HL 26: Ultra-fast phenomena

Time: Wednesday 9:30–13:00 Location: EW 202

HL 26.1 Wed 9:30 EW 202

Towards femtosecond on-chip electronics based on plasmonic hot electron nano-emitters — Christoph Karnetzky[1,2], Philipp Zimmermann[1,2], Noelia Fernandez[1,3], •Christopher Trummer[1,2], Carolina Duque-Sierra[1,2], Martin Wörle[4], Reinhard Kienberger[4], and Alexander W. Holleitner[1,2] — [1]Walter Schottky Institute and Physics Department, Technical University of Munich, Am Coulombwall 4a, 85748 Garching, Germany — [2]Nanosystems Initiative Munich (NIM), Schellingstr. 4, 80799 Munich, Germany — [3]Max Planck Institut für Quantenoptik, Hans Kopfermann Str. 1, 85748 Garching, Germany — [4]Physik-Department E11, Technical University of Munich, James-Franck-Str. 1, 85748 Garching, Germany

To combine the advantages of ultrafast nano-optics with an on-chip communication scheme, optical signals with a frequency of several hundreds of THz need to be down-converted to coherent electronic signals of GHz or less.Here, we demonstrate that 14 fs optical pulses in the near-infrared can drive electronic on-chip circuits with a bandwidth up to 10 THz. The electronic pulses propagate in macroscopic striplines on a millimeter scale. We exploit femtosecond photoswitches based on tunneling barriers in nanoscale metal junctions to drive the pulses. The non-linear ultrafast response is based on a combination of plasmonically enhanced, multi-photon absorption and quantum tunneling, and gives rise to a field emission of ballistic electrons propagating across the nanoscale junctions. Our results pave way towards femtosecond electronics integrated in wafer-scale quantum circuits.

HL 26.2 Wed 9:45 EW 202

Tunable high harmonics from nanorings swirled by optical vortices — •Jonas Wätzel and Jamal Berakdar — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Karl-Freiherr-Von-Fritsch-Str. 3, 06112 Halle (Saale)

The interaction of light carrying orbital angular momentum, also called optical vortices, with matter opens the door to exciting effects and mechanisms beyond the optical dipole selection rules. We demonstrated in the past that the transfer of OAM to charge density can be used to manipulate and steer the carrier dynamics. A direct consequence is the possibility to generate a sizable, directed photocurrent.

Here we report on the irradiation of intercalated nanorings by optical vortices which ignites a charge flow that emits coherent trains of high harmonic bursts. The frequencies and time structures are highly controllable by the topological charge of the driving vortex beam. As a demonstration of the fundamental quantum mechanical tunneling process, the non-equilibrium orbital magnetic moment triggered in a ring is translated to the smaller and larger attached rings leading, respectively, to high and low-frequency harmonic generation.

Our findings show that the frequencies of the emitted harmonics are tunable by changing the waist and/or the winding number of the optical vortex, without the need to increase the pulse intensity which, in return, could lead to material damage. The proposed setup is non-destructive as short vortex pulses of moderate intensities are needed, and it offers a versatile tool for nanoscale optical and spectroscopic applications such as local, single beam pump-probe experiments.

HL 26.3 Wed 10:00 EW 202

Ultrafast quasi-particle dynamics in graphene nanoribbons. — •Raphael German, Jingyi Zhu, Boris Senkovskiy, Alexander Grüneis, and Paul H.M. van Loosdrecht — II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany

The opening of a bandgap in one-dimensional graphene nanoribbons paves the road toward carbon based optical applications. Here, we report on a study of the optical dynamics in N=7 armchair graphene nanoribbons (7-AGNR) using steady state and time-resolved spontaneous Raman spectroscopy. The Raman spectra show a strong resonance behavior for excitation energies around 2.2 eV, which is interpreted as an excitonic Raman resonance. We use the resonant enhancement to study both the phonon as well as the exciton population dynamics in 7-AGNRs. The observed lifetime of the D and G phonons is found to be limited to about 2 ps due to optical-acoustical phonon scattering. The exciton population dynamics shows a multi-exponential decay which is interpreted in terms of the presence of an inhomogeneous distribution of defect bound excitons and dark states.

HL 26.4 Wed 10:15 EW 202

High-harmonic generation from tailored solid targets — •Murat Sivis[1,2], Marco Taucer[2], Kyle Johnston[2], Giulio Vampa[2], André Staudte[2], Andrei. Yu. Naumov[2], David. M. Villeneuve[2], Paul B. Corkum[2], and Claus Ropers[1] — [1]4th Physical Institute - Solids and Nanostructures, Georg-August University, Göttingen, Germany — [2]National Research Council of Canada and University of Ottawa, Ottawa, Canada.

In recent years, high-harmonic generation (HHG) in semiconductor and dielectric crystals has enabled new all-optical means to investigate solid-state matter [1,2]. On the other hand, solid targets offer unique opportunities to develop novel types of sources for coherent extreme-ultraviolet radiation with tailored wave fields. Here, we present a study on high-harmonic generation in locally modified zinc oxide and silicon targets driven by femtosecond laser pulses at 2 μm central wavelength [3]. We demonstrate how the local intensity, polarization and phase of the generated radiation (up to the ninth harmonic order of the fundamental) can be controlled by changing the structural and chemical composition of the target. Our results indicate unprecedented means to link high-harmonic generation with optoelectronics, suggesting solid-target HHG as an all-optical probe for ultrafast dynamics on the nanoscale.

[1] S. Ghimire, *et al. Nat. Phys.* **7**, 138-141 (2011).
[2] G. Vampa,*et al. Nature* **522**, 462-464 (2015).
[3] M. Sivis *et al. Science* **357**, 303-306 (2017).

HL 26.5 Wed 10:30 EW 202

Electron mobility and lifetime in GaAs/$In_xGa_{1-x}As$ core/shell nanowires studied by optical pump – THz probe spectroscopy — •Ivan Fotev[1,2], Leila Balaghi[1,2], René Hübner[1], Johannes Schmidt[1], Markus Hähnel[1], Harald Schneider[1], Manfred Helm[1,2], Emmanouil Dimakis[1], and Alexej Pashkin[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]TU Dresden, Germany

We utilize ultrafast optical pump – terahertz probe spectroscopy in order to investigate charge carrier response of GaAs/$In_xGa_{1-x}As$ core/shell nanowires (NWs) produced by molecular beam epitaxy. The NWs were $\approx$2 μm long. The GaAs core diameter was 25 nm and the InGaAs shell thickness was 80 nm. We studied the shells with different compositions, from $x = 0.20$ to $x = 0.44$.

From the pump-probe measurements we extracted terahertz photoconductivity of NWs and used the localized surface plasmon model to fit the results. The charge carrier lifetimes were estimated to be around 80–100 ps while the extracted electron mobilities reach 3700 $cm^2V^{-1}s^{-1}$ at room temperature. Even without a surface passivation shell, these values are higher than those in previously studied GaAs/AlGaAs core/shell nanowires, but still lower than the ones for bulk InGaAs. Possible reasons (sources of electron scattering) which affect the mobility will be discussed.

HL 26.6 Wed 10:45 EW 202

The role of the Σ-point in the ultrafast dynamics of intervalley hole scattering in PbTe — •Prashant Padmanabhan, Manpreet Kaur, Kestutis Budzinauskas, and Paul H. M. van Loosdrecht — II. Physics Institute, University of Cologne, Germany

PbTe is a leading thermoelectric material, notable for its low thermal conductivity and large carrier mobility at low doping levels. Using time-resolved differential reflectivity measurements, we investigate the ultrafast relaxation of highly excited carriers, probing the dynamics of electron-phonon interactions on the femtosecond and picosecond timescales. Our experimental and theoretical results show that phonon-mediated intervalley scattering involving the Σ-point plays a significant role in the hole cooling process due to the unique topology of its valence band. In addition, anomalous temperature dependencies in the carrier relaxation rates show the dramatic influence of the softening of phonons characteristic of incipient ferroelectrics.

HL 26.7 Wed 11:00 EW 202

Finite system effects on high harmonic generation: from atoms to solids — •Kenneth Hansen[1], Dieter Bauer[2], and Lars Bojer Madsen[1] — [1]Department of Physics and Astronomy, Aarhus

University, DK-8000, Denmark — [2]Institute of Physics, University of Rostock, 18051 Rostock, Germany

Using time-dependent density field theory (TDDFT)[1] high harmonic generation (HHG) has been studied in one-dimensional structures of intermediate sizes from a single nucleus upto hundreds of nuclei. The well known HHG cutoff for atomic systems is observed to extent linearly with system size and is found to converge into previously observed cutoffs for bulk solids only for large systems. The change from atomic HHG to solid state HHG is observed from system sizes of 6-8 nuclei and is first fully converged at system sizes of 60 nuclei. The systems size dependence of the observed HHG cutoffs is found to follow the limitations of movement of classical electron-hole pairs in the band structure. Because of the correlation between recombination energy and electron-hole propagation length high energy recombination events are not possible in small systems, but become available for larger systems resulting in the change of the cutoff energies with system size. When varying the field intensity we observe that the cutoffs move linearly with the intensity even for small systems that are far from a true bulk solid.

Kenneth K. Hansen, Tobias Deffge, Dieter Bauer, *High-order harmonic generation in solid slabs beyond the single-active-electron approximation*, Phys. Rev. A 96, 053418 (2017).

15 min. break.

HL 26.8 Wed 11:30 EW 202

Lightwave-driven electron-hole recollisions in layered materials — •Christoph P. Schmid[1], Fabian Langer[1], Stefan Schlauder[1], Philipp Nagler[1], Tobias Korn[1], Christian Schüller[1], Peter G. Hawkins[2], Johannes T. Steiner[2], Ulrich Huttner[2], Stefan W. Koch[2], Mackillo Kira[3], and Rupert Huber[1] — [1]University of Regensburg, 93040 Regensburg, Germany — [2]University of Marburg, 35032 Marburg, Germany — [3]University of Michigan, Ann Arbor, Michigan 48109, USA

Utilizing intense light pulses to realize collisions of valence electrons with their parent ion lies at the heart of high-harmonic generation and attosecond science. In solids, a similarly powerful collider scheme for quasiparticles would be highly desirable. Here, we demonstrate a sub-cycle quasiparticle collider. Electron-hole pairs are resonantly prepared in tungsten diselenide, while phase-controlled multi-THz waveforms accelerate and recollide them. This ballistic dynamics manifests itself in the emission of high-order sidebands, the spectra and sub-cycle time structure of which carry key information about the colliding quasiparticles, such as the excitonic binding energy. We also show that lightwave acceleration can not only change the translational motion of quasiparticles, but even control internal quantum attributes such as the spin and the valley pseudospin. We introduce this new paradigm by demonstrating lightwave-driven intervalley transport of valley-polarized electron-hole pairs in monolayer tungsten diselenide, opening a new pathway towards ultimately fast valleytronics at optical cycle scales.

HL 26.9 Wed 11:45 EW 202

Decay channels of the coherently excited A_{1g} phonon in antimony — •Sergej Krylow[1], Eeuwe S. Zijlstra[1], Fairoja Cheenicode Kabeer[2], Tobias Zier[1], Bernd Bauerhenne[1], and Martin E. Garcia[1] — [1]Universität Kassel, Theoretische Physik II — [2]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin

The analysis of phonon decay channels is of great importance in order to understand the dynamics of a system excited by an ultrafast laser pulse. Femtosecond laser excitation of Antimony generates a coherent A_{1g} phonon and, at the same time, softens the covalent bonds between the atoms. Both effects crucially affect the dynamics of antimony after laser excitation. It is in general difficult to disentangle the influence of both effects and to extract information about the decay channels of the coherent A_{1g} phonon. In this work we develop a method to analyze the phonon decay channels in ultrafast excited antimony using ab initio molecular dynamic simulations. Our simulations allow us to account for all phonon degrees of freedom, which was previously not possible. In particular we find, that at low excitation densities the dominating decay channel is a third order scattering process for which one A_{1g} phonon decays into two other phonons. At high excitation densities a fourth order scattering process becomes dominant for that two A_{1g} phonons decay into two phonons.

HL 26.10 Wed 12:00 EW 202

Laser-induced vacancy diffusion in silicon — •Tobias Zier and Martin E. Garcia — Theoretische Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Defects, like, vacancies and/or impurities in a crystal are an ambivalent topic in the scientific dialogue. On the one hand, it is tried to decrease the number of impurities due to the high efficiency of pure materials. On the other side well defined defects are the basis of promising new effects, like, NV centers in diamond as a possible one-photon emitter. Nevertheless, in both cases a controlled mobility of crystal defects is of high interest. In order to study the possibility to guide vacancies by femtosecond-laser pulses we performed ab initio molecular dynamics simulations of laser-excited silicon with a defect density of 3.5 %. Besides the changed mobility of the vacancies by the femtosecond-laser excitation we additionally analyzed their impact on ultrafast phenomena, like, nonthermal melting and thermal phonon squeezing.

HL 26.11 Wed 12:15 EW 202

Where are the "relaxors" and what are they doing? — •Wolfgang Donner[1], Florian Pforr[1], Kai-Christian Meyer[1], Marton Major[1], Karsten Albe[1], and Uwe Stuhr[2] — [1]Technische Universität Darmstadt, Germany — [2]Paul Scherrer Institut, Switzerland

We report on the nano-scale structure and picosecond dynamics of Ba-doped sodium bismuth titanate piezoelectrics. We used diffuse neutron scattering and a combination of Molecular Dynamics Simulation (MD) and Quasi-Elastic Neutron Scattering (QENS) to identify the origin of the frequency-dependence of the dielectric permittivity ("relaxor-behavior") in these materials. Despite the ps-range of the MD and QENS investigations, we assume that also lower frequency ranges of the permittivity are affected by the dynamics of the 20 nm sized tetragonal platelets which we identify as the "relaxors".

References: PRB 94, 014105 (2016), PRB 96, 184107 (2017)

HL 26.12 Wed 12:30 EW 202

Ultrafast electron dynamics in the nodal-line semimetal ZrSiSe — •Gianmarco Gatti, Alberto Crepaldi, Silvan Roth, and Marco Grioni — EPFL, Lausanne, Switzerland (CH)

ZrSiSe is a semimetal where metallic and linearly dispersing bulk conduction and valence bands cross each other along a closed nodal-line in the momentum space. The nonsymmorphic symmetry of the crystal protects the degeneracy of these bands along the whole Brilouin zone edge. Surface states, predicted by calculations and detected by angle-resolved photoemission spectroscopy (ARPES) also contribute to the electrical conduction of this material. A very fast relaxation dynamics of the order of 400 fs of both the bulk and the surface states is revealed by the means of time-resolved ARPES.

HL 26.13 Wed 12:45 EW 202

Phase-Filling Singularities in Femtosecond Transient Dielectric Spectra of Germanium — •Shirly Espinoza[1], Mateusz Rebarz[1], Steffen Richter[1], Oliver Herrfurth[2], Miroslav Kloz[1], Rudiger Schmidt-Grund[2], Jakob Andreasson[1], and Stefan Zollner[3] — [1]ELI Beamlines, Institute of Physics, Czech Academy of Science, Na Slovance 2, 18221 Prague, Czech Republic — [2]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstr. 5, 04103 Leipzig, Germany — [3]Department of Physics, New Mexico State University, Las Cruces, New Mexico 88003-8001, USA

By exciting semiconductors with ultra-short laser pulses and studying the non-equilibrium material, information about the band structure and the dynamics of the generation and relaxation of carriers can be obtained. Time-resolved ellipsometry allows the measurements of changes in the dielectric function of solid state materials in the femtosecond time-scale. In semiconductors, these changes can be assigned to several ultrafast processes such as carrier generation, band gap renormalization, Burstein-Moss shift, carrier-phonon scattering, carrier-carrier scattering, and phase filing singularities. This work presents recent results on femtosecond transient dielectric spectra of undoped Germanium at room temperature. The carriers were generated by the excitation with a 1.55 eV laser beam. The predicted Fermi singularity (Xu et al., Phys.Rev.Lett.118, 2017, 267402) was observed lasting a few picosenconds.