDA Takuya; HOSODA Makoto
Department of Applied Physics, Graduate School of Engineering, Osaka City University, Japan

We have investigated transmission characteristics of a double-layered free-standing wire-grid polarizer (W-WG) by finite-differential time-domain simulations (FDTD). FDTD calculation results show that transmission properties of TE- and TM- terahertz waves through W-WG depend on relative grid configuration (p) between two layers, when layer space (ℓ) is smaller than grid spacing (g). Especially, TM-transmittance (T_{TM}) of W-WG at $p = g/2$ drastically decreases with decreasing ℓ, however, T_{TM} of W-WG at $p = 0$ increases with decreasing ℓ. The calculated extinction ratio of W-WG at $\lambda = 10g$ is estimated 10^{-10}, which is much smaller than that calculated by Fabry-Perot model using the transmission characteristics of single WG. We will analyze and discuss their transmission properties by Fabry-Perot model and parallel-plate waveguide model.

Pos1.24 **Enhancement of terahertz emission from GaAs/AlAs coupled multilayer cavities by InAs quantum dots on (113)B-oriented substrates**

KITADA Takahiro [a]; OGARANE Masanori [a]; TAKAMOTO Toshiaki [a]; KUMAGAI Naoto [a]; LU Xiangmeng [a]; MORITA Ken [b]; ISU Toshiro [a]
a)Center for Frontier Research of Engineering, Institute of Technology and Science, Tokushima University, Japan, b)Graduate School of Engineering, Chiba University, Japan

We have recently proposed planar-type and room-temperature-operable terahertz (THz) emission devices based on the difference frequency generation (DFG) of two cavity modes in a GaAs/AlAs coupled multilayer cavity which consists of two equivalent cavity layers and three distributed Bragg reflector (DBR) multilayers. The optical frequency difference between the two modes can be precisely defined in the THz region by the number of periods in the intermediate coupling DBR multilayer. The internal electric field of each cavity mode is strongly enhanced in both cavity layers, so that strong THz-DFG of the two modes can be realized when the coupled multilayer cavity structure is grown on a non-(001) GaAs substrate. In this paper, we studied THz-DFG from the coupled multilayer cavities with self-assembled InAs quantum dots (QDs) grown on (113)B-oriented GaAs substrates by molecular beam epitaxy. The temporal THz waveforms were measured at room temperature by simultaneous excitation of the two cavity modes using femtosecond laser pulses. The measurements were also performed for the reference coupled cavity sample having no QDs. Significant enhancement of THz-DFG of the two modes was observed by introducing five QD layers into the top-side cavity region because of the excellent second-order nonlinearity of InAs QDs.

Pos1.25 **Electron Dynamics in Bi "Relativistically" Accelerated via Intense Terahertz Transient**

MINAMI Yasuo [a]; ARAKI Kotaro [a]; D. DAO Thang [bc]; NAGAO Tadaaki [bc]; KITAJIMA Masahiro [abcd]; TAKEDA Jun [a]; KATAYAMA Ikufumi [a]
a)Department of Physics, Graduate School of Engineering, Yokohama National University, Japan, b)WPI-MANA, National Institute for Materials Science, Japan, c)JST-CREST, Japan, d)LxRay Co., Ltd

With an intense terahertz (THz) wave spectroscopy, we observed a nonlinear-electron dynamics at L point in the Brillouin zone of bismuth (Bi). The band structure at L point is approximated to be a hyperbolic curve, which means that the motion of the electron can be analogously expressed by the relativistic dynamics. To achieve the "relativistic" electron acceleration, we applied the intense terahertz electric field transient. In the analysis, the "relativistic" energy-momentum relation is taken into account, which enables us to reveal the transient motion of the carrier electron both in k space and in real space. From the analysis, it is also clarified that the electron were accelerated near the "light velocity" with a "relativistic beta" of 0.92. In the region, the "relativistic" dynamics dominates the motion of the electrons, which is the reason of the nonlinear response of electrons in Bi at L point.

Pos1.26 **Nonlinear effects on solids induced by THz FEL**

IRIZAWA Akinori [a]; KAWASE Keigo [a]; KATO Ryuko [a]; FUJIMOTO Masaki [a]; ISOYAMA Goro [a]; SAKAMOTO Kazuyuki [b]; NAGASHIMA Takeshi [c]
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An intense THz FEL has been developed and employed for searching nonlinear effects of lower energy photons, such as THz, far infrared lights. We have investigated nonlinear absorptions on several types of semiconductors having different band structures and gap sizes. On focus point of THz FEL light, the maximum electric field is estimated beyond 3 MV/cm. We will talk about the detail of these first

observations, and discuss differences and origins of nonlinear excitations in semiconductors in THz region.

Pos1.27 **Terahertz wave responses in two-dimensional metal mesh metamaterial with laser-cut structure**

NAKAJIMA Makoto [a]; SEKINE Yudai [b]; SAITO Yuumi [b]; OKUI Yuichiro [a]; KANG Boyoung [a]; TAKANO Keisuke [a]; OTO Ken-ichi [b]; HANGYO Masanori [a]
a)Institute of Laser Engineering, Osaka University, Japan, b)Department of Physics, Chiba University, Japan

We have investigated the transmittance response of THz waves in the two-dimensional metal mesh metamaterial with laser-cut structures. The metal mesh films with the pitch of 290 micrometers and the thickness of ~6 micrometers on polyethylene terephthalate were measured by transmission-type THz time domain spectroscopy. The transmission spectra of semiconductor-like with the Drude tale are observed for the metal mesh film without cut structures. The absorption peak appears after inserting the laser-cut. With increasing the cut structure, the width of the absorption becomes broad and the spectrum changes into the insulator-like. This spectrum change from semiconductor to insulator reflects a decrease of the conductivity in the two-dimensional metal mesh, it is closely related to Percolation phenomena. The polarization properties of THz wave after transmission were investigated. No polarization changes were observed for the mesh sample without laser-cut structure and the single-cut sample which has one cut in a mesh. We have found that the large polarization rotation-angle and ellipticity around 0.11 THz in the double-cut sample which has two cuts of one side and next side in a mesh. This response of the polarization rotation can be explained by the anisotropic structures with the laser-cut.

Pos1.28 **Terahertz absorption properties of Mg_2SiO_4 ceramics**

NEDELCU Liviu [a]; GEAMBASU Cezar Dragos [a]; BANCIU Marian Gabriel [a]; IWAMAE Atsushi [b]; FURUYA Takashi [b]; TANI Masahiko [b]
a)Multifunctional Materials and Structures Laboratory, National Institute of Materials Phyics, Romania, b)Research Center for Development of Far-Infrared Region, University of Fukui, Japan

Low-loss temperature-stable dielectric materials are very attractive solutions for size and weight reduction of the wireless communications equipment. Due to their cost-effective production, low dielectric loss ceramics have been employed for manufacturing of substrates, waveguides, lenses, filters, antennas, etc. In this work, we report on the synthesis and terahertz absorption properties of the Mg_2SiO_4 (MSO) ceramics. Such silicate-based ceramics have been extensively studied for millimeter-wave applications. However, their terahertz properties are very important as modern telecommunications tend to migrate in the submillimeter-wave domain. MSO samples were prepared by using solid-state reaction method. The ball-milled MgO and SiO_2 powders were calcined at 1150 ºC / 4h. The calcined powders mixed with 2 % polyvinyl alcohol were uniaxially pressed and sintered at temperatures between 1300 ºC and 1400 ºC. The obtained samples with were structurally and morphologically characterized. The absorption properties were investigated in the 0.3 - 2.5 THz range by using a terahertz time-domain spectrometer on transmission set-up. For all sintered samples the absorption coefficient is small (~1 cm-1) to about 0.5 THz. However, a strong increase of sample's absorption above 1 THz has been noticed. Terahertz data will be discussed and compared with those measured in microwave domain.

Pos1.29st **Terahertz magnetic control of spin orientation during the laser-induced spin reorientation transition in orthoferrites using split-ring resonator**

KURIHARA Takayuki [a]; WATANABE Hiroshi [a]; SEKINE Yudai [b]; SAITO Yuumi [b]; NAKAJIMA Makoto [c]; OTO Ken-ichi [b]; SUEMOTO Tohru [a]
a)Insitute for Solild State Physics, The University of Tokyo, Japan, b)Department of Physics, Chiba University, Japan, c)Institute for Laser Engineering, Osaka University, Japan

Control of macroscopic magnetic order by THz radiation is one of the emerging field that has significant importance both from technological and fundamental point of view. In this presentation, we focused on spin reorientation transition (SRT) in erbium orthoferrite ($ErFeO_3$), wherein the magnetization easy-axis rotates by 90 degrees by temperature change. By irradiating with femtosecond 800nm pulses we can instantaneously tilt its easy-axis from in-plane (**M**//a) to out-of-plane (**M**//c) On the surface of the sample we fabricated split-ring resonator (SRR), which produced enhanced out-of-plane magnetic field **H**z//*c* when excited by THz electric field.The out-of-planemagnetization was probed by Faraday rotation of transmitted 800 nm pulse. Without THz pulses we observed no Faraday rotation after heating by optical pump, which indicates that equal amount of M//$\pm c$ domains were produced. However, when THz pulse was present the Faraday rotation appeared, suggesting that the magnetization was aligned by magnetic fields of SRR. Furthermore, varying the time delay between the optical- and THz a period of ~5 ps, which was

assigned to that of the resonance mode of SRR. This confirms that the magnetization wasactually aligned by the magnetic field of SRR.

Pos1.30 **A New System for Classifying Detection of Objects Using Sub-THz Passive Body Scanner**

MORI Koji [a]; SATO Junichi [a]; SHIMOSAKO Ryoji [a]; HIROMOTO Norihisa [b]
a)KSK Corporation, Japan, b)Shizuoka University, Japan

The body scanner has superiority in real-time operation regarding to detect concealed weapons and contrabands such as explosives, guns, knives, narcotics, drugs etc. carried by suspicious persons in airport and other important facilities. Especially the passive body scanner is promising for the inspections of persons because of its advantage in the protection of privacy and safety for human health. Recently we are developing a new system which enable us to classify the concealed objects measuring reflection and emission based on passive body scanner. It is possible not only to identify the location of the concealed object but also to classify the kinds of material such as metal and nonmetal, which has been thought to be impossible so far. The new system will expand the scope of utilization and application of the body scanner to the eplacement of metal detectors in the airport, security facilities in the Olympic events and so on.

Pos1.31 **Carrier dynamics of Ta_3N_5 photoanode for water oxidation by optical-pump terahertz-probe spectroscopy**

HIRAYAMA Heijiro [a]; NISHITANI Junichi [b]; NAGASHIMA Takeshi [c]
a)Department Analysis Technology Center, R&D Management Headquarters, FUJIFILM Co., Japan, b)Institute for Solid State Physics, The University of Tokyo, Japan, c)Institute for Fundamental Sciences, Faculty of Science and Engineering, Setsunan University, Japan

Sunlight-driven photoelectrochemical water splitting is a potential means of obtaining hydrogen as a clean, sustainable and storable fuel. For the improvement of the solar energy conversion efficiency, development of various photocatalysts has been explored. It is important to analyze the elementary process in the artificial photosynthesis, such as light absorption, charge separation, charge transport, and water splitting, and to identify the factor of inefficiency. We have used optical-pump terahertz-probe spectroscopy (OPTP) (time-resolved terahertz spectroscopy) to explore the dynamics of carriers generated in Ta_3N_5 that is the semiconductor for artificial photosynthesis. OPTP provides subpicosecond resolution of carrier dynamics, which allows us to analyze the process of the charge separation. We measured carriers in Ta_3N_5 powder dispersed in the polymer film induced by a pump pulse with 400 nm wavelength. Carrier mobility and photo-to-carrier yield in a few ps were estimated based on the application of the Drude-Smith model. We discuss the dynamics of carriers generated in Ta_3N_5 thin films.

Pos1.32st **Direct measurement of nonlinear absorption in low-temperature-grown GaAs at 1.5 micrometer excitation**

MURATA Hayato; TOMINAGA Yoriko; KADOYA Yutaka
Graduate School of Advanced Sciences of Matter, Hiroshima University, Japan

It has been reported that phohoconductive antennas (PCAs) on low- temperature-grown- (LTG-) GaAs can serve as a THz detector even for 1.5 micrometer excitation although its efficiency is not high at present. The efficiency is expected to be improved by utilizing the nonlinear absorption effectively. However, there have been insufficient investigations on the nonlinear absorption of 1.5 micrometer pulses in LTG-GaAs. This work aims to evaluate directly the nonlinear absorption in LTG-GaAs by a kind of transmission measurement. We made LTG-GaAs thin film samples that is removed from the GaAs substrate and metalized with Ti/Au working as a back mirror by means of metal-metal bonding techinique. Then we measured the reflectance (practically transmittance) for the 1.5 micrometer pulses from a mode lock fiber laser. In a reference sample (Glass/Ti/Au), the transmittance was confirmed to be independent on the incident power. In contrast, in LTG-GaAs samples, the transmittance was found to depend on the incident power, namely, nonlinear absorption was observed. The LTG-GaAs sample annealed at 500ºC showed a larger nonlinearity than that annealed at 600ºC. The results suggest that the nonlinear absorption is related to the density of the mid-gap states in the LTG-GaAs controlled by the annealing temperature.

Pos1.33st **Study on THz Antenna-Coupled Bolometer utilizing SOI MOSFET**

UETA Takeo [a]; SUZUKI Yuya [a]; SATOH Hiroaki [a]; TIWARI Ajay [a]; HIROMOTO Norihisa [a]; BRÜNDERMANN Erik [b]; INOKAWA Hiroshi [a]
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We report the use of silicon on insulator (SOI) metal-oxide-semiconductor field-effect transistors (MOSFET) for antenna-coupled bolometers in the THz region. Specifically, the MOSFET is suspended above the cavity etched inside the silicon substrate for thermal isolation, the gate electrode serves as the heater (load resistor for the antenna), and the temperature rise is sensed as the change in the

threshold voltage. Due to the amplifying function of the MOSFET, an electrical responsivity exceeding 2000 V/W can be attained, which is an order of magnitude larger than that of Ti-based bolometers with similar dimensions. The effective temperature coefficient of resistance (TCR) is also found to be comparable to those of VOx and a-Si.

Pos1.34 **Terahertz nondestructive imaging with two-dimensional uncooled bolometer array**

NAKANISHI Atsushi [a]; KAWADA Yoichi [a]; DEWA Daisuke [a]; TAKAHASHI Hironori [a]; ISHIHARA Masatoshi [b]; KITAURA Ryusuke [b]; YAMAZAKI Masahiro [b]

a)Central Research Laboratory, Hamamatsu Photonics K. K., Japan, b)Solid State Division, Hamamatsu Photonics K. K. Japan

We fabricated a 128 X128 antenna-coupled amorphous silicon bolometer array with a pixel pitch of 160μm. We constructed a transmission imaging system, consisting of a bolometer array, an imaging lens, an illumination lens, and a 2.52 THz gas laser. The antenna design was optimized for the laser frequency of 2.52 THz. We designed and fabricated an aspheric plastic lens in order to obtain sufficiently high imaging performance with a smaller number of lenses. Terahertz imaging with a spatial resolution of approximately 1 mm was demonstrated using only a single f/1.5 lens for imaging. A wooden board covered with wallpaper was imaged. The board had several holes 2 mm in diameter drilled in it to reproduce the worm-eaten condition of wooden building material. The holes were revealed using the terahertz imaging system. Nondestructive terahertz imaging of other hidden samples was also demonstrated, such as distinguishing different kinds of liquid contained in the same opaque container.

Pos1.35 **Attempt to conformation control of biological proteins by using intense coherent THz-wave**

NOTAKE Takashi; NAWATA Kouji; TAKIDA Yuma; TOKIZANE Yu; HAN Zhengli; MINAMIDE Hiroaki

RIKEN, RAP, Japan

Development of control methods for protein conformation is one of the most important topics in life science because the biological functions of proteins can be determined by the conformation. Conformation is formed and changed as a result of weak interactions such as hydrogen bonding and van der Waals' force among many side-chains of amino-acid residues. We investigated influence of terahertz wave irradiation to protein conformation by using intense monochromatic terahertz wave with high peak power and low average power to separate off thermal effect. Circular dichroism in UV region and fluorescence spectra were measured to diagnose conformation changes for irradiated and unirradiated protein samples. Experimental result showed spectra differences in both measurement and indicate that conformation change in protein may be induced by interaction between intense terahertz wave field and higher order structure of protein.

Pos1.36st **Close Proximity Terahertz Communications Using Phase Modulation and Array Antennas**

OOGIMOTO Kazuki [a]; INUBUSHI Yuuki [a]; HIROKAWA Jiro [b]; NAGATSUMA Tadao [a]

a)Graduate School of Engineering Science, Osaka University, Japan, b)Department of Electrical and Electronic Engineering, Tokyo Institute of Technology, Japan

In recent years, close-proximity and/or short-range wireless link for inter-device communications such as NFC and TransferJet have been developed, which offer maximum data rates of about 500 Mbps. In order to increase the data rate by 100 times and beyond, the use of terahertz waves, whose frequencies range from 100 GHz to 10 THz, has proven to be promising. However, there is a very significant problem in the use of such ultrahigh-frequency/ultrashort-wavelength radio waves for short-distance communications. The problem is that a standing-wave effect, which is caused between the transmitter and receiver antennas closely located each other, leads to an instability of wireless communications. In this paper, we propose a combination of two novel approaches to overcome this problem. First, we introduce a phase modulation of carrier signals at frequencies of higher than that of the data rate. Moreover, we employ a planar array structure of antennas to improve the near-field uniformity in comparison with a horn antenna. We experimentally demonstrate that these approaches are valid even for almost zero antenna-distances in the 120-GHz-band wireless link systems.

10:30-12:10 Poster Session Pos2

Room ; 43, 44

Pos2.01 **Low-frequency Vibrational Dynamics of Poly(lactic acid) Stereocomplex Studied by THz spectroscopy and Solid-state DFT Simulation**

ZHANG Feng[a]; TOMINAGA Keisuke[a]; HAYASHI Michitoshi[b]; WANG Houng-Wei[b]; NISHINO Takashi[c]

a)Molecular Photoscience Research Center, Kobe University, Japan, b)Center for Condensed Matter Sciences, National Taiwan University, Taiwan, c)Department of Chemical Science and Engineering, Graduate School of Engineering, Kobe University, Japan

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, e.g. 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 ntermolecular translations, librations and intramolecular vibrations. Preliminary iscussions will be made on this basis to provide insight into the anomalous temperature dependence of THz modes.

Pos2.02 **Room temperature carrier lifetime measurements of coupled and uncoupled GaAs/AlGaAs quantum wells through optical pump terahertz probe and time resolved photoluminescence**

AFALLA Jessica [ab]; JACULBIA Rafael [b]; HIRAOKA Sho [a]; OHTA Kaoru [a]; BALGOS Ma. Herminia [b]; VASQUEZ John Daniel [b]; SALVADOR ARNEL Arnel [b]; SOMINTAC ARMANDO Armando [b]; ESTACIO Elmer [b]; TOMINAGA Keisuke [a]*a)Molecular Photoscience Research Center, Kobe University, Japan, b)National Institute of Physics, University of the Philippines Diliman, Philippines*

Two asymmetric double quantum wells (DQW) consisting of 5 pairs of wide (WW) and narrow (NW) GaAs wells separated by $Al_{0.3}Ga_{0.7}As$ barriers were grown via molecular beam epitaxy. For both samples, the energy separation between NW and WW well conduction band levels were designed to be ~35 meV, close to the GaAs LO-phonon energy. To distinguish the samples, the nominal barrier widths were 25 Å in one sample ("coupled"), and 100 Å for the other ("uncoupled"). Finite well calculations show that a 25 Å barrier thickness yields electron wavefunctions that permit tunnelling from NW to WW; while a 100 Å barrier provides sufficient uncoupling between wells. Room temperature carrier lifetimes were measured using both time-resolved photoluminescence (TRPL) and an optical-pump THz-probe (OPTP) set-up. From both measurements, carrier lifetimes measured for the coupled DQW were shorter than for the uncoupled DQW, caused likely by tunnelling. The shorter radiative lifetimes obtained from TRPL only measured a difference of ~30 ps between the DQWs, while the measured true carrier lifetime difference using OPTP was ~288 ps. Results showed that OPTP can be used as a novel, alternative all-optical, non-contact method at room temperature, offering greater ease of use and faster measurement.

Pos2.03 **Measurements of CO gas absorption line parameters in terahertz region**

YOSHIDA Kyosuke; KUMAZAWA Ryoichi; SUGIE Ryuichi; YOSHIKAWA Masanobu

Toray Research Center Inc. Japan

The absorption spectra of CO gas in terahertz region at different total pressures and concentrations with a foreign gas of N_2 or O_2 were recorded using a terahertz time-domain spectroscopy (THz-TDS) with a resolution of 0.05 cm^{-1}. The several absorption lines of CO pure rotational transitions were observed in the measured terahertz absorption spectra. The N_2- and O_2-pressure broadening coefficients at room temperature were determined by fitting the Lorentzian line shapes to the observed absorption lines, and the air-pressure broadening coefficients were estimated. The parameters obtained agreed well with the values in the high-resolution transmission HITRAN database.

Pos2.04st **Direct measurement of Fresnel coefficients for circular polarization in THz frequency region**

MORIMOTO Tomohide; YAMASHITA Genki; AGAI Masaya; ASHIDA Masaaki
Graduate School of Engineer Science, Osaka University, Japan

We propose a novel method for the measurement of Fresnel coefficients for circular polarization in THz frequency region. The time-domain reflection spectroscopy using a THz achromatic wave plate and a polarized beam splitter allows the direct evaluation of the reflection coefficients for circular polarization. We experimentally demonstrated it for a doped InSb wafer using a wave plate based on the parallel metal waveguides. This technique will open a new characterization method of the doped semiconductors.

Pos2.05 **Terahertz time-domain attenuated total reflection spectroscopy using a fluorine-based liquid**

AKIYAMA Koichiro; KAWADA Yoichi; YASUDA Takashi; NAKANISHI Atsushi; TAKAHASHI Hironori
Hamamatsu Photonics K.K. Japan

We studied terahertz time-domain attenuated total reflection (ATR) spectroscopy using a Si ATR prism, which served as both a terahertz emitter and a terahertz receiver. In a typical ATR measurement, a solid sample, such as a powder or a plate, must be pressed against the prism surface to force the sample into contact with the surface. However, the prism may be deformed or damaged when a solid sample is pressed against the prism surface with a strong force. To overcome this problem, we propose a new solid sample measuring method using a liquid. In this method, we utilize the adhesion force acting between a liquid and a solid sample. As a result, by interposing the liquid between the prism surface and the solid sample, the solid sample can be measured without pressing it. We used a fluorine-based inert liquid, which was suitable for this method because it has low absorption and low dispersion in the terahertz region, and its refractive index is approximately 1.37. In addition, many materials are insoluble in this liquid. We measured several powder samples by using this method and confirmed the same absorption peaks as found using the conventional ATR method.

Pos2.06 **Terahertz response of RuO_2 nanosheets**

KUSUMOTO Masashi [a]; NAKATA Yousuke [c]; MIYAMARU Fumiaki [ac]; TAKEDA Mitsuo W. [a]; SUGIMOTO Wataru [bc]
a)Department of Physics , Faculty of Science , Shinshu University, Japan , b)Department of Textile Science , Faculty of Textile Science and Technology, Shinshu University, Japan, c)Center for Energy and Environmental Science, Shinshu University, Japan

We investigate the electromagnetic property of RuO_2 nanosheet in terahertz (THz) region. In our study, we prepared RuO_2 nanosheets on quartz substrates, and measured their complex transmission spectra in terahertz region as an evaluating method of electromagnetic characteristics of the nanosheet in THz region. We calculated sheet impedance of nanosheets from the measured complex transmission spectra and found that real parts of the sheet impedances have almost constant values at around 1 THz. These values are same order as that measured at DC. This result indicates the validity of our evaluating method. Therefore, this measurement of sheet impedance in terahertz region enables noncontact and nondestructive evaluation of sheet impedance of nanosheets.

Pos2.07 **Theoretical study in assigning low-frequency dynamics of bio molecules.**

KAMBARA Ohki
RIE, Shizuoka University, Japan

To assign low-frequency spectra of crystal molecules, theoretical calculation support must be needed. Vibrational bands in the terahertz area of small organic molecules with the molecular weight less than ca. 200, including 2-furoic acid and anthracene, were successfully assigned by comparing THz spectra with density functional theory (DFT) calculation under periodic boundary condition. However, DFT is usually applied for the small molecules only. The more powerful tool to calculate the chemical states of the larger molecules, like proteins or DNAs, is molecular dynamics (MD) simulation. MD simulation calculate the system of particles, where forces between the particles and potential energy are defined by interatomic potentials or molecular mechanics force fields. Then, the chemical properties of thermal contribution or the interacting dynamics in the low-frequency area, which cannot be analyzed by the normal DFT calculations, will be obtained. To ensure the calculating ability of MD simulation, some biomolecules crystals with the middle molecular weight, which are the borderline region between the target of DFTs and MDs are calculated and compared in this paper.

Pos2.08st **Enhancement of phase measurement sensitivity in terahertz frequency-domain spectroscopy**

KODA Yuki; HISATAKE Shintaro; NAGATSUMA Tadao
Graduate School of Engineering Science, Osaka University, Japan

Photonics-based terahertz frequency-domain spectrometers (THz-FDS) have a high signal-to-noise ratio, a high spectral resolution and a broad bandwidth. We have proposed a self-heterodyne technique to measure not only the amplitude but also the phase information in the THz-FDS. It has been recently reported that the phase measurement is useful to analyze pharmaceutical materials having a small absorption rate in the THz region. However, conventional THz-FDS have the phase fluctuation of about ten degrees over a few minutes measurement. This is mainly due to the temperature change of optical fibers used in the THz-FDS. In this paper, we propose a practical technique to enhance a sensitivity of the phase measurement. We place the sample under test on a portion of the transparent plate, and rotate it at several tens of hertz to enable the phase modulation of THz waves. By applying a lock-in detection tuned at the modulation frequency, the impact on the measurement of above fluctuation induced by optical fibers can be reduced. As a result, peak-to-peak value of the phase fluctuation in five minutes was as small as 1.2 degrees. Thus, the sensitivity of the phase measurement is enhanced by a factor of ten compared with the conventional system.

Pos2.09 **Dip structure in metal mesh devices with squared- and trapezoid-shape holes**

FUJIMURA Takuya [a]; EHARA Yoshinobu [a]; NASHIMA Shigeki [a]; HOSODA Makoto [a]; KONDO Takashi [b]; KAMBA Seiji [b]; SUZUKI Tetsuhito [c]; OGAWA Yuichi [c]

a)Osaka City University, Japan, b)Murata Manufacturing, Co., Ltd., Japan, c)Kyoto University, Japan

The metal mesh devices (MMDs), which are composed of micro-structures and two dimensional periodic hole arrays in the metal sheet. These devices show anomalous transmission properties originated from surface mode, and are proposed as sensor application. The transmission properties of MMDs with squared holes show sharp dip structures in transmission anomaly only at oblique incident wave. Recently, dip structures in MMDs with trapezoid-shape holes are observed at normal incident wave. However, the detail results, e.g. the influence of hole shape in MMDs on dip structure, has not been measured. Therefore, we investigated the hole shape dependence of dip structure in MMDs with squared- and trapezoid-shape holes by Terahertz-time domain spectroscopy and FDTD simulation. We found that incident angle dependence of dip frequency of MMDs with squared- and trapezoid- shape holes at most of the same however the depth of spectral dip of MMD with squared-shape holes is smaller. From FDTD simulation, we also observed asymmetrically-distributed electric field in apertural area at dip frequency, and that was enhanced with asymmetric increase of hole shape. We will discuss the influence of hole shape in MMDs on dip structure using the coupling efficiency between incident wave and resonant mode originated from dip structure.

Pos2.10 **High efficiency Multimode Laser Diode THz TDS systems using Laser Chaos and Super focusing with Metal V-grooved Wave guide**

KUWASHIMA Fumiyoshi [a]; SHIRAO Takuya [a]; KISHIBATA Toshihiro [a]; AKAMINE Yusuke [a]; IWAO Kazuyuki [a]; OOI Manatu [a]; TANI Masahiko [b]; KURIHARA Kazuyoshi [c]; YAMAMOTO Kohji [b]; NAGASHIMA Takeshi [d]; NAKAJIMA Makoto [e]; HANGYO Masanori [e]

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The generation of a wide-range THz wave is 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 1.6times signal is detected using MVG compared with conventional system using Si lens.

Pos2.11 **A trial of spectrum control of terahertz waves by shaping femtosecond laser pulses**

TAKAHASHI Hisanari; TAKAHASHI Koji; WATANABE Koyo; INOUE Takashi; TAKAHASHI Hironori

Central Research Laboratory, Hamamatsu Photonics K.K. Japan

We attempted to control terahertz (THz) spectra by shaping femtosecond laser pulses emitted from a Ti:sapphire laser oscillator. We used a pulse shaper with a spatial light modulator to shape the laser pulses. We divided a pump laser pulse into multiple pulses using the pulse shaper to tune the THz wave spectra. The pulse shaper has two spectral modulation modes: a phase-only mode and a phase-and-intensity mode. We evaluated THz wave pulses with a THz-TDS system that used photoconductive antennas to emit and detect THz waves. We got a spectral bandwidth of 5 THz in the case of a single optical pulse of 20 fs. We generated spectrally-tuned THz wave pulses with these modes. The experimental results showed that the peak spectral amplitude of the THz wave generated

with phase-and-intensity modulation was 10 % higher than that generated with phase-only modulation.

Pos2.12 **Polarization-Variable Emitter for THz-TDS**

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We report on progress in development of linear polarization-variable emitter for terahertz time-domain spectroscopy. The results on its microfabrication, the finite element method modeling of appropriate bias distribution between its electrodes, the finite-difference time-domain simulated spectral output, and actual experimental testing are presented. The contribution and ways of reductions of the lead line resonances on emitter desired spectral and polarization outputs are also discussed. The possible applications of polarization-variable emitter together with our recently reported polarization-sensitive detector are outlined for non-destructive evaluation of materials quality and state, e.g. to detect the production, damage, or stress-induced optical anisotropy in various materials as well as for magneto-optical phenomena (Kerr and Faraday rotations) and ellipsometric detections in the terahertz range.

Pos2.13st **High power and broadband terahertz wave generation from $LiNbO_3$ ridge waveguide**

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Efficient high power terahertz (THz) wave generation is essential for the realization of THz measurement systems with a high dynamic range. Photoconductive antennae (PCA) have been used widely as THz wave emitters, with femtosecond laser excitation. A typical PCA produces THz waves with an average power of a few tens of nanowatts and a spectral bandwidth that extends up to a few THz. Compared to nonlinear crystals, however, PCAs have several limitations, including relatively narrow spectral bandwidths, low damage thresholds, and the inability to produce high-power THz radiation due to saturation, even when using a high-power pump. In our experiment, we demonstrated THz wave generation using a MgO:$LiNbO_3$ ridge waveguide (7μm wide, 3μm thick, 10 mm long) via optical rectification of femtosecond pulses, adopting the principal of the prism-coupled Cherenkov phase-matching method. Here, a half-cone-type silicon lens is attached to the waveguide to efficiently extract the THz waves. We constructed a terahertz time-domain spectroscopy system using the waveguide as a THz source and a PCA as a detector. The resulting $LiNbO_3$ ridge waveguide has a wider frequency and higher dynamic range than a typical THz source.

Pos2.14st **The enhancement of THz radiation from cluster plasma produced by two-color laser pulses**

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Terahertz waves have high potential for a great variety of applications. To make these applications practicable, more intense THz pulses are necessary and some concepts for the generation of high power THz waves have been proposed. To use plasmas as a THz wave source, the energy of incident laser is not limited by the damage of source. Therefore, plasmas produced by intense laser are a promising and attractive THz wave source. We have proposed the cluster plasma as THz wave source, which has both the advantages of solid and gas plasmas. We have studied THz radiation from argon cluster plasmas produced by intense two-color laser pulses. The experiment has been done with a Ti:sapphire chirped-pulse amplification system operating with a central wavelength of 810 nm. A BBO crystal is placed in the beam path to produce two-color laser pulses; a second harmonic (SH) and a fundamental waves. The angular distribution of THz radiation has been measured for the laser energy of 10 mJ and the laser pulse durations of 200 fs. The THz emission generated from Argon cluster plasma in forward direction is enhanced by this two-color pulse irradiation.

Pos2.15 **Tunable picosecond terahertz light source**

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We developed a widely tunable (1-15 THz) picosecond terahertz (THz) light source formed of a 1 μm picosecond laser, optical parametric amplifiers and terahertz difference frequency generator. The OPA-1, 2, employed by periodically poled stoichiometric lithium tantalite crystals (PPSLT: crystal length of 35 mm, fan-out grating of Λ= 29-31 μm), were injection-seeded by extracavity 1.5 μm laser diodes (ECLD-1, 2). The wavelength of OPA-2 output was tuned in a frequency range of 1510-1635 nm, while the output from the OPA-1 had a specified wavelength of 1509 nm. The outputs from

OPA-1, 2 were focused onto a 4'-dimethylamino-N-methyl-4-stilbazolium tosylate (DAST) crystal, so as to generate a THz difference-frequency output in a frequency region of 1-15THz. The THz output exhibited a linewidth of ~120 GHz, and its average power was measured to be 0.1mW at 4 THz. This system, showing a wide tunability (1-15THz), narrowband (~120GHz), and moderate average power, has the potential to provide a novel THz molecular spectroscopy with a high speed and a high spectral resolution.

Pos2.16 **Observation of Amplified Spontaneous Terahertz Emission from Optically Pumped Monolayer Intrinsic Graphene**

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Due to the unbalance between the nonequilibrium ultrafast carrier energy relaxation and relatively slow recombination dynamics in optically pumped graphene, the population inversion and resultant gain can be obtained in a wide terahertz (THz) frequency region. This enables the creation of graphene-based THz lasers. We report on the observation of an amplified spontaneous THz emission in optically pumped graphene. A CVD-grown epitaxial graphene transferred onto a SiO_2/Si substrate was installed as a gain medium in a Fabry-Perot resonator composed with ITO mirrors. Raman spectroscopy revealed the graphene to be undoped, D-peak free, and monolayer. The sample was pumped by a 1.55- μm wavelength, 10-MHz repetition, 1-W average output, 1.8-ps FWHM pulsed fiber laser. We observed electromagnetic radiation from the sample at 300K using a Fourier transform far-infrared spectrometer with a 4.2-K cooled Si bolometer. The observed spectra exhibit a broadband (1.5 to 6 THz) emission nature with Fabry-Perot longitudinal modes and a pumping intensity dependence. The obtained results are interpreted as an amplified spontaneous THz emission.

Pos2.17 **Analysis for effects of external structures in RTD-integrated terahertz bow-tie antennas on radiation characteristics**

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A resonant tunneling diode (RTD) has been studied for one of semiconductor terahertz sources. The RTD with an appropriate integrated antenna is a typical structure for terahertz device. On the other hand, a bow-tie antenna has been widely investigated as one of self-complementary antennas having broadband characteristics in a case with ideal structure. In this presentation, a terahertz bow-tie antenna structure is proposed and designed with respect to (1) an integration with a resonant tunneling diode, (2) an integration with external microstrip lines, and (3) a existence of semi-insulating or insulating substrate. Our analysis is on the based of cooperation of plural methods; (1) numerical electromagnetic simulations, (2) modern multi-purpose optimization method such as the particle swarm optimization, (3) linear electrical circuit analysis, (4) nonlinear numerical calculation for dynamic operation of device including the nonlinear equivalent circuit of a RTD. Appropriate structural designs are clarified with respect to broadband radiation characteristic, and terahertz comb type of oscillation in the proposed integrated device.

Pos2.18 **A three-dimensional antenna for a SBD-based imager operating at 1 THz**

DEBRAY Alexis; SEKIGUCHI Ryota; OUCHI Toshihiko

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A novel three-dimensional antenna intended at an imager operating at 1 THz and based on Schottky barrier diode (SBD) was investigated. The antenna was designed to achieve better coupling with waves impinging directly onto the substrate, and better impedance matching along a wide range of SBD impedance when compared with conventional planar antennas and patch antennas. A terahertz sensor was designed around a silicon SBD (Schottky contact area: 0.385 μm square) operating as a rectifier. Silicon allows for monolithic integration with CMOS-based amplifiers and switches, and for the use of bulk micro-fabrication techniques for the antenna. The antenna is based on a metallic ring (diameter: 70 μm) operating around its second anti-resonance. Simulations made by HFSS show a large impedance peak (over 500 ohm depending on the geometry) and a radiation pattern perpendicular to the ring. The antenna also integrates a reflector to achieve direct coupling with waves impinging onto the substrate. After the SBD was fabricated onto silicon wafers, the antenna was integrated using a typical micro-fabrication process. Experimental characterizations showed a Johnson noise-equivalent power (NEPJ) of 65 pW/rtHz at 1 THz, reduced 90 times when compared with a log-periodic antenna.

Pos2.19 **Contact grating device using a Fabry-Perot type resonator for terahertz wave generation**

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Optical rectification in nonlinear dielectric crystals with pulse front tilting method is commonly used for generating a high-power pulse THz wave. A setup of the pulse front tilting is constructed of diffraction grating and imaging optics. In this setup, the conversion efficiency from pump laser to THz wave decreases with increasing laser power due to an imaging error occurred by a large area excitation, which is introduced to prevent the nonlinear crystal from laser damage. To overcome this problem, a simple setup without imaging optics has been proposed, where a transmission grating is directly fabricated on a surface of a nonlinear crystal. This is so called contact grating setup. However, the predicted diffraction efficiency is low (less than 20%). Here we propose a new idea to improve diffraction efficiency, which is based on a principle of a Fabry-Perot resonator. Dielectric multilayer located between a surface grating layer and a $LiNbO_3$ substrate works as a Fabry-Perot type resonator for the diffraction wave and increased diffraction efficiency drastically. In this presentation, we report a basic thinking behind the design and detailed calculation results. An evaluation on fabricated contact grating device and preliminary results of THz wave generation will also be reported.

Pos2.20 **AlGaAs/GaAs quantum cascade lasers with modulation Al composition barriers design lasing at 3.7 THz, 145 K**

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The currently critical limitation of terahertz quantum cascade lasers (THz QCLs) applications is the need for the cryogenic cooling below ~200 K. The recently best temperature performing designs are mainly based on the resonant phonon depopulation scheme for extraction utilizing the AlGaAs/GaAs material systems with all the barriers Al concentration 15 %. Here we consider one more design freedom of change the barriers height in THz QCLs; design the injection/extraction layers and emission layers with different barriers height in order to realize the different design purpose which is difficult to achieve simultaneously at the same barriers height QCLs. We based on the 3-wells resonant tunneling injection design; optimize a lower composition (comparison with other barriers) wide emission barrier at the emission layers in order to reduce the non-radiative scattering. An external thin and high layer at the widest extraction/injection well is also added in order to improve the extraction by interface roughness (IR) scattering and reduce the parasitic injection leakage comes from non-radiative thermally activated longitudinal phonon scattering at high temperature operation. The primary experiment results succeed lasing at 3.7 THz with 112K operation.

Pos2.21 **Extremely high power photoconductive antennas**

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The terahertz time domain spectroscopy (THz-TDS) system with a femtosecond laser and the photoconductive antennas is widely used for the terahertz electromagnetic wave measurements, and is expected to develop the various applications. However, the sensitivity of THz-TDS system is still unsatisfactory for the actual applications in industrial fields. It is considered that the power-sensitivities of systems are required at least 100-times higher than that of the conventional ones in order to realize the comparable performance to the mid-infrared Fourier transform infrared spectroscopy systems. The photoconductive antennas are one of the key devices affecting the system performances. High output power and high sensitivity photoconductive antennas meet strong demands in the market. In this paper, we report high power emission photoconductive antennas optimizing electrode shape and using insulation layers. We have demonstrated 100 times higher power photoconductive antenna compare to the conventional one (Hamamatsu G10620-11). The developed high power antennas drastically improve the sensitivity of THz-TDS systems, and provide the chance to be of wide application of the terahertz measurements.

Pos2.22 **Room temperature operation of a CW THz measurement system based on difference frequency generation in GaP crystal**

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We have constructed a simple and easy CW THz measurement system of which all the parts operated at room temperature. The light source was a monochromatic CW THz signal generator based on the principle of Difference Frequency Generation (DFG) under non-collinear phase-matching conditions in a Gallium Phosphide (GaP) crystal between two infrared (IR) beams from fiber lasers. Linearly polarized beams were supplied by Yb-doped fiber lasers of which wavelengths were 1064.1 and 1053.1 nm, and their linewidths were better than 0.1 nm (~30 GHz). THz wave generated at 2.95 THz was detected by a Deuterated L-Alanine Tri-glycine Sulphate (DLATGS) pyroelectric detector or by a focal

plane THz bolometer array. Due to high enough power of the generated THz wave, beam profile and divergence could have been analyzed. The beam size at the output surface of the GaP crystal was estimated to be 140 µm x 610 µm, which is reasonable compared with the focus size of the input IR beams. The entire system is compact and portable, and it can work as non-stop system. As the initial cost and running costs of the system are inexpensive, it must be suitable for practical monitoring applications in continuous-flow manufacturing settings.

Pos2.23 **Fabrication and Evaluation of VO_x Thin Films by Metal-Organic Decomposition for Solid-State Devices**

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Vanadium oxide (VO_x) is a promising material for solid-state devices such as bolometer detectors and switching devices in THz-wave region because of its metal-insulator transition (MIT) properties due to the thermal and electrical triggers. In this study, VO_x films were fabricated by metal-organic decomposition (MOD) and evaluated for solid-state devices. VO_x precursor films were fabricated by MOD. Then, the films were fired with a temperature of 500-720 °C, time of 5-20 min and pressure of 1.2-10 Pa in O_2 and the air (O_2: 21 %). The electrical properties of VO_x thin films after the precursor films were fired at a reduced pressure in O_2 were poor. However, VO_x thin film after the precursor film was fired at 650 °C for 10 min with 1.2 Pa in the air exhibited an abrupt phase transition in the *R-T* characteristic, and a temperature coefficient of resistance was 4.6 %/K. This value is over one order higher than those of Bi and Ti bolometers. Furthermore, the VO_x film exhibited an electrically triggered MIT in the *I-V* characteristic and a switching operation with a threshold voltage of ~6.0 V. These characteristics are applicable to bolometer detectors and switching devices.

Pos2.24 **Wave plate composed of stacked parallel metal plates in THz frequency region**

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We demonstrated an achromatic terahertz wave plate composed of stacked parallel metal plates. It consists of an ensemble of parallel plate waveguides; the high and low propagation speeds of waves in TE and TM waveguide modes with the same group velocity cause a constant phase difference over a wide frequency region. We fabricated parallel plate waveguides with the different structures (a through-hole/pillar array) on the surface of the metal sheets in order to tune the center frequency of the available region from 0.5 THz to 2.5 THz. These will create new possibilities for the application of THz technologies.

Pos2.25st **Terahertz-field-induced irreversible decrease in transmittance for randomly arranged aluminum particles**

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We demonstrate terahertz (THz)-field-induced decrease in transmittance for randomly and densely arranged aluminum (Al) particles with subwavelength sizes. The transmittance for the Al particles in the THz region decreases irreversibly after the irradiation of the intense THz pulses. The threshold field that induces irreversible decrease is 40 kV/cm. Above the threshold field, more decrease is observed in the transmittance with higher electric field of the THz pulses. The decrease occurs in the polarization direction of the THz pulses, which implies that local field enhancement between the Al particles contributes to the irreversible change.

Pos2.26 **Ge-Sb-Te interfacial phase change memory material for THz device applications.**

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GeTe/Sb_2Te_3 interfacial phase change memory (iPCM) consisting of GeTe sub-layers and Sb_2Te_3 sub-layers is promising candidate for non-volatile electrical memory and also has received considerable attention due to its topological nature. By means of topological nature of iPCM, herein, we propose a new application that is terahertz (THz) and infrared (IR) lights detection. Topological insulator possesses Dirac cones and therefore capable of absorbing any low-frequency light. In three dimensional topological insulators, Dirac cone only exist in the top and bottom surfaces and the theoretical absorption coefficient is limited to 1.15 %. However, a specific structure of iPCM is theoretically predicted to be a Dirac semimetal and has a possibility of high-efficient THz and IR absorber. For the band gap tunability along with the phase change property as well as the high scalability, iPCM is expected to be a suitable candidate for a material of high-performance two-dimensional THz and IR imaging devices with additional functions such as polarization

sensitivity, wavelength selectivity, and high-speed response. We designed and built the iPCM-based lights detection system and confirmed that our system can detect high-intensity THz pulse.

Pos2.27 **Theoretical considerations of comparison between terahertz and optical superfocusings in a metallic V-groove**

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Plasmonic superfocusing of terahertz waves in the metallic V-groove is theoretically investigated by quasi-separation of variables, which is an analytical method to solve a wave equation of surface plasmon modes in tapered waveguides. The terahertz superfocusing considerably differs in wavenumber behavior from optical one because metallic permittivities in terahertz and optical regions approximate large imaginary and negative values, respectively. It is theoretically found that the wavenumber of terahertz superfocuing approaches a finite value at the apex of V-groove while that of optical superfocusing approach infinity.

Pos2.28 **Investigations on dielectric parameters of some ferroelectric materials in Terahertz waves**

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Ferroelectric materials are very important for Terahertz applications and their accurate characterization is crucial for the development of THz techniques. In this work, preparation and investigations of potassium dihydrogen phosphate KH_2PO_4 and barium strontium titanate $(Ba_{1-x},Sr_x)TiO_3$ are presented. On one side, KH_2PO_4 single crystals were grown in dynamic regime by using fractional recrystallisation in order to reduce the impurity levels. On another side $(Ba_{1-x}, Sr_x)TiO_3$ films were deposited on MgO substrates by pulsed laser deposition from ceramic targets. Morphological and structural investigations were carried out on manufactured materials. Moreover, time domain THz spectroscopy measurements were carried out on x-cut and y-cut KH_2PO_4 crystalline samples and on $(Ba_{1-x},Sr_x)TiO_3$ ceramics and films deposited on MgO. Transmission setup with 10mm aperture was used. The samples thickness limited the investigation range to 0.1 to 1.5 THz.

Pos2.29st **Development of 3D tomographic system using terahertz wave parametric source**

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We demonstrate a high dynamic range, 3-dimensional terahertz wave computed tomography (3D THz-CT) system. The emission and detection of terahertz wave in this system were accomplished by optical parametric process and heterodyne detection respectively. The system covers the frequency range of 0.6-2.8 THz with the maximum dynamic range of 80 dB. As a potential industrial application of this system to visualize the internal structures of the sample, we show a 3D image of a pencil showing a lead inside it.

Pos2.30 **Analysis of Diffusion Process of Pseudo-polymorphism Conversion from Theophylline Monohydrate to the Anhydride in a Tablet by using a Terahertz Chemical Imaging System**

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Pseudo-polymorphism conversion of an active pharmaceutical ingredient (API) sometimes causes quality deterioration such as decrease of dissolution rate of API. Authors continuously studied about pseudo-polymorphism conversion of theophylline during a granulation and drying processes as the critical quality attribute (CQA). In this study, we examined diffusion process of pseudo-polymorphism conversion from theophylline monohydrate to the anhydride in the polyethylene tablet by using a terahertz spectroscopy and chemical imaging. The polyethylene tablet (20 mmφ) which contains 10w/w% of theophylline monohydrate was fixed by the metal clip and the tablet was heated at 80 ºC through the clip. A Gallium-Phosphide (GaP) terahertz signal generator system equipped with pyroelectric DTGS detectors was used for terahertz measurement. Images were acquired in 100 x 100 points with a step size of 300 µm. Although the pseudo-polymorphism conversion was started around the clip, diffusion of the conversion spread unevenly. The monohydrate still existed after 1 week heating at the diagonal position of the tablet from the clip. According to the thermographic measurement, the heat distribution on the tablet was limited around the clip. These results suggest that the conversion which was started around the clip will promote successive conversion from the monohydrate to the anhydride.

Pos2.31st **Heterodyne Terahertz Electro-optic Sampling Using Position Sensitive Detector**

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We have recently reported a new electro-optic (EO) sampling scheme, the "heterodyne EO sampling," where the EO sampling signal is detected as direct intensity changes in the probe beam without using any polarization-control optics for detection of terahertz (THz) waves. The heterodyne EO signal has a spatial distribution originating from the non-collinear phase-matching process: i) the signal polarity is reversed on the opposite half of the sampling beam cross section and ii) THz frequency components are detected angularly resolved in proportion to the frequency. Utilizing these spatial distribution characteristics of the heterodyne EO sampling signal, we proposed and demonstrated a detection method using Position Sensitive Detector (PSD). When detecting the probe beam at PSD, since the signal output is amplified by a factor proportional to the distance from the center of the detection position, we can obtain a heterodyne signal that is more sensitive to the high frequency side. Further, since the common mode noise is suppressed by the difference detection circuit in the PSD, we can expect a better signal to noise ratio as compared to the ordinary heterodyne detection with a single photodiode. The detection bandwidth obtained with PSD was broader than that with a single photodiode.

Pos2.32st **Terahertz Detection in Double-Graphene-Layer Heterostructures**

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Double-graphene-layer (DGL) heterostructures have recently been investigated in a number of experimental and theoretical works due to their various potential applications in optical modulation, terahertz (THz) emission/detection, and THz photo-mixing and more. Here, we report experimental observation of the THz detection in the DGL structures. We demonstrate that photon-assisted resonant inter-GL transitions enables DGL structures as potential THz detectors. The DGL structures are composed of two graphene layers separated by an atomically thin h-BN barrier layer. The bias voltage applied between the GLs induces the electron gas in one and hole gas in the opposite GL forming the DGL capacitor. The band-offset energy between the Dirac points of the GLs and the depolarization shift determine the energies of the photons absorbed in the inter-GL resonant-tunneling transitions. The resonant tunneling causes all excess charges in the n-type GL to recombine with the holes in the p-type GL. Due to nonlinear resonant-tunneling inter-GL transitions, the device exhibit an negative differential conductivity (NDC) over a wide range of the gate voltages. A clear NDC peak was observed at 100 K in our DGL devices. The detection experiments were done at 330 K, an oblique incidence configuration was choose to maximize the THz electric field component perpendicular to the GLs. As a result, a clear increase in the photocurrent was observed with increasing the bias voltage, which is in good agreement with theoretical calculations.

Pos2.33 **Visualization of Vulcanization Reaction in Elastomer Compounds by Terahertz Time-domain Spectroscopy**

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Among various processes of elastomer productions, the vulcanization is one of the most essential one, which determines the product property. In the traditional method, the condition of the vulcanization is normally decided in advance by torque-cure time curves and concentration of network chain-cure time curves. These methods are based on destructive estimations, and they cannot be applied to real-time monitoring of vulcanization reactions. The authors have been developing nondestructive estimation methods of elastomer products by terahertz time-domain spectroscopy (THz-TDS) in order to overcome the problems of the conventional methods. In this study, visualization of the vulcanization reaction in elastomer compounds was investigated by the THz-TDS system. The elastomer sample was prepared based on polymer of butadiene rubber (BR), in which filler material of carbon black was not added to simplify the analysis and to improve signal-to-noise ratio of the signals. It was found that the THz absorbance indicated the minimum values at near the optimum cure time of T90 decided by the conventional torque-cure time curve. This tendency agrees with the results obtained in other elastomer samples based on styrene-butadiene rubber (SBR). It was suggested that the lower THz absorbance reflected the spread of the network structure in the sample.

Pos2.34 **The THz imager with Thin Cholesteric Liquid Crystal Film**

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Terahertz (THz) wave has been received tremendous attention because of wide applicability with high safety, which property is suitable for the nondestructive evaluation. The THz imaging is promising application to realized that. In this study, we investigate to develop an intuitive detection system with cholesteric liquid crystal (CLC) not connected any electric detection devices. The CLC reflects selective spectral band where determined its helical pitch and anisotropy. Upon irradiation intense THz wave, the temperature rise results in color change of the reflected color from CLC surface. Since visualization of the THz beam profile with only thin liquid crystal film was successfully achieved, we demonstrated that the CLC is a good candidate as a simple THz imager analyzing the projected THz beam profile on the CLC surface compared with knife-edge method and THz camera. Furthermore, in order to improve the sensitivity we employed metamaterial as an absorbing layer. The resonance of the metamaterial enhanced the absorbance and increased the temperature of CLC surface.

Pos2.35st **Development for ultrasensitive terahertz ESR spectroscopy of metal protein using a microcantilever**

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High-frequency electron spin resonance (HFESR) technique in the THz range has great advantages in understanding microscopic properties of spin systems, such as high spectral resolution and application to zero-gap spin systems. Moreover, multi-frequency ESR measurements allow detailed THz spectroscopy of spin Hamiltonian. However, because of the lack of intense light sources, a sensitivity of HFESR measurement is not generally high, and its application to low-spin-concentration sample such as biomaterial is quite difficult. To solve this problem, our group has developed an ultrasensitive HFESR technique using a microcantilever. In this technique, nanogram-order sample is mounted on a cantilever end, and ESR absorption is detected as a cantilever deflection caused by magnetic resonance force. So far spin sensitivity as high as 10^9 spins/gauss is achieved and multi-frequency ESR of microgram-order sample was possible in the THz range of up to 370 GHz. In this study, we developed specially designed probe head for cantilever-detected ESR detection system for biomaterials in sub-THz and THz range. For metal protein samples, quick sample exchange became possible and background noise level was substantially reduced. In the presentation, details of our apparatus and future prospects will be reported.