O 48: Graphene: Dynamics

Time: Wednesday 10:30–13:00 Location: MA 041

O 48.1 Wed 10:30 MA 041

Electron-phonon interactions and carrier transport in graphene — •Tae Yun Kim[1], Nicola Marzari[2], and Cheol-Hwan Park[1] — [1]Department of Physics, Seoul National University, Seoul 151-747, Korea — [2]Theory and Simulations of Materials (THEOS) and National Center for Computational Design and Discovery of Novel Materials (MARVEL), École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

The transport properties of graphene have received much attention partly for its possible applications in electronic devices. In particular, as recently reported, electron-phonon interactions are important in determining the intrinsic carrier transport properties [1,2]. Based on previous studies, we investigate further the carrier transport properties of graphene in terms of carrier density and other physical variables and find connection with experimental results on this matter.

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[1] C.-H. Park, N. Bonini, T. Sohier, G. Samsonidze, B. Kozinsky, M. Calandra, F. Mauri, and N. Marzari, Nano Lett. 14, 1113 (2014).

[2] T. Sohier, M. Calandra, C.-H. Park, N. Bonini, N. Marzari, and F. Mauri, Phys. Rev. B 90, 125414 (2014).

O 48.2 Wed 10:45 MA 041

Non-linear luminescence and four-wave mixing from graphene, probed by femtosecond pulse shaping — •Richard Ciesielski[1], Alberto Comin[1], Matthias Handloser[1], Torben Winzer[2], Ermin Malic[2], and Achim Hartschuh[1] — [1]Ludwig-Maximilians-Universität, AK Hartschuh, Butenandtstr. 5-11, 81377 München — [2]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Germany

Ultrafast optical excitation of graphene leads to two main nonlinear emission signals in the visible. The first was described as incoherent non-linear photoluminescence (NLPL). The second results from near-degenerate four-wave mixing which is extraordinarily strong in graphene as compared to other materials. We investigated the two types of emission for different layer thickness using confocal microscopy and a 15 fs pulsed laser at 1.55 eV with a pulse shaper. Spectrally resolved autocorrelation scans revealed a continuously decreasing decay time of the NLPL from 1.2 eV towards 2.8 eV. Comparing the dynamics observed for different layers allows us to identify the influence of substrate induced doping. Finally, we were able to separate a weaker third contribution induced by the microscopic polarization of graphene [1].

Financial support by the DFG through the Nanosystems Initiative Munich (NIM) and the ERC (NEWNANOSPEC) is gratefully acknowledged.

[1] T. Winzer, R. Ciesielski, M. Handloser et al., arXiv:1411.0531v1 (2014).

O 48.3 Wed 11:00 MA 041

Microscopic description of intraband absorption in graphene — •Faris Kadi[1], Ermin Malic[1], Torben Winzer[1], Manfred Helm[2], Fabian Göttfert[2], Martin Mittendorff[2], Stephan Winnerl[2], and Andreas Knorr[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Germany — [2]Helmholtz- Zentrum Dresden-Rossendorf, Dresden, Germany

We present a microscopic explanation for the occurrence of the controversially discussed transient negative differential transmission observed in optical pump-probe measurements in graphene [1]. Within the density matrix formalism we investigate the transient transmission with respect to optical interband as well as phonon-assisted intraband transitions. While interband processes yield a positive contribution due to absorption bleaching, we find intraband transitions to decrease differential transmission. Interestingly, in the low excitation regime, the phonon-assisted absorption prevails over the absorption bleaching resulting in the experimentally observed negative differential transmission [2]. The zero-crossing occurs within the first hundreds of femtoseconds and is followed by a recovery of the transmission spectrum on a picosecond timescale in a good agreement with experimental observations. [1] S.Winnerl, F. Göttfert, M. Mittendorff, et al., Journal of Physics: Condensed Matter 25, 054202 (2013) [2] F. Kadi, T. Winzer, E. Malić, et al., Phys. Rev. Lett. 113, 035502, (2014)

O 48.4 Wed 11:15 MA 041

Anisotropic Intravalley Scattering in Strongly Doped Graphene — •Daniela Dombrowski[1], Wouter Jolie[1], Sven Runte[1], Marin Petrović[2], Fabian Craes[1], Jürgen Klinkhammer[1], Marko Kralj[2], Predrag Lazić[3], Eran Sela[4], and Carsten Busse[1] — [1]II. Physikalisches Institut, Universität zu Köln, Germany — [2]Institut za fiziku, Croatia — [3]Institut Ruđer Bošković, Croatia — [4]Raymond and Beverly Sackler School of Physics and Astronomy, Tel-Aviv University, Israel

We perform Fourier-transform scanning tunneling spectroscopy (FT-STS) studies on Cs intercalated graphene on Ir(111). Angle-resolved photoemission spectroscopy (ARPES) measurements show, that the Cs strongly n-dopes graphene and shifts the Fermi level into the region of strong trigonal warping. We observe intervalley scattering and additionally a clear feature of intravalley scattering, which exhibits an anisotropic intensity distribution with dominant scattering in Γ-M direction.

In the linear region of the Dirac cone, conservation of pseudospin leads to the suppression of intravalley scattering since the direction of the pseudospin is either parallel or antiparallel to the momentum, thus the system has well defined chirality. This is no longer valid in the trigonal warping region near the Van-Hove singularity.

The FT-STS results are supplemented by density functional calculations of the electronic band structure and simulations of the scattering pattern based on the T-matrix theory.

O 48.5 Wed 11:30 MA 041

Theory of coherent light emission in graphene — •Roland Jago, Torben Winzer, Andreas Knorr, and Ermin Malic — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Germany

Within the density matrix formalism we present a microscopic and full quantized theoretical description of the coupled carrier, phonon and photon dynamics in graphene implemented in a photonic crystal nanocavity. We demonstrate that under strong optical excitation a spectrally broad and long-lived population inversion can be achieved. In the case of free-standing graphene non-radiative Coulomb-induced carrier-recombination on a femtosecond time scale prevents an efficient emission of coherent photons. To partially suppress this ultrafast recombination, we propose to support graphene on a substrate having high-dielectric screening. In this case, our calculations reveal a temporarily extended population inversion, that remains stable up to some tens of picoseconds under realistic conditions. In particular we observe the emission of coherent laser light suggesting graphene as gain medium for lasers [2].

[1] T. Winzer, E. Malic and A. Knorr, Phys. Rev. B 87, 165413 (2013) [2] R. Jago, T. Winzer, A. Knorr and E. Malic, arXiv:1409.8182 (2014)

O 48.6 Wed 11:45 MA 041

Phonon dynamics of graphene on copper substrate — •Naira S. Grigoryan, Eeuwe S. Zijlstra, and Martin E. Garcia — Theoretical Physics, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

In the framework of density functional theoretical calculations, the lattice dynamical properties of graphene with and without a Cu(111) substrate have been investigated and analyzed using our in-house code for highly excited valence electron systems (CHIVES). We find that the lattice dynamics exhibits large sensitivity to the presence of copper. In particular, the appearance of a nearly dispersionless phonon branch at ~1.5THz makes this system a potential mirror for light molecules. We further show that there is a lifting of the degeneracy of the ZO and ZA modes at the M- point.

O 48.7 Wed 12:00 MA 041

Non-equilibrium Carrier Relaxation in Graphene investigated with tr-ARPES — •Mariana Chavez Cervantes[1], Raghu Tomar[1], Hubertus Bromberger[1], Haiyun Liu[1], Stefan Link[2],

Ulrich Starke[2], Andrea Cavalleri[1,3], and Isabella Gierz[1] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany — [3]Department of Physics, Clarendon Laboratory, University of Oxford, Oxford, United Kingdom

We used time- and angle-resolved photoemission spectroscopy (tr-ARPES) based on high order harmonics generation for the extreme ultra-violet (XUV) probe to investigate the relaxation of photo-excited carriers in quasi-freestanding epitaxial graphene samples. From the data we determined the energy dependence of the scattering rate that, according to Ref. [1,2], is predicted to follow the imaginary part of the *equilibrium* self-energy. In order to test this hypothesis we compare the scattering rate measured at different sample temperatures and for different pump fluences with the equilibrium self-energy determined from high-resolution static ARPES experiments as described in Ref. [3,4].

[1] M. Sentef et al., Phys. Rev. X 3, 041033 (2013)
[2] A. F. Kemper et al., Phys. Rev. B 90, 075126 (2014)
[3] A. Bostwick et al., Nat. Phys. 3, 36 (2007)
[4] I. Gierz et al., Faraday Disc. 171 (1), 311 (2014)

Invited Talk O 48.8 Wed 12:15 MA 041

Electronic structure and electron dynamics in two-dimensional materials — •Philip Hofmann — Department of Physics and Astronomy, Aarhus University

Two-dimensional materials can be grown epitaxially and in high quality on different substrates, and this can be exploited to study their electronic structure and different many-body effects. In this talk I will review the growth and electronic properties of epitaxial graphene, bilayer graphene and single-layer MoS_2. Specifically, I will focus on the electronic structure of these materials as studied by angle-resolved photoemission spectroscopy. This technique does not only give access to the materials' band structure but also to many-body effects such as the electron-electron and electron-phonon interaction. This is particularly so for the time-resolved variety of the technique in which the carrier dynamics can be followed in real time.

O 48.9 Wed 12:45 MA 041

Dirac carrier thermalization on the sub 10fs timescale observed by tr-ARPES — •Sven Aeschlimann[1,2], Mariana Chavez Cervantes[1], Francesca Calegari[1,3], Cephise Cacho[4], Emma Springate[4], Stefan Link[2], Ulrich Starke[2], Klaus Kern[2,5], Andrea Cavalleri[1,6], Christian R. Ast[2], and Isabella Gierz[1] — [1]MPI for the Structure and Dynamics of Matter, Hamburg, Germany — [2]MPI for Solid State Research, Stuttgart, Germany — [3]IFN, Consiglio Nazionale delle Ricerche, Milano, Italy — [4]Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell, United Kingdom — [5]EPFL, Lausanne, Switzerland — [6]University of Oxford, United Kingdom

We used time- and angle-resolved photoemission spectroscopy (tr-ARPES) with extreme ultra-violet (XUV) probe pulses from high order harmonics generation (HHG) to observe the ultrafast electron dynamics in photo-excited quasi-freestanding epitaxial graphene monolayers. By the use of the hollow core fiber compression technique, we produced 8 fs pulses, which are utilized both for driving HHG and for photo-excitation. These ultrashort pulses allowed us to observe the initial thermalization of photo-excited carriers via electron-electron scattering with unprecedented temporal resolution. We find that, at early times, the carrier distribution neither follows a Fermi-Dirac distribution nor the non-equilibrium distribution expected for a population-inverted state [1]. We attribute this to the short duration of the pump pulse on the order of the electron-electron scattering time.

[1] I. Gierz et al., Nature Materials 12, 1119 (2013)