TT 21: Transport: Graphene and Carbon Nanotubes

Time: Tuesday 15:45–19:00 Location: EB 202

TT 21.1 Tue 15:45 EB 202

Electromagnetic response of graphene. — •Sergey Mikhailov and Klaus Ziegler — Institute for Physics, University of Augsburg, 86135 Augsburg, Germany

Recently discovered new carbon based material - graphene - demonstrates a number of interesting and unusual transport and optical properties. Our recent predictions of a new transverse electromagnetic mode in graphene [1] and of its strongly non-linear electromagnetic behavior [2] shows that this material can be used in terahertz electronics for higher-harmonics generation at microwave and terahertz frequencies. In this work we study the influence of the self-consistent field effects, the radiative decay and the scattering on the non-linear electromagnetic response of graphene, and find the optimal experimental conditions, under which the higher harmonics generation effect can be observed in this material.

[1] S. A. Mikhailov, K. Ziegler, Phys. Rev. Lett. 99, 016803 (2007).
[2] S. A. Mikhailov, Europhys. Lett. 79, 27002 (2007).

TT 21.2 Tue 16:00 EB 202

Diffusion and localization in carbon nanotubes and graphene ribbons — •Norbert Nemec[1], Klaus Richter[1], and Gianaurelio Cuniberti[2] — [1]Institut für theoretische Physik, Universität Regensburg, 93040 Regensburg — [2]Institute for Material Science, TU Dresden, 01062 Dresden

We study transport length scales in carbon nanotubes and graphene ribbons under the influence of Anderson disorder. We present generalized analytical expressions for the density of states, the elastic mean free path and the localization length in arbitrarily structured quantum wires. These allow us to analyze the electrical response near the van Hove singularities and in particular around the edge state in graphene nanoribbons. Comparing with the results of numerical simulations, we demonstrate that both the diffusive and the localized regime are well represented by the analytical approximations over a wide range of the energy spectrum. In graphene nanoribbons, we find that the zigzag edge state causes a strong reduction of the localization length in a wide energy range around the Fermi energy.

TT 21.3 Tue 16:15 EB 202

Aharonov-Bohm effect and broken valley-degeneracy in graphene rings — •Patrik Recher[1,2], Björn Trauzettel[3], Adam Rycerz[4], Yaroslav Blanter[2], Carlo Beenakker[1], and Alberto Morpurgo[2] — [1]Instituut-Lorentz, Universiteit Leiden, P.O. Box 9506, 2300 RA Leiden, The Netherlands — [2]Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands — [3]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [4]Marian Smoluchowski Institute of Physics, Jagiellonian University, Reymonta 4, 30-059 Kraków, Poland

We analyze theoretically the electronic properties of Aharonov-Bohm rings made of graphene. We show that the combined effect of the ring confinement and applied magnetic flux offers a controllable way to lift the orbital degeneracy originating from the two valleys, even in the absence of intervalley scattering. The phenomenon has observable consequences on the persistent current circulating around the closed graphene ring, as well as on the ring conductance. We explicitly confirm this prediction analytically for a circular ring with a smooth boundary modelled by a space-dependent mass term in the Dirac equation. This model describes rings with zero or weak intervalley scattering. We compare our analytical model to another type of ring with strong intervalley scattering. For the latter case, we study a ring of hexagonal form with lattice-terminated zigzag edges numerically. We find for the hexagonal ring that the orbital degeneracy can still be controlled via the flux, similar to the ring with the mass confinement.

TT 21.4 Tue 16:30 EB 202

Quantum transport in graphene-based nanosystems — •Jürgen Wurm[1,2], Michael Wimmer[1], Inanc Adagideli[1], Harold Baranger[2], and Klaus Richter[1] — [1]Institut für theoretische Physik, Universität Regensburg, 93040 Regensburg — [2]Department of Physics, Duke University, Durham, NC 27708, USA

We numerically investigate the ballistic transport properties of graphene rings and other graphene-based nanostructures using a recursive Green function algorithm to calculate the conductance. Recently, the first transport experiments in ring systems made of graphene have been reported, and Aharonov-Bohm oscillations in the conductance were observed [1]. While our simulations confirm the Aharonov-Bohm oscillations in rings, as well as other quantum interference phenomena such as weak localization and universal conductance fluctuations in chaotic cavities, we also find effects of conductance suppression that are not present in usual two-dimensional electron gases.

[1] S. Russo, J.B. Oostinga, D. Wehenkel, H.B. Heersche, S.S. Sobhani, L.M.K. Vandersypen, A.F. Morpurgo, cond-mat 0711.1508 (2007)

TT 21.5 Tue 16:45 EB 202

Conductance and mobility of charge carriers in graphene on silicon carbide — •Johannes Jobst[1], Sergey Reshanov[1], Daniel Waldmann[1], Heiko B. Weber[1], Konstantin V. Emtsev[2], and Thomas Seyller[2] — [1]Lehrstuhl für Angewandte Physik, Universität Erlangen-Nürnberg, Staudtstr. 7/A3, 91058 Erlangen, Germany — [2]Lehrstuhl für Technische Physik, Universität Erlangen-Nürnberg, Erwin-Rommel-Str. 1, 91058 Erlangen, Germany

We have studied the electronic transport properties of few-layer graphene grown by thermal treatment of 6H silicon carbide. Both graphene grown on the carbon face and on the silicon face were investigated. The transport properties of large area films were characterized in van der Pauw geometry. Mobilities up to $7000\,\mathrm{cm}^2/\mathrm{Vs}$ were observed. In addition, micrometer-sized Hall bar structures were fabricated, which allowed for the determination of Hall mobility and density of charge carriers. The size of these structures was reduced to atomically flat terraces of the silicon carbide surface. However, opposite to our expectations, Hall mobilities determined in these structures did not exceed values of $1000\,\mathrm{cm}^2/\mathrm{Vs}$. The role of surface contamination is discussed.

TT 21.6 Tue 17:00 EB 202

Photocurrent and radiation induced suppression of transport in graphene — Konstantin Efetov[1,2], Mikhail Fistul[1], and •Sergey Syzranov[1] — [1]Theoretische Physik III, Ruhr-Universität Bochum, 44801 Bochum, Germany — [2]L.D. Landau Institute for Theoretical Physics RAS, 119334 Moscow, Russia

We study the ballistic transport in graphene subject to the coordinate dependent potential $U(x)$ and irradiated by monochromatic electromagnetic field (EF). The resonant interaction of quasi-particles with an external radiation opens *dynamical gaps* in their spectrum, resulting in a strong modification of current-voltage characteristics of graphene junctions. The gaps' values are proportional to the amplitude of EF. We obtain that the quasi-particle transmission in diverse junctions, e.g. unipolar (p-p or n-n) junctions, is determined by the tunneling through the gap, and can be fully suppressed for large enough radiation powers. In the case of a p-n junction, as the height of the potential $U(x)$ is larger than the photon energy, the directed current (*photocurrent*) flows through the junction without any dc bias voltage applied. Such a photocurrent arises as a result of inelastic quasiparticles' tunneling assisted by one- or two-photon absorption. We calculate current-voltage characteristics of diverse graphene based junctions and estimate their parameters necessary for the experimental observation of the photocurrent and transmission suppression.

15 min. break

TT 21.7 Tue 17:30 EB 202

Spin injection with rough graphene nanoribbons — •Michael Wimmer[1], Inanç Adagideli[1], Savaş Berber[2], David Tománek[2], and Klaus Richter[1] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040, Germany — [2]Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824-2320, USA

We investigate spin conductance in zigzag graphene nanoribbons and propose a spin injection method based only on graphene. Combining density functional theory with tight-binding transport calculations, we find that nanoribbons with asymmetrically shaped edges show a nonzero spin conductance and can be used for spin injection. Furthermore, nanoribbons with rough edges exhibit mesoscopic spin conductance fluctuations with a universal value of rms $G_s \approx 0.4e/4\pi$.

[1] M. Wimmer, I. Adagideli, S. Berber, D. Tomanek, K. Richter, arXiv:0709.3244 (2007)

TT 21.8 Tue 17:45 EB 202

Long-range spin interaction between Quantum dots in a Graphene nanoribbon — •Matthias Braun and Guido Burkard — Institut für Theoretische Physik C, RWTH-Aachen, Germany

Recently it was proposed to realize spin qubits in graphene ribbons with semiconducting armchair boundaries [1]. The band gap arising in ribbons does avoid the Klein tunneling i.e., enable a confinement of electrons. Since the band gap is significantly smaller than in conventional semiconductors, RKKY is not necessarily the dominant spin-spin interaction between the qubits. Indeed, we show that a superexchange mechanism can lead to a tunable long-range spin-spin interaction. We model the system by two Anderson impurities coupled by a common lead. We remove all first and second order tunneling processes by a two-stage Schrieffer-Wolff transformation, and integrate out the lead degrees of freedom. At the end we arrive at an effective fourth order spin Hamiltonian. We can identify different kinds of interactions such as RKKY or superexchange. Which interaction dominates the spin dynamics depends on system parameters. We are particularly interested in the superexchange process as this spin interaction can not only couple adjacent quantum dots but also next-to-nearest neighbors.

[1] Nature Phys. **3**, 192 (2007).

TT 21.9 Tue 18:00 EB 202

Orthogonality catastrophe and Kondo effect in graphene — •Martina Hentschel[1] and Francisco Guinea[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, D-01187 Dresden — [2]Instituto de Ciencia de Materiales de Madrid, CSIC, E-28049 Madrid, Spain

We analyze Anderson's orthogonality catastrophe in graphene, at energies close to the Dirac point. It is shown that in the clean system, the orthogonality catastrophe is suppressed due to the vanishing density of states at the Dirac point. In the presence of preexisting localized states at the Dirac energy, the orthogonality catastrophe shows features similar to those found in normal metals with a finite density of states at the Fermi level [1]. We argue that, therefore, also the presence or absence of edge states is crucial for the behavior of the system. The implications for the Kondo effect induced by magnetic impurities, and for the Fermi edge singularities in tunneling processes, are also discussed.

[1] M. Hentschel and F. Guinea, Phys. Rev. B **76**, 115407 (2007).

TT 21.10 Tue 18:15 EB 202

Scrutinizing the conductance and noise of ac driven carbon-based nanostructures — •Luis Foa Torres and Gianaurelio Cuniberti — Institute for Materials Science, Dresden University of Technology, D-01062 Dresden, Germany.

Time-dependent excitations provide an opportunity to achieve control through selective excitations, opening an avenue for both fundamental research and practical applications. Due to their outstanding electrical properties, carbon-based nanostructures offer an ideal playground to study such phenomena in low dimensions. Here we focus on the effects of ac driving on the conductance and the shot noise of single walled carbon nanotubes and graphene nanoribbons. Our calculations, which are based on Floquet theory and take into account the full electron dynamics, are aimed to bridge the gap between theory and recent experiments carried out in the Fabry-Perot regime. Numerical results are complemented by analytical calculations based on a simplified model. The effects of decoherence are further explored by using a phenomenological model.

TT 21.11 Tue 18:30 EB 202

Optoelectronic Measurements on Hybrid Systems made out of Carbon Nanotubes (CNTs) and the Photosystem I (PS I) — •Simone Lingitz[1], Markus Mangold[1], Itai Carmeli[2], Ludmila Frolov[2], Chanoch Carmeli[2], Shachal Richter[2], and Alexander Holleitner[1] — [1]Walter Schottky Institut, TUM, Garching, Deutschland — [2]Center for NanoScience, Tel Aviv University, Israel

We examine the Photosystem I (PS I) covalently bound to carbon nanotubes (CNTs) by optoelectronic transport spectroscopy [1]. The PS I is a protein complex located in the thylacoid membrane of plants, algae and cyanobacteria which mediates the light-induced electron transfer in the photosynthetic pathway. As a nano-sized, high-efficient bioenergetic unit, the photosynthetic reaction centre is a promising candidate for applications in molecular nano-optoelectronics. In order to electrically contact the photoactive proteins, a cysteine mutant is generated at one end of the PS I by genetic engineering and to this reactive group the CNTs are covalently bound via chemical self-assembly using carbodiimide chemistry. Due to this combination of an energy transformation and a transport unit, this hybrid nanosystem provides an ideal basis for optoelectronic applications. In my talk, I will present wavelength and power dependent photoresponse measurements on such a CNT-PS I heterostructure in comparison to a pure CNT device. [1] S. Lingitz, M. Mangold, et al. in preparation (2008).

TT 21.12 Tue 18:45 EB 202

Supercurrent through carbon nanotubes with Nb contacts — •Emiliano Pallecchi, Markus Gaass, and Christoph Strunk — University of Regensburg, Germany

We report on low temperature transport measurements on a multiwall carbon nanotube (MWNT) coupled to niobium leads. We used a very careful filtering scheme which is essential in order to measure small supercurrents. To provide damping at the plasma frequency, we used on chip resistors and capacitors. Depending on the gate voltages the sample shows both, proximity induced supercurrent and Coulomb blockade. The supercurrent showed narrow resonances corresponding to the Coulomb resonances at lower transmission. We found supercurrents up to 30nA, which is, to our knowledge, this is the highest value observed so far. At very low temperature the IV characteristics are characterized by hysteretic switching; when increasing T the hysteresis is gradually suppressed. In the hysteretic regime, we have also measured switching histograms to gain further information on the switching mechanism.