O 7: Graphene: THz, NIR and Transport Properties (HL with O/TT)

Time: Monday 9:30–11:30 Location: ER 270

O 7.1 Mon 9:30 ER 270

Ratchet effects in graphene with a lateral periodic potential — •P. Olbrich[1], J. Kamann[1], J. Munzert[1], M. König[1], L.E. Golub[2], L. Tutsch[1], J. Eroms[1], F. Fromm[3], Th. Seyller[3], D. Weiss[1], and S.D. Ganichev[1] — [1]University of Regensburg, Regensburg, Germany — [2]Ioffe Institute, St. Petersburg, Russia — [3]Technical University of Chemnitz, Germany

We report on the observation of terahertz (THz) radiation induced photocurrents in (a) epitaxially grown and (b) exfoliated graphene with a lateral periodic potential. The samples were covered with an insolating layer and a sequence of asymmetrically spaced thin/thick metallic stripes. While in the reference of sample (a) under normal incidence of THz radiation no photosignal was observed, the illumination of the lateral periodic potential resulted in pronounced photosignals, consisting of polarization dependent and independent contributions. In case of sample (b) the thin/thick metallic stripes act as a dual top gate structure to vary the potential profile and a back gate allows to change the carrier type and density of the sample. Here, the photocurrent reflects the degree of asymmetry induced by different top gate potentials and even vanished for a symmetric profile. Moreover, around the Dirac point the photocurrent shows strong oscillation. We discuss the experimental data, taking into account the calculated potential profile, near field effects of light scattering and the theoretical model [1, 2].

[1] E. L. Ivchenko and S. D. Ganichev, JETP Lett. 93, 673 (2011).
[2] P. Olbrich et al., Phys. Rev. B 83, 165320 (2011).

O 7.2 Mon 9:45 ER 270

Mechanically Modulated Graphene for THz-Nanoelectronics. — •Jonas Sichau[1], Timothy Lyon[1], August Dorn[1], Amaia Zurutuza[2], Amaia Pesquera[2], Alba Centeno[2], and Robert Blick[1] — [1]Center for Hybrid Nanostructures, Institutes of Nanostructure and Solid State Physics, University of Hamburg, Jungiusstrasse 11c, 20355 Hamburg, Germany. — [2]Graphenea S.A., 76 Tolosa Hiribidea, Donostia-San Sebastian, E-20018, Spain.

Graphene offers very high charge carrier mobility and a mean free path of several microns at room temperature. Consequently, it is a promising material for THz electronics [1]. For flat monolayer graphene, studies on microwave-photo excited transport have found spin resonance and zero-field pseudo-spin splitting [2]. The aim of our work is to investigate spatially modulated graphene under microwave excitation. Once carriers are propagating ballistically through the undulated graphene sheet, it is predicted that THz-radiation should be emitted [1].

We fabricated extremely large graphene membranes of up to 1 mm side lengths and transferred these onto a SiO_2-substrate. The pitch and height of the mechanical modulation are of the order of 200 nm and 50 nm, respectively. The measurements are performed with a variable temperature insert (VTI) at magnetic fields up to 12T. The microwave signal is coupled to the sample via a micro inductor forming a resonator with the graphene sheet. With this configuration we are able to probe magnetotransport and the interaction with electromagnetic radiation.

[1] Tantiwanichapan et al., Nanotechnology 24, 375205 (2013)
[2] Mani, R.G. et al., Nat. Commun., 3:996 (2012)

O 7.3 Mon 10:00 ER 270

Investigations on the polarization dependent carrier excitation in graphene with low energetic photons — •Jacob Otto[1,2], Martin Mittendorff[1,2], Torben Winzer[3], Ermin Malic[3], Andreas Knorr[3], Harald Schneider[1], Manfred Helm[1,2], and Stephan Winnerl[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]Technische Universität Berlin, 10623 Berlin, Germany

We demonstrate that in graphene a nonequelibrium charge carrier distribution retains its anisotropic nature on a 10 ps timescale if the photon energy is below the optical phonon energy. Recently evidence for an anisotropic carrier distribution has been found in near-infrared pump-probe experiments with varied angle between the orientation of pump and probe polarization [1]. This anisotropy vanishes after 150 fs due to electron optical-phonon scattering. Extending this study to the mid-infrared range ($E_{Photon} = 74$ meV), i.e. to energies below the optical phonon energy, allows to strongly suppress this scattering mechanism. In accord with microscopic theory, traces of an anisotropic distribution on a 10 ps timescale are found. Note that carrier-carrier scattering, acting on a 10 fs timescale, is mainly colinear and therefor preserves the anisotropic distribution on rather long timsecales.

[1] M. Mittendorff, T. Winzer, E. Malic, A. Knorr, C. Berger, W. A. de Heer, H. Schneider, M. Helm and S. Winnerl *Nano Lett.* 2014, 14, 1504-1507

O 7.4 Mon 10:15 ER 270

Magnetotransport in small angle twisted bilayers of folded graphene — •Johannes Rode[1], Hennrik Schmidt[1,2], Dmitri Smirnov[1], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover — [2]Centre for Advanced 2D Materials and Graphene Research Centre, National University of Singapore

Naturally occurring double-layer graphene consists of two hexagonal lattices in Bernal-stacking, described by a translational displacement between layers. While this type of bilayer is most commonly studied, the introduction of a rotational mismatch opens up a whole new field of rich physics, especially at small interlayer twist[1,2]. We investigate magnetotransport measurements on twisted graphene bilayers, prepared by folding of single layers. These reveal a strong dependence on the twist angle, which can be estimated by means of sample geometry. At small rotation, superlattices with a wavelength in the order of 10 nm arise and are observed by friction atomic force microscopy. Magnetotransport measurements in this small-angle regime show the formation of satellite Landau fans, which are attributed to additional Dirac singularities in the band structure[3].

[1] Lopes dos Santos, J. M. B., Peres, N. M. R. & Castro Neto, A. H. *Phys. Rev. Lett.* **99**, 256802.
[2] Mele, E. J. *Phys. Rev. B* **84**, 235439.
[3] Schmidt, H., Rode, J. C., Smirnov, D. & Haug, R. J. *Nat. Commun.* (accepted, Nov. 2014).

O 7.5 Mon 10:30 ER 270

Carrier dynamics in Landau-quantized graphene — •Florian Wendler[1], Martin Mittendorff[2], Stephan Winnerl[2], Manfred Helm[2], Andreas Knorr[1], and Ermin Malic[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

We investigate the carrier dynamics in Landau-quantized graphene after an optical excitation using microscopic time-resolved calculations as well as differential transmission measurements. The calculations are performed within the density matrix theory accounting for the carrier-light, carrier-carrier, and carrier-phonon interaction which allows for a microscopic explanation of the experimental spectra.

The energy spectrum of Landau-quantized graphene is characterized by non-equidistant Landau levels where the optical selection rules enable a selective excitation of specific transitions. This is exploited to investigate the carrier dynamics in the energetically lowest Landau levels where an unexpected sign reversal in pump-probe spectra, observed in experiment and theory, provides an evidence for strong Auger scattering [1]. Based on our calculations we predict a substantial carrier multiplication [2]. Furthermore, the theory reveals the occurrence of population inversion in Landau-quantized graphene, suggesting its application as gain medium for a widely tunable Landau level laser[3].

[1] M. Mittendorff et al., Nat. Phys., DOI:10.1038/nphys3164.
[2] F. Wendler et al., Nat. Commun. 5:3703 (2014).
[3] F. Wendler, and E. Malic, arXiv:1410.2080v1.

O 7.6 Mon 10:45 ER 270

Giant magnetophotoelectric effect in suspended graphene — •Jens Sonntag, Annika Kurzmann, Martin Geller, Ralf Schützhold, and Axel Lorke — Faculty of Physics and CeNIDE, University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany

Due to the broad absorption bandwidth and the possibility for carrier multiplication, graphene is a promising candidate for optoelectric applications.

In this context, we performed photocurrent measurements on a suspended graphene field-effect transistor structure in a magnetic field in the quantum Hall regime. Using an illumination power of only 3 μW, our device generates a current of up to 400 nA without an applied bias, which corresponds to a photoresponsivity of 0.14 A/W. To the best of our knowledge, this is one of the highest values ever measured for single layer graphene. Furthermore, the high current suggests that every absorbed photon creates more than 8 charge carriers, so that carrier multiplication is apparent.

We discuss these photocurrents in the framework of magnetothermoelectric effects and recent calculations of photocurrent generation in edge channels [1]. Taking into account the observed gate voltage, magnetic field and polarization dependence, we develop a quasi-ballistic model for the measured photocurrent. It includes edge channel transport and charge carrier multiplication and is in good agreement with the experimental results.

[1] Queisser et al. Phys. Rev. Let. **111**, 046601 (2013)

O 7.7 Mon 11:00 ER 270

Ballistic transport in graphene antidot arrays — •Andreas Sandner[1], Tobias Preis[1], Christian Schell[1], Paula Giudici[1], Kenji Watanabe[2], Takashi Taniguchi[2], Dieter Weiss[1], and Jonathan Eroms[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany — [2]National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

We report on the observation of antidot peaks in ρ_{xx} in monolayer-graphene (MLG), encapsulated between hexagonal boron nitride (hBN). The hBN-MLG-hBN heterostructures were fabricated with a dry transfer pick-up technique; subsequently mesas were etched in Hall bar geometry and contacted with 1-dimensional side contacts. The periodic antidot lattice was defined in a following step by additional electron-beam lithography and reactive ion etching.

We performed measurements on stacks with different antidot lattice periods down to 100 nm. Several peaks in magnetoresistance can be identified and assigned to orbits around one and several antidots. This proves ballistic transport in our graphene heterostructures, in spite of the critical etching step for small lattice periods. We show measurements at different temperatures and can study antidots peaks down to very low carrier densities (n = $2 \cdot 10^{11}$ cm^{-2}) and magnetic fields (B = 0.5 T). At higher magnetic fields, well defined quantum Hall plateaus with filling factors down to $\nu = 1$ are observed, even at an antidot period of 100 nm.

O 7.8 Mon 11:15 ER 270

Ballistic supercurrents in suspended graphene — •Markus Weiss and Christian Schönenberger — Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel

Since the discovery of graphene there have been numerous efforts to use this material as a Josephson weak link between two superconductors. Devices based on oxidized silicon substrates have been produced a few years ago, and have shown bipolar, gate-tuneable supercurrents. The observation of effects are that unique to the Dirac semimetal graphene however has been prevented up to now by the large disorder modulation of the electric potential in graphene on silicon based substrates. For the direct observation of e. g. specular Andreev reflection, the disorder modulation of the Dirac point would have to be smaller that the proximity induced superconducting gap, a regime that cannot be reached in conventional devices. The road to cleaner graphene might go via deposition onto commensurate substrates like hexagonal boron nitride, or the removal of the silicon oxide substrate and suspension of graphene. The latter technique has been perfected in the recent years for devices with normal metal contacts, but turned out to be difficult to realize for superconducting contacts due to incompatibilities of superconducting materials with the fabrication process.

We have developed a device architecture that allows the realization of suspended graphene devices with superconducting contacts, and will show first experimental results, like the ballistic Josephson current through a graphene weak link.