DY 4: Graphene I (organised by TT)

Time: Monday 10:30–13:00 Location: HSZ 03

Invited Talk DY 4.1 Mon 10:30 HSZ 03

Spin-orbit coupling in graphene: single layer, bilayer, trilayer, and graphite — •Jaroslav Fabian — Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany

In graphene at the Fermi level the spin-orbit splitting is about 25 μeV. Our first-principles [1] and tight-binding [2] investigations show that the splitting originates from d orbitals that hybridize with the p_z ones and form the π band. In an external transverse electric field there is an additional splitting of the bands (the Bychkov-Rashba effect). This extrinsic splitting is solely due to the hybridization of the σ and π orbitals, and is about 10 μeV for typical fields of 1 V/nm. In bi- and trilayer graphene, and in graphite, the intrinsic splitting is also due to the d electrons. The extrinsic splitting at K points has the intrinsic value, of 25 μeV; somewhat away from K the splitting saturates to the Bychkov-Rashba value similar to the single layer graphene. This work is supported by the DFG SFB 689.

[1] M. Gmitra, S. Konschuh, C. Ertler, C. Ambrosch-Draxl, and J. Fabian, *Band-structure topologies in graphene: spin-orbit coupling effects from first principles,* Phys. Rev. B 80, 235431 (2009).
[2] S. Konschuh, M. Gmitra, and J. Fabian, *Tight-binding theory of the spin-orbit coupling in graphene,* Phys. Rev. B 82, 245412 (2010).
[3] C. Ertler, S. Konschuh, M. Gmitra, and J. Fabian, *Electron spin relaxation in graphene: the role of the substrate,* Phys. Rev. B(R) 80, 041405 (2009)

DY 4.2 Mon 11:00 HSZ 03

Electron transport and spins in graphene — •Jan Bundesmann[1], Michael Wimmer[2], and Klaus Richter[1] — [1]Institut für theoretische Physik, Universität Regensburg, Deutschland — [2]Instituut-Lorentz, TU Leiden, The Netherlands

The weak atomic spin-orbit interaction (SOI) in graphene leads to the assumption of large spin relaxation times. Simulations, taking into account spin-scattering from charged impurities in the substrate, yielded spin relaxation times [1] much larger than spin injection experiments in graphene [2,3].
Still assuming that the model of spins scattered at charged impurities is correct, we implemented a tight-binding model for graphene in the presence of SOI.
In our work the focus lies on the effects of SOI on electron transport (i.e. low energy excitations and the role of symmetry classes manifested, e.g., in weak localization) as well as its influence on spin transport in the diffusive regime.

[1] Ertler, Konschuh, Gmitra and Fabian, Phys. Rev. B **80**, 041405(R) (2009)
[2] Tombros, Josza, Popinciuc, Jonkman and van Wees, Nature **448**, 571 (2007)
[3] Han, Pi, McCreary, Li, Wong, Swartz and Kawakami, Phys. Rev. Lett. **105**, 167202 (2010)

DY 4.3 Mon 11:15 HSZ 03

Electric field control of spin rotation in bilayer graphene — •Paolo Michetti[1], Patrik Recher[1], and Giuseppe Iannaccone[2] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, 97074 Würzburg — [2]Dipartimento di Ingegneria dell'Informazione, Universita' di Pisa, Via G. Caruso 16 - 56122 - Pisa (Italy)

The manipulation of the electron spin degree of freedom is at the core of the spintronics paradigm, which offers the perspective of reduced power consumption, enabled by the decoupling of information processing from net charge transfer.

Graphene, with its potentially long spin-coherence length, is a promising material for spin-encoded information transport. However, the small spin-orbit interaction is also a limitation for the design of conventional devices based on the canonical Datta-Das spin field-effect transistors. An alternative solution can be found in magnetic doping of graphene or, as discussed in the present work, in exploiting the proximity effect between graphene and ferromagnetic oxides (FOs). Graphene in proximity to FO experiences an exchange proximity interaction, that acts as an effective Zeeman field for electrons in graphene, inducing a spin precession around the magnetization axis of the FO.

Here we show that in an appropriately designed double-gate field-effect transistor, with a bilayer graphene channel and FO used as a gate dielectric, spin-precession of carriers can be turned ON and OFF with the application of a differential voltage to the gates. This feature is directly probed in the spin-resolved conductance of the bilayer.

DY 4.4 Mon 11:30 HSZ 03

Graphene Superlattices Studied by Ab-Initio Methods — •Lars Matthes, Karsten Hannewald, Jürgen Furthmüller, and Friedhelm Bechstedt — Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität, Jena, Germany

The peculiar electronic properties of graphene have stimulated extensive research towards graphene-based electronics. Hereby, of particular interest are quasi-1D structures such as graphene nanoribbons [1] or, more recently, graphene superlattices [2] which allow a systematic tuning of the band structure. An impressive example for such modifications has been predicted by recent Kronig-Penney-type calculations [2] for a single graphene layer subject to a 1D periodic potential where a rather counterintuitive anisotropic renormalization of the Fermi velocity due to the Klein paradox is expected. Here, we present first-principles DFT calculations of graphene superlattices using the VASP code. The influence of the periodic external potential on the charge-carrier redistribution and corresponding screening effects is investigated in detail. The resulting consequences for the ab-initio band structure including anisotropy effects are studied and compared with analytical calculations based on the Dirac Hamiltonian. Deviations due to self-consistent inclusion of screening effects and nonlinear dispersions are analyzed. Finally, consequences for the practical realization of graphene superlattices with 1D transport properties are discussed.

[1] See, e.g., U. Treske, F. Ortmann, B. Oetzel, K. Hannewald, F. Bechstedt, phys. stat. sol. (a) 207, 304 (2010)
[2] C-H. Park et al., Nature Phys. 4, 213 (2008)

15 min. break

DY 4.5 Mon 12:00 HSZ 03

Nanomachining a Tunneling Barrier in Graphene — •Patrick Barthold and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, D-30167 Hannover, Germany

Utilizing an atomic force microscope, graphene is nanomechanically structured. It is selectively folded in order to produce two dimensional systems that are only a few Angstrom apart. Aditionally, insulating lines are crafted within the sample without inducing any chemical contamination which, in contrast, is inevitable, when traditional structuring methods, e.g. etching procedures, are used. Such manufactured tunneling barriers are characterized by electrical transport measurements at low temperatures on an exemplary few-layer sample. In the conductivity through this barrier we find a gap around zero bias voltage. The conductivity shows a backgate dependent opening of a band gap in the sample. Due to the asymmetric design of the emitter and collector we find an asymmetry in the backgate dependent conductivity through the barrier.

DY 4.6 Mon 12:15 HSZ 03

Evidence for Josephson-coupled superconducting regions at the interfaces of highly oriented pyrolytic graphite — •Ana Ballestar, Jose Barzola-Quiquia, and Pablo Esquinazi — Abteilung für Supraleitung und Magnetismus, Institut für Experimentelle Physik II, Universität Leipzig, Linnéstrasse 5, 04103 Leipzig, Germany

The first observation of superconductivity in doped graphite goes back to 1965 when it was observed in the potassium graphite intercalated compound C8K. A considerable amount of studies had reported this phenomenon in intercalated graphite compounds or doped graphite, however the superconducting properties of pure graphite are still under discussion. Indirect evidences for superconductivity at graphite interfaces have been recently published. In order to better understand these interfaces properties, we prepared micro structured samples (Lamellas) from pure highly oriented pyrolitic graphite. By reducing the dimension in the in plane configuration to $\sim$ 200 nm we can measure the electrical response of graphite interfaces. We obtained evidence for the existence of Josephson-coupled quasi two dimensional superconducting regions. Temperature dependence of the voltage, as well as

I(V) characteristic curves indicate that superconductivity exists even above 150 K. The results support the view that HOPG is a system with interfaces containing non-percolative superconducting domains immersed in a semiconducting graphene-based matrix.

DY 4.7 Mon 12:30 HSZ 03

Tuning the electronic structure of graphene through ac fields: dynamical gaps and polarization effects — •Hernan L. Calvo[1,2], Horacio M. Pastawski[1], Stephan Roche[3], and Luis E. F. Foa Torres[1] — [1]Instituto de Fisica Enrique Gaviola and FaMAF UNC, 5000 Cordoba, Argentina — [2]Institut für Theoretische Physik A, RWTH Aachen University, D-52056 Aachen, Germany — [3]CIN2, CSIC-ICN, Campus UAB, E-08193 Barcelona, Spain

Thanks to its outstanding electrical, mechanical and thermal properties, graphene research is one of the most rapidly advancing fronts ever. Moreover, applications are around the corner, from ballistic transistors to ultracapacitors everything seems possible. Fortunately, there are still many fascinating open problems like the interaction between a laser field and the electrons in graphene. In this work, we discuss this issue within the non-adiabatic regime in terms of both Dirac band and tight-binding models and contrast the obtained results. Notably, we find that the interaction with the field gives rise to back-scattering processes that open dynamical gaps in the electronic structure. The strong dependence of these phenomena on the polarization is emphasized. Our predictions show that these effects should be observable with present laser technology, thereby opening promising prospects for graphene-based opto-electronic devices.

DY 4.8 Mon 12:45 HSZ 03

Relaxation dynamics of graphene in magnetic fields close to the Dirac point — •Martin Mittendorff[1], Stephan Winnerl[1], Paulina Plochocka[2], Piotr Kossacki[2], Harald Schneider[1], Milan Orlita[2], Marek Potemski[2], Mike Sprinkle[3], Claire Berger[3], Walter A. de Heer[3], and Manfred Helm[1] — [1]Institut für Ionenstrahlphysik und Materialforschung, Helmholtz-Zentrum Dresden Rossendorf, Germany — [2]Grenoble High Magnetic Field Laboratory, France — [3]Georgia Institute of Technology, Atlanta, USA

The relaxation dynamics in graphene is of key importance for understanding the basic material properties as well as for high-frequency electronic and opto-electronic device applications. In addition to single colour pump-probe experiments in the THz range (photon energy: 14-30 meV) without magnetic field, we performed experiments at a photon energy of 18 meV in magnetic fields up to 1.34 T. For photon energies larger than twice the Fermi energy (approx. 10 meV) positive pump-probe signals were observed while for smaller photon energies pump-induced absorption occurred due to carrier heating. Relaxation times were around 30 ps. At magnetic fields around 0.23 T the pump-probe signal increases by a factor of 2.5. At this field the splitting of the zeroth to first Landau level is resonant with the photon energy.