HL 13: Ultra-Fast Phenomena

Time: Tuesday 9:30–12:15 Location: H33

HL 13.1 Tue 9:30 H33

Ultrafast hot charge carrier transport across graphene nano-gaps — •Johannes Gröbmeyer, Philipp Zimmermann, and Alexander Holleitner — Walter Schottky Institute and Physics Department, Technical University of Munich, Germany

We study the hot charge carrier transport across nanoscale junctions for ultrafast electric pulse generation on the nanometer scale. To avoid laser ablation problems common to metal based photoemission devices, we investigate the possibility of graphene nanojunctions positioned on a sapphire substrate. We create the emitter-collector structure by bisecting a graphene strip utilizing a helium ion beam to create a ˜30 nm wide nano-gap. Due to substrate interaction with the helium ion beam this gap is filled by a bulge of highly defected sapphire. Measuring the ultrafast and time-integrated charge carrier transport, we find evidence of an ultrafast photoemission across this gap. Our work demonstrates that graphene based nano-gaps have the potential of replacing photoconductive switches at low temperatures.

HL 13.2 Tue 9:45 H33

Studying hot electron transport in bismuth with transient all optical pump-probe spectrocopy — •Fabian Thiemann[1], Germán Sciaini[2], Alexander Kassen[1], and Michael Horn-von Hoegen[1] — [1]University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany — [2]University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1, Canada

Bismuth as a Peierls-Jones distorted semimetal is famous for its photoexcited coherent optical phonon modes and its delicate interplay with the electron dynamics. Especially the A_{1g} phonon mode at $\approx 3\,\mathrm{THz}$ and its characteristic softening upon photoexcitation is easily accessible and can be studied with all optical pump-probe spectroscopy, solely by monitoring the change in reflectivity $\Delta R/R_0$. The number of excited carriers in bismuth influences the atomic potential energy surface and thus the mode's softening. Therefore, in turn, we employed the redshift of the A_{1g} mode as a robust quantity to determine the spatial distribution of excited carriers and the absorbed energy density in the carrier system. A homogenous distribution due to ultrafast transport of hot carriers was observed, limited by an effective carrier penetration depth that is way beyond the optical skin depth.

HL 13.3 Tue 10:00 H33

Ultrafast Dynamics of Inter- and Intraband Transitions in GaP Investigated by fs-Time Resolved Ellipsometry — •Rüdiger Schmidt-Grund[1], Noah Stiehm[1], Erich Runge[1], Martin Zahradník[2], Shirly Espinoza[2], Mateusz Rebarz[2], Jakob Andreasson[2], and Stefan Krischok[1] — [1]TU Ilmenau, Technische Physik I and Theoretische Physik I, Weimarer Straße 32, 98693 Ilmenau, Germany — [2]ELI Beamlines, Fyzikální ústav AV ČR, Za Radnicí 835, 25241 Dolní Břežany, Czech Republic

We discuss the ultrafast dynamics of the dielectric function after excitation with a high-power laser pulse of the semiconductor GaP in the spectral range around the fundamental absorption edge, measured by pump-probe fs-time resolved spectroscopic ellipsometry [1,2]. The excited hot carriers cause several effects: we observe in different regions of the Brillouin zone both, Pauli-blocking of valence-to-conduction-band transitions and arising of new intra-conduction and -valence-band transitions, enabled by carrier scattering within the Brillouin zone and in particular tunnelling to the indirect minimum. We understand our observations with the help of density functional theory from which we derived band structure, transition matrix elements and the joint density of states between bands energetically relevant in our study. Our results show long lasting non-equilibrium phenomena (> ns), probably due to carrier trapping processes.

[1] S. Richter *et al.*, Rev. Sci. Instrum. **92**, 033104 (2021).
[2] S. Richter *et al.*, New J. Phys. **22**, 083066 (2020).

HL 13.4 Tue 10:15 H33

Multiparameter determination of time-resolved photoluminescence measurements — •Sebastian Bohm[1], Max Grossmann[1], Stefan Heyder[1], Klaus Schwarzburg[2], Peter Kleinschmidt[1], Erich Runge[1], and Thomas Hannappel[1] — [1]Fakultät für Mathematik und Naturwissenschaften, Technische Universität Ilmenau, Ehrenbergstraße 29, 98693 Ilmenau — [2]Institut Solare Brennstoffe, Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin

Accurate knowledge of radiative, non-radiative, and trapping photoluminescence lifetimes is crucial for the understanding and improvement of semiconductor devices. In principle, these parameters can be obtained from time-resolved photoluminescence spectroscopy (TRPL) measured at different excitation level, see, e.g., M. W. Gerber and R. N. Kleiman, J. Appl. Phys. 122, 095705 (2017), DOI 10.1063/1.5001128. We show that a full multi-parameter estimation based on a suitable maximum likelihood estimator and state-of-the-art non-linear multi-parameter optimization yields superior results compared to conventional data analysis.

HL 13.5 Tue 10:30 H33

Strategies for Automating Femtosecond Time-Resolved Ellipsometry Data Analysis — •Noah Stiehm[1], Yixuan Zhang[2], Erich Runge[3], Stefan Krischok[1], Hongbin Zhang[2], and Rüdiger Schmidt-Grund[1] — [1]Technische Universität Ilmenau, Fachgebiet Technische Physik I, Weimarer Straße 32, 98693 Ilmenau, Germany — [2]Technische Universität Darmstadt, Research Group Theory of Magnetic Materials, Otto-Berndt-Straße 3, 64287 Darmstadt — [3]Technische Universität Ilmenau, Fachgebiet Theoretische Physik I, Weimarer Straße 32, 98693 Ilmenau, Germany

With the recently developed experimental method of femtosecond time-resolved spectroscopic ellipsometry [1], it is possible to obtain the transient dielectric function of a sample after excitation in a pump-probe scheme. However, modeling the experimental data manually with established ellipsometry modeling workflows is cumbersome and significantly reduces the throughput of the experiment. Here we present strategies I) to formalize the experience and physical intuition usually entering modeling strategies, II) to reduce computational costs by application of dimensionality reduction techniques, especially in the additionally required ab-initio theory calculations, and III) to improve stability, to enable an automated modeling pipeline with minimal human intervention.

[1] S. Richter *et al.*, Rev. Sci. Instrum. 92, 033104 (2021).

15 min. break

HL 13.6 Tue 11:00 H33

Coherent Dynamics of Charge-Transfer Excitons — •Markus Stein[1], Melanie Fey[1], Christian Fuchs[2], Wolfgang Stolz[2], Kerstin Volz[2], and Sangam Chatterjee[1] — [1]Institute of Experimental Physics I and Center for Materials Research, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany — [2]Department of Physics and Material Sciences Center, Philipps-Universität Marburg, Renthof 5, 35032 Marburg, Germany

Charge carrier transport phenomena through internal interfaces in semiconductor heterostructures are currently in the spotlight of scientific research due to the advancing miniaturization of devices. However, how internal interfaces in semiconductor heterostructures affect the coherent dynamics, i.e., the transition from a coherent polarization to a population, is largely unexplored. To shed some light on the subject, we use a GaInAs/GaAs/GaAsSb type-II like double quantum well structure which, due to its design, exhibits a charge-transfer exciton resonance in the linear absorption. This allows us to study the coherent dynamics of charge-transfer excitons and excitons that can relax across the internal interface into a charge-transfer state by means of degenerate four-wave-mixing. Furthermore, adding an optical prepulse, the phase relaxation of charge-transfer excitons subjected to collisions with either free carriers or incoherent excitons is investigated.

HL 13.7 Tue 11:15 H33

Intense terahertz radiation via the transverse thermoelectric effect — •Tim Priessnitz[1,2], Petar Yordanov[1], Min-Jae Kim[1,2,3], Georg Cristiani[1], Gennady Logvenov[1], Bernhard Keimer[1], and Stefan Kaiser[1,2,3] — [1]Max-Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]4th Physics Institute and Research Center SCoPE, University of Stuttgart, 70569 Stuttgart, Germany — [3]Institute of Solid State and Materials Physics, Technical University Dresden, 01069 Dresden, Germany

Terahertz (THz) radiation became a powerful tool with widespread ap-

plications ranging from imaging and spectroscopy to nonlinear optical control of materials. However, efficient and scalable THz sources remain rare. Here, we present a novel approach to generate powerful THz radiation making use of an ultrafast current induced via the transverse thermoelectric effect (TTE). We realize this in off-cut grown thin films of the delafossite $PdCoO_2$ and the cuprate $La_{1.84}Sr_{0.16}CuO_4$ driven by femtosecond laser pulses resulting in an ultrafast transient diffusion of charge carriers. Characterizing the resulting THz radiation, we find it comparable in power and spectral bandwidth to standard emitters based on nonlinear crystals. A first basic model including the Seebeck anisotropy, electrical and thermal conductivities and the transient diffusivity allows materials based predictions. Due to its simplicity and potential for scalability in terms of multiple tunable material parameters, THz generation based on the TTE opens a new avenue for high-field THz generation and novel cost-efficient emitters.

HL 13.8 Tue 11:30 H33

Clocking the dynamics of correlated Bloch electrons on an attosecond time scale — •Josef Freudenstein[1], Markus Borsch[2], Manuel Meierhofer[1], Dmytro Afanasiev[1], Christoph Peter Schmid[1], Fabian Sandner[1], Marlene Liebich[1], Anna Girnghuber[1], Matthias Knorr[1], Mackillo Kira[2], and Rupert Huber[1] — [1]University of Regensburg, 93051 Regensburg, Germany — [2]University of Michigan, Ann Arbor, Michigan 48109, USA

Delocalized Bloch electrons and the low-energy correlations between them determine key properties of solids. To directly capture how many-body correlations affect the actual motion of Bloch electrons, sub-femtosecond temporal precision is desirable. Here, we study attosecond shifts in the dynamics of charge carriers at the Fermi level, combining sub-fs resolution with meV energy selectivity. Coherent excitons are injected in bulk and monolayer tungsten diselenide and subsequently accelerated by multi-terahertz light fields. Quasiparticle collisions lead to the emission of high-order sidebands, which contain key information about the ballistic dynamics of the charge carriers. We show how the excitonic binding energy, the strength of the driving field, the valley polarization and Pauli blocking influence these dynamics on an attosecond time scale and faithfully reproduce these results with quantum-dynamic many-body computations in a Wigner-function representation. This opens a new pathway to understanding emergent quantum dynamics and phases and sets a corner stone for future optoelectronics and quantum-information processing.

HL 13.9 Tue 11:45 H33

Time-resolved ellipsometry on CuI thin films — •Carola Emminger[1,2], Evgeny Krüger[1], Michael Bar[1], Shirly Espinoza[3], Martin Zahradnik[3], Mateusz Rebarz[3], Felix-Florian Delatowski[3], Jakob Andreasson[3], Michael Seifert[4], Silvana Botti[4], Chris Sturm[1], and Marius Grundmann[1] — [1]Felix-Bloch Institut für Festkörperphysik, Universität Leipzig, Germany — [2]Institut für Physik, Humboldt-Universität zu Berlin, Germany — [3]ELI Beamlines, Czech Republic — [4]Institut für Festkörpertheorie und Optik, Friedrich-Schiller-Universität Jena, Germany

We report the impact of the carrier dynamics on the dielectric function of CuI thin films by means of femtosecond pump-probe spectroscopic ellipsometry. As expected, we observe a strong decrease of the exciton peak due to the pump pulse, which starts to recover after 200-300 fs. Interestingly, we notice a small increase in absorption below the band gap after a delay time of about 400 fs, which might be explained by valence- to valence-band transitions resulting from the laser-induced increased carrier density. At about 10 ps, the dielectric function has almost fully recovered. We analyze the delay-time dependent dielectric function and discuss possible explanations for the changes related to the carrier density.

HL 13.10 Tue 12:00 H33

Gain recovery dynamics after stimulated emission in type-II semiconductor laser materials — •Markus Stein[1], Felix Schäfer[1], Janine Lorenz[1], Johannes Steiner[2], Jörg Hader[3], Jerry Moloney[3], Torsten Meier[2], Stephan W. Koch[4], and Sangam Chatterjee[1] — [1]Institute of Experimental Physics I and Center for Materials Research, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany — [2]Department of Physics, Paderborn University, Warburger Strasse 100, D-33098 Paderborn, Germany — [3]Wyant College of Optical Sciences, University of Arizona, 1630 East University Boulevard, Tucson, Arizona 85721, USA — [4]Department of Physics and Material Sciences Center, Philipps-Universität Marburg, Renthof 5, 35032 Marburg, Germany

Type-II active devices combine the advantages of spectrally broad, temperature-stable efficient gain with the potential for electrical injection pumping. Intrinsic charge-carrier relaxation dynamics limit the feasible repetition rates beyond constraints of cavity design and heat removal. Here, we investigate the recovery of material gain after a stimulated emission process in an InGaAs/GaAs/GaAsSb heterostructure, experimentally simulating the operation condition of a pulsed laser system. In an optical pump - optical probe setup, a first optical pulse injects hot charge carriers. Subsequently, a second pulse tuned to the broad spectral region in which gain is observed is used to stimulate emission. A detailed analysis of the dynamics after stimulated emission reveals that the physical limit for the highest possible laser repetition rate for this material system is in the range of 100 GHz.