HL 59: THz and MIR physics in semiconductors

Time: Thursday 9:30–12:30 Location: POT 151

HL 59.1 Thu 9:30 POT 151

Light impact ionization in HgTe quantum wells close to critical thickness — •Stefan Hubmann[1], Grigory Budkin[2], Michael Urban[1], Vasily Bel'kov[2], Eugenius Ivchenko[2], Alexander Dmitriev[2], Johannes Ziegler[1], Dimitriy Kozlov[3], Nikolay Mikhailov[3], Sergey Dvoretsky[3], Ze-Don Kvon[3], Dieter Weiss[1], and Sergey Ganichev[1] — [1]Terahertz Center, University of Regensburg, 93040 Regensburg, Germany — [2]Ioffe Institute, 194021 St. Petersburg, Russia — [3]Rzhanov Institute of Semiconductor Physics, 630090 Novosibirsk, Russia

We report on the observation of terahertz radiation induced band-to-band impact ionization in HgTe quantum well structures close to critical thickness characterized by a nearly linear energy dispersion. This carrier multiplication process is detected for frequencies from 0.6 to 1.07 THz and in a temperature range from 4 to 90 K. Furthermore, the product of the angular radiation frequency ω and the momentum relaxation time τ is close to unity denoting a transition between the quasi-static regime $\omega\tau \ll 1$ and the high-frequency regime $\omega\tau \gg 1$. We developed a microscopic theory of light impact ionization for both regimes in HgTe quantum wells with nearly linear energy dispersion. We show that the probability of impact ionization in the transition regime is proportional to $\exp(-E_0^2/E^2)$, of the radiation electric field amplitude E and the characteristic field parameter E_0, where E_0 is strongly dependent on the radiation frequency.

HL 59.2 Thu 9:45 POT 151

Towards plasmonic tunnel gaps by on-chip laser ablation for on-chip THZ applications — •Michael Zartenar[1], Philipp Zimmermann[1,2], Alexander Höttger[1], Noelia Fernandez[1], Anna Nolinder[1], Kai Müller[1], Jonathan Finley[1,2], and Alexander Holleitner[1,2] — [1]Walter Schottky Institute and Physics Department, Technical University of Munich, Am Coulombwall 4a, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

We demonstrate that prestructured metal plasmonic nanogaps can be shaped on-chip to below 10 nm by femtosecond laser ablation. We explore the plasmonic properties and the nonlinear photocurrent characteristics of such formed tunnel junctions. The photocurrent can be tuned from multiphoton absorption toward the laser-induced strong-field tunneling regime in the nanogaps, and gives rise to a field emission of ballistic hot electrons propagating across the nanoscale junctions. We show that a unipolar current of hot electrons is achieved by designing the plasmonic enhancement factors in the junctions to be asymmetric, which allows ultrafast electronics on the nanometer scale. We particularly demonstrate that femtosecond optical pulses in the near-infrared (NIR) applied to such nanogaps can drive electronic circuits with a prospective bandwidth of up to 10 THz. We thank the DFG for funding via the Cluster of Excellence e-conversion.

HL 59.3 Thu 10:00 POT 151

Modeling of the Hot Carrier Dynamics in Graphene THz Magneto Plasmons — •Florian Stawitzki[1], Sebastian Matschy[1], Stephan Winnerl[2], Matt Chin[3,4], Thomas E. Murphy[4], and Martin Mittendorff[1] — [1]Universität Duisburg-Essen, Duisburg, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [3]US Army Research Laboratory — [4]University of Maryland, College Park, MD, US

Patterning graphene in plasmonic structures leads to resonant absorption and an increased light-matter interaction that also results in enhanced THz non-linear absorption. The charge carriers in graphene can be heated efficiently, leading to a decrease in chemical potential. This causes an ultrafast redshift of the plasmon frequency, and thus a strong increase in transmission at the resonance frequency. Here we study the dynamics of THz plasmons in an array of micrometer sized discs of bilayer graphene on SiC. These plasmons hybridize with the cyclotron motion in strong magnetic fields leading to splitting of the plasmon resonance into two branches that can be distinguished with circularly polarized radiation. We experimentally and theoretically investigate the nonlinear absorption in magnetic fields of up to 10T. A two-temperature model is used to simulate the time dependent temperature of the charge carriers. The results are in good agreement with pump-probe measurements performed at the free-electron laser FELBE at HZDR.

We thank the German Research Foundation for funding through CRC 1242.

HL 59.4 Thu 10:15 POT 151

Mid-infrared induced transparency in boron-doped diamond — •Alexander Paarmann[1], Sergey Pavlov[2], Andreas Pohl[3], Martin Wolf[1], and Heinz-Wilhelm Hübers[2,3] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]Institute of Optical Sensor Systems, German Aerospace Center (DLR), Berlin, Germany — [3]Humboldt University Berlin, Berlin, Germany

The properties of deep impurity levels in elemental semiconductors have important implications for many applications, ranging from electronic and optoelectronic devices to superconductivity. Remarkably, boron dopants implanted into high-quality diamond single crystals result in exceptionally large binding energies leading to impurity state transitions around 350 meV, i.e., in the mid-infrared spectral range.

Facilitated by the localized nature of the electronic impurity levels, such systems typically show very strong nonlinear-optical interactions. This can be used, for instance, to probe the ultrafast dynamics to elucidate the relaxation mechanism of photo-excited states with pump-probe spectroscopy [1]. Moreover, as we show here, the bleaching of the fundamental impurity transition also leads to a dramatic fluence dependence of the transmission. This opens up many possibilities for using boron-doped diamond for nonlinear-optical applications.

[1] S.G. Pavlov, et al., Diamond & Related Materials 92, 259 (2019)

HL 59.5 Thu 10:30 POT 151

Anisotropic nonlinear THz response of bilayer graphene — •Angelika Seidl[1,2], Peter Richter[3], Thomas Seyller[3], Harald Schneider[1], Manfred Helm[1,2], and Stephan Winnerl[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf — [2]Technische Universität Dresden, Dresden — [3]Technische Universität Chemnitz, Chemnitz

The intraband absorption of doped graphene is utilized in novel devices for the THz frequency range, in particular for detectors and modulators. In many cases the nonlinear THz response can be understood as a hot carrier effect, i.e. by modelling the response of an isotropic hot Fermi-Dirac distribution of carriers [1]. We have performed degenerate pump-probe experiments at 2 THz on quasi-freestanding bilayer graphene (QFBLG) on SiC utilizing the free-electron laser FELBE.We find a pump-induced transmission, corresponding to a reduced Drude absorption of hot carriers. The induced transmission is about two times lager for the case of co-polarized pump and probe beam as compared to the cross-polarized case, which clearly indicates an anisotropic distribution of carriers after intraband excitation. The fluence dependence of this phenomenon is discussed for fluences up to 10 $\mu J/cm^2$.

[1] H. A. Hafez, S. Kovalev, J.-C. Deinert, Z. Mics, B. Green, N. Awari, M. Chen, S. Germanskiy, U. Lehnert, J. Teichert, Z. Wang, K.-J. Tielrooij, Z. Liu, Z. Chen, A. Narita, K. Müllen, M. Bonn, M. Gensch and D. Turchinovich, Nature textbf561, 507 (2018).

30 min. break

HL 59.6 Thu 11:15 POT 151

Symmetry breaking and circular photogalvanic effect in epitaxial $\mathbf{Cd_xHg_{1-x}Te}$ films — Stefan Hubmann[1], Grigory Budkin[2], •Maximilian Otteneder[1], Dmitro But[3], Daniel Sacré[1], Ivan Yahniuk[3], Kilian Diendorfer[1], Vasily Bel'kov[2], Dmitry Kozlov[4], Nikolay Mikhailov[4], Sergey Dvoretsky[4], Vasily Varavin[4], Vladimir Remesnik[4], Sergey Tarasenko[2], Wojciech Knap[3], and Sergey Ganichev[1] — [1]Terahertz Center, University of Regensburg, Regensburg, Germany — [2]Ioffe Institute, St. Petersburg, Russia — [3]International Research Centre CENTERA, Institute of High Pressure Physics, Warsaw, Poland — [4]Rzhanov Institute of Semiconductor Physics, Novosibirsk, Russia

We report on the observation of symmetry breaking and the circular photogalvanic effect (CPGE) in $\mathrm{Cd}_x\mathrm{Hg}_{1-x}\mathrm{Te}$ alloys. We demonstrate that irradiation of bulk epitaxial films with circularly polarized terahertz radiation leads to the CPGE yielding a photocurrent whose direction reverses upon switching the photon helicity. This effect is forbidden in bulk zinc-blende crystals by symmetry arguments and, therefore, its observation indicates either symmetry reduction of the bulk material or that photocurrents are excited in topological surface states formed in alloys with low cadmium concentration. Bulk states play a crucial role since the CPGE is also clearly detected in samples with non-inverted band structure and therefore we suggest that strain is a reason of the symmetry reduction. We develop a theory of the CPGE showing that it results from quantum interference of different pathways contributing to the free-carrier absorption of radiation.

HL 59.7 Thu 11:30 POT 151

Nonlinear charge transport in GaAs/InGaAs core/shell nanowires at terahertz frequencies — •Rakesh Rana[1], Leila Balaghi[1,2], Ivan Fotev[1,2], Harald Schneider[1], Manfred Helm[1,2], Emmanouil Dimakis[1], and Alexej Pashkin[1] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Center for advancing electronics Dresden (cfaed), Technische Universität Dresden, 01062 Dresden, Germany

We report the high-field transport and the plasmonic response of GaAs/InGaAs core/shell nanowires (NWs) by employing optical pump - terahertz probe spectroscopy with peak electric fields up to 2 MV/cm. The plasmon mode experiences a systematic redshift and a suppression of the spectral weight with the increase of the driving THz field. The electron mobility exhibits a threshold-like behavior and starts to decrease for peak electric fields above 0.7MV/cm. This phenomenon is assigned to the increase of the effective mass due to the intervalley scattering in InGaAs. Our analysis shows the absence of the carrier multiplication in NWs even for fields beyond 1 MV/cm, in contrast to bulk InGaAs. Remarkably, the linear dependence between the plasmon spectral weight and the square of its frequency breaks down in the high field regime. Our theoretical modeling demonstrates that this behavior stems from a non-uniform distribution of the local electric field inside the NW leading to intervalley scattering mainly in its middle part. The discovered properties prove the potential of NWs for terahertz band nanoelectronics.

HL 59.8 Thu 11:45 POT 151

μJ -level picosecond far-infrared pulses generated via difference frequency mixing in organic DSTMS crystal — •Jiang Li[1,3], Rakesh Rana[1], Alexej Pashkin[1], Manfred Helm[1,2], and Harald Schneider[1] — [1]Institute of Ion Beam Physics and Material Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Institute of Applied Physics, Technische Universität Dresden, Dresden, Germany — [3]Institute of Fluid Physics, CAEP, Mianyang, Sichuan, China

We report on the generation of narrowband far-infrared pulses with energies up to 3 μJ. The technique relies on difference-frequency generation in the organic nonlinear crystal DSTMS from two linearly chirped near-infrared pulses. The tunability of the difference frequency ranging from 9 to 24 THz is achieved by tuning the frequency of the pump pulses. The measured output power was observed to increase monotonically with frequency. Our simulation based on a 1-D nonlinear wave equation model reproduces this behavior and attributes it mainly to the frequency-dependent far-infrared absorption in DSTMS. As the two near-infrared pulses are derived from the signal outputs of two optical parametric amplifiers pumped by the same Ti: sapphire femtosecond amplifier, the generated THz transient is envelop-phase stable and can be accurately sampled using an electro-optic detection scheme. This THz source provides many attractive possibilities for selective excitation of low-energy transitions or high-harmonic generation in condensed matter.

HL 59.9 Thu 12:00 POT 151

Interband Cascade Photodetectors for Light Detection in the mid Infrared — •Andreas Bader[1], Anne Schade[1], Florian Rothmayr[2], Caroline Kistner[2], Johannes Koeth[2], Fabian Hartmann[1], and Sven Höfling[1] — [1]Technische Physik, Physikalisches Institut, Julius-Maximilians-Universität Würzburg — [2]nanoplus Nanosystems and Technologies GmbH, Gerbrunn

Interband cascade photodetectors (ICD) [1] based on InAs/GaSb type-II superlattice (SL) absorbers present a novel type of photodetectors for applications in the infrared spectral region. By adjusting the period of the SL, the cut-off wavelength can be tailored in a wide range from SWIR (1-3μm) up to VLWIR ($> 14\mu$m) [2]. Cascading multiple discrete absorbers in series allows for high absorption while mitigating internal losses in the absorber within the carrier diffusion length. Furthermore, cascading reduces the overall noise leading to a higher detectivity [3]. These properties allow for the use of ICDs in multiple possible applications like gas sensing, thermal imaging and medical diagnostics. We present our work on a five-stage ICD for gas sensing applications in the MIR. A responsivity of 0.24 A/W was achieved in photovoltaic operation at room temperature. The ICD shows a cut-off wavelength of 4.7μm. The absorption of gaseous H_2O and CO_2 was investigated and clear absorption lines were resolved.

[1] Li et al, APL, 86, 10 (2005)
[2] Christol et al, Proc. of SPIE, 10563, 204 (2017)
[3] Hinkey et al, 114, 104506 (2013)

HL 59.10 Thu 12:15 POT 151

MBE-growth of p-doped InAs on undoped GaSb terahertz emitter — •Cyril Sadia-Salang[1], Rommel Jagus[1], Gerald Angelo Catindig[2], Alexander De Los Reyes[2], Armando Somintac[2], Arnel Salvador[2], and Elmer Estacio[2] — [1]Materials Science and Engineering Program, University of the Philippines Diliman, Quezon City 1101, The Philippines — [2]Condensed Matter Physics Laboratory, National Institute of Physics, University of the Philippines Diliman, Quezon City 1101, The Philippines

In this contribution, a terahertz (THz) wave surface emitter consists of a thin epitaxial layer of p-type InAs grown via molecular beam epitaxy on an undoped GaSb substrate. Multilayer buffer structures were grown prior to forming the p-InAs epilayer. These structures include 3 periods of 20-nm undoped GaAs and 260-nm undoped InAs, and 10 periods of InGaAs(3 nm)/GaAs(3 nm) superlattice as a way of minimizing surface roughness. The first 2 min of deposition of each GaAs buffer and InAs buffer proceeded with application of growth interruption. The second sample was capped with an n-doped GaAs to contribute to surface smoothening. The THz emission efficiency of p-InAs epilayers was evaluated using 1.55 μm femtosecond laser excitation in reflection geometry. The THz signal strength of the p-InAs epilayer is comparable to that of an InGaAs-based emitter. Additional improvement should be obtained by using thin InAs layer on GaSb in the transmission geometry.