HL 40: THz and MIR Physics in Semiconductors

Time: Friday 9:30–11:45 Location: H33

HL 40.1 Fri 9:30 H33

Generation of intense sub-half-cycle terahertz pulses from spatially indirect interband transitions — •Christian Meineke[1], Michael Prager[1], Johannes Hayes[1], Qiannan Wen[2], Lukas Kastner[1], Dieter Schuh[1], Kilian Fritsch[3], Oleg Pronin[3], Markus Stein[4], Sangam Chatterjee[4], Mackillo Kira[2], Rupert Huber[1], and Dominique Bougeard[1] — [1]University of Regensburg, 93040 Regensburg — [2]University of Michigan, Ann Arbor, Mi 48109 — [3]Helmut Schmidt University, 22043 Hamburg — [4]Justus Liebig University, 35392 Giessen

Ultimately short phase-stable terahertz (THz) pulses form the bedrock of THz lightwave electronics, where the carrier field creates a transient bias to control electrons on sub-cycle time scales. Here, we introduce a fully scalable high-repetition-rate THz source generating intense phase-locked and strongly asymmetric sub-cycle field transients. The key idea is to engineer electronic wavefunctions in type-II aligned semiconductor quantum wells such that resonant interband photoexcitation induces an ultrafast charge separation over several nanometers even without any bias. Our detailed quantum mechanical analysis reveals that local charging dynamics lifts the spatial separation of electrons and holes, leading to an abrupt decrease of the dipole moment, generating one single pronounced positive field peak. The THz bandwidth is scalable up to the mid-infrared by reducing the pump pulse duration. The versatility of our emitter allows adjusting waveforms, spectra, and field strengths to many applications, such as ultrabroadband spectroscopy and femtosecond nanoscopy.

HL 40.2 Fri 9:45 H33

Exploring mid-infrared transient gain in graphene — •Kalliopi Mavridou[1,2], Angelika Seidl[1,2], Rakesh Rana[1], Alexej Pashkin[1], Manfred Helm[1,2], and Stephan Winnerl[1] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, Dresden 01328, Germany — [2]Faculty of Physics and Center for Advancing Electronics Dresden, Technische Universität Dresden, Dresden 01062, Germany

In our study we employ a powerful method, namely a three-pulse pump-probe technique, that was first suggested by Kim *et al.*[1], to explore the possibility to achieve transient gain photon energies below the optical phonon energy (∼ 200 meV) in graphene. Intriguingly, this technique is not widely established and to our knowledge has never been used in the mid- or far-infrared spectral range. The principle behind this method relies on the effect of a strong pre-pump pulse of 1.55 eV photons, which can cause a transient population inversion at lower energies. This population inversion is evidenced by a sign flip of the mid-infrared (86 meV photon energy) pump-probe signal that is related to either absorption or stimulated emission of mid-infrared photons of the pump beam. We present the results on multilayer graphene obtained under various experimental configurations. Our findings shed light into the completion of rapid thermalization via Coulomb scattering and carrier cooling via optical phonons.

1. Kim, K.; Urayama, J.; Norris, T.; Singh, J.; Phillips, J.; Bhattacharya, P. *Appl. Phys. Lett.*, **2002**, *81*, 670-672.

HL 40.3 Fri 10:00 H33

Elastic and inelastic exciton scattering in InGaAs multi-quantum wells — •Daniel Anders, Markus Stein, and Sangam Chatterjee — Institute of Experimental Physics I and Center for Materials Research (LAMA), Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany

The interaction of optically injected excitons amongst each other as well as with electrons is one of the most fundamental questions in semiconductor physics. In the past, scattering processes in semiconductors between charge carriers and excitons have been studied intensively using a wide variety of experimental methods, e.g., four-wave-mixing spectroscopy, time-resolved photoluminescence spectroscopy, or optical pump - optical probe spectroscopy. In contrast to the aforementioned methods optical pump - terahertz probe spectroscopy allows to distinguish between elastic and the destructive inelastic scattering processes of excitons. While the linewidth of the intraexcitonic resonance provides a measure for the total scattering rate of all scattering processes, the change of the intraexcitonic oscillator strength is only sensitive to inelastic scattering processes. In this work, we compare exciton-electron and exciton-exciton scattering and determine the respective contributions of elastic and inelastic scattering processes.

HL 40.4 Fri 10:15 H33

Highly superlinear terahertz photoconductance in GaAs quantum point contacts in the deep tunneling regime — •Maximilian Otteneder[1], Marcel Hild[1], Ze-Don Kvon[2,3], Ekaterina E. Rodyakina[2,3], Mikhail M. Glazov[4], and Sergey D. Ganichev[1,5] — [1]Terahertz Center, University of Regensburg, Regensburg, Germany — [2]Novosibirsk, Russia — [3]Novosibirsk, Russia — [4]St. Petersburg, Russia — [5]CENTERA, Institute of High Pressure Physics, Warsaw, Poland

A highly superlinear in radiation intensity photoconductance induced by continuous wave terahertz laser radiation with low intensities has been observed in quantum point contacts made of GaAs quantum wells operating in the deep tunneling regime. For very low values of the dark conductance $G_{\rm dark}/G_0 \approx 10^{-6}$, with the conductance quantum $G_0 = 2e^2/h$, the photoconductance scales exponentially with radiation intensity and increases by almost four orders of magnitude at already 100 mW/cm^2. This effect is observed for a radiation electric field oriented along the source drain direction. We provide model considerations of the effect and attribute it to the variation of the tunneling barrier height by the radiation field due to local diffraction effects. We also demonstrate that cyclotron resonance due to an external magnetic field manifests itself in the photoconductance, completely suppressing the photoresponse.

15 min. break

Invited Talk HL 40.5 Fri 10:45 H33

Ultrafast subcycle dynamics of deep-strong light-matter coupling — •Joshua Mornhinweg[1], Maike Halbhuber[1], Laura Diebel[1], Viola Zeller[1], Josef Riepl[1], Cristiano Ciuti[2], Dominique Bougeard[1], Rupert Huber[2], and Christoph Lange[3] — [1]Universität Regensburg, Germany — [2]Université de Paris, France — [3]TU Dortmund, Germany

Subcycle interactions of strong light fields and electric charges lead to multi-octave spanning dynamics such as high-harmonic generation. In optical microcavities, even vacuum field fluctuations can drive non-perturbative light-matter coupling. Once the rate of energy exchange between the cavity and the matter mode becomes of the order of the carrier frequency of light, ultrastrong coupling (USC) emerges, and the profound modification of the vacuum ground state gives rise to novel phenomena such as cavity-mediated superconductivity. Here, we explore intriguing subcycle effects of USC including non-adiabatic dynamics occurring during quasi-instantaneous switch-off of the coupling, for which we observe sub-polariton-cycle polarization oscillations. Additionally, we drive USC with strong coherent THz fields to reveal nonlinear interactions between the polariton states, breaking the normal-mode approximation. Finally, we present deep-strong coupling (DSC) of multiple light and matter modes, creating a spectrum of Landau magneto-polaritons which covers 6 optical octaves, a coupling strength of $\Omega_{\rm R}/\omega_{\rm c} \approx 3.0$, and a record virtual ground state population exceeding 1 photon. Our results open up new avenues for dynamically tailoring of USC and DSC on strongly subcycle timescales.

HL 40.6 Fri 11:15 H33

Probing Free Electrons in InSb with Terahertz Shockwave Spectroscopy — •Peter Fischer, Gabriel Fitzky, Davide Bossini, Alfred Leitenstorfer, and Ron Tenne — Department of Physics and Center for Applied Photonics, University of Konstanz, D-78457 Konstanz, Germany

The Auger process, a non-radiative three-particle recombination, is critical especially in narrow-band semiconductors where it sets a fundamental efficiency limit for optoelectronic applications. Since their characteristic response frequencies fall within a broadband interval in the terahertz and mid-infrared range, quantitative studies of the electron dynamics in these materials remain challenging. Here, we demonstrate a new pump-probe technique able to monitor the free carrier plasma by observing its signature in the transient terahertz reflectivity spectrum. A broadband terahertz source, providing at the same time maximum temporal resolution, emerges from slicing the electric-field transient on a subcycle time scale, effectively generating a shockwave. Applying this transient to InSb after interband excitation, we find that the Auger-recombination coefficient increases by a factor of two from room temperature to 4.2 K. Furthermore, the importance of electron trapping to accurately model carrier dynamics is illustrated. Our approach exclusively targets the response of free charge carriers, disentangled from other contributions by e.g. bound excitons. Therefore, it offers a tool complementary to established time-resolved techniques.

HL 40.7 Fri 11:30 H33

Nonlinear photocurrents induced by terahertz radiation in twisted bilayer graphene — •Stefan Hubmann[1], Philipp Soul[1], Giorgio di Battista[2], Marcel Hild[1], Kenji Watanabe[3], Takashi Taniguchi[3], Dmitri Efetov[2], and Sergey Ganichev[1] — [1]Terahertz Center, University of Regensburg, 93040 Regensburg, Germany — [2]ICFO, Castelldefels, Barcelona 08860, Spain — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

We report on the observation of nonlinear photocurrent and photoconductivity in twisted bilayer graphene (tBLG) with twist angles below 1°. We show that excitation of the tBLG bulk causes a photocurrent, whose sign and magnitude are controlled by the orientation of the radiation electric field and the photon helicity. The developed theory shows that the current is formed by asymmetric scattering in gyrotropic tBLG. For the observed photocurrents, we demonstrate the emergence of pronounced oscillations upon variation of the gate voltage, which correlate with the oscillations of the sample resistance. These photocurrent oscillations originate in interband transitions between a multitude of subbands in tBLG. Furthermore, at higher radiation intensities, we detected a nonlinear intensity dependence of bulk photogalvanic current and photoconductivity. These nonlinear photoresponses are caused by the interplay between interband, intersubband, and intraband transition. This interplay is controlled by the Fermi level position with respect to the Moiré subbands. We show that the photosignals saturate with rising intensity, while contributions from different transitions differ in their respective saturation behavior.