O 86: Graphene VI

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

O 86.1 Fri 10:30 MA 041

Observation of an activation barrier in the interaction between graphene and a metal tip by using atomic force-microscopy and -spectroscopy — •Thomas Hofmann, Alfred J. Weymouth, Joachim Welker, and Franz J. Giessibl — University of Regensburg, Faculty of Experimental and Applied Physics, Universitätsstrasse 31, D-93053 Regensburg

For chemical bonding of adsorbed atoms onto graphene, the participating carbon atom has to change its hybridization state from sp_2 to sp_3. This rehybridization has been described for bonding of hydrogen on graphite, leading to an activation barrier [1]. We studied the interaction of a tungsten tip with monolayer graphene with a low temperature atomic force microscope. As the tip is approached to the surface, atomic contrast initially is obtained in a repulsive regime, i.e. the carbon atoms appear to repel the tip similar to measurements on pentacene [2]. Upon further reducing the distance, the image contrast flips and the carbon atoms attract the tip, as has been proposed by DFT calculations [3]. Force versus distance spectroscopy shows a pronounced barrier that has to be overcome before the carbon atoms appear attractive.

[1] L. Jeloaica, V. Sidis, Chem. Phys. Lett. 300, 157 (1999)
[2] L. Gross *et al.*, Science 325, 5944 (2009)
[3] M. Ondráček *et al.*, Phys. Rev. Lett. 106, 176101 (2011)

O 86.2 Fri 10:45 MA 041

Graphene studied with a multi-tip STM — •Stefan Korte, Vasily Cherepanov, and Bert Voigtländer — Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, 52425 Jülich, Germany, and JARA-Fundamentals of Future Information Technology

Graphene produced by exfoliation promises clean, defect free two-dimensional sheets. However, for conductance measurements, electrical contacts have to be created. This is usually done by lithography or other processing methods that might contaminate the graphene. With a multi tip STM unprocessed graphene flakes on SiO_2 have been contacted for local four point measurements with flexible probe placement and geometry. Four point conductance measurements and potentiometry on graphene will be presented.

O 86.3 Fri 11:00 MA 041

Micro Four-Point Probe Measurements of Graphene on Silicon Carbide — •Edward Perkins[1], Lucas Barreto[1], Felix Fromm[2], Christian Raidel[2], Thomas Seyller[2], and Philip Hofmann[1] — [1]Institut for Fysik og Astronomi, Aarhus Universitet, Ny Munkegade 120, Aarhus 8000C, Denmark — [2]Institut für Physik der Kondensierten Materie, Universität Erlangen-Nürnberg, Erwin-Rommel-Strasse 1, D-91058 Erlangen, Germany

Four-point probe measurements are the classic method for investigating conductivity independent of contact resistances. By implementing this technique at the micron scale, in ultra-high vacuum, clean, local measurement of the conductivity is possible. By varying the effective separation of the contact probes, discrimination between conduction through the bulk and the surface can be achieved.

Data from both monolayer graphene on silicon carbide and hydrogen-intercalated quasi-freestanding graphene will be presented. The transport is shown to be two-dimensional in character, and the measured conductivity is combined with photoemission data to extract the mobility.

O 86.4 Fri 11:15 MA 041

Time-Resolved Two-Photon Photoemission of Unoccupied Electronic States of Periodically Rippled Graphene on Ru(0001) — •Nico Armbrust, Jens Güdde, Peter Jakob, and Ulrich Höfer — Fachbereich Physik und Zentrum für Materialwissenschaften, Philipps-Universität, D-35032 Marburg

The well characterized graphene layers epitaxially grown on Ru(0001) have attracted a lot of interest up to now due to their periodically rippled structure caused by the strong interaction with the metal substrate. Here, the dynamics of unoccupied electronic states of graphene on Ru(0001) have been explored by time- and angle-resolved two-photon photoemission (2PPE). We identify a Ru derived resonance and a Ru/graphene interface state at 0.91 eV and 2.58 eV above the Fermi level, as well as three image-potential derived states close to the vacuum level. The most strongly bound, short lived and least dispersing image-potential state is suggested to have some quantum-well character with a large amplitude below the graphene hills. The two other image-potential states are attributed to a series of slightly decoupled states. Their lifetimes and dispersions are indicative of electrons moving almost freely above the valley areas of the moiré superstructure of graphene.

O 86.5 Fri 11:30 MA 041

Photoluminescence in graphene antidot lattices — Daniel Hutzler, •Stefanie Heydrich, Jonathan Eroms, Dieter Weiss, Tobias Korn, and Christian Schüller — Institut für Experimentelle und Angewandte Physik, Universität Regensburg

We present recent observations of the behavior of photoluminescence in patterned single and bilayer graphene. It was reported previously [1,2], that femtosecond pulsed laser excitation creates an electron-hole plasma in graphene which emits a broadband luminescence. We have observed this luminescence in graphene patterned with antidot lattices as well as in pristine graphene.

We utilize fast, high-resolution scans to map graphene flakes on Si/SiO2-substrates. Thus, a luminescence image of both the flake and its structured areas is created.

In structured areas, the absolute intensity of the photoluminescence is smaller than in pristine flakes due to parts of the graphene having been etched away. However, the observed signal in the patterned flakes is larger than expected from the mere amount of illuminated graphene. This enhancement is roughly 1/15 of the expected signal in single layer and 1/7 in bilayer graphene. It is possible that additional charge carriers at the antidot edges [3] cause this increase in luminescence.

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[1] R.J. Stöhr et al., Phys. Rev. B 82, 121408(R) (2010)
[2] C.H. Lui et al., Phys. Rev. Lett. 105, 127404 (2010)
[3] S. Heydrich et al., Appl. Phys. Lett. 97, 043113 (2010)

O 86.6 Fri 11:45 MA 041

Angle resolved Coulomb- and phonon-induced carrier dynamics in graphene — •Torben Winzer, Andreas Knorr, and Ermin Malic — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, 10623 Berlin, Germany

We investigate the relaxation dynamics of optically excited charge carriers in graphene within the density matrix formalism resolved in time, momentum, and angle. The focus lies on the interplay between carrier-carrier and carrier-phonon scattering channels immediately after an excitation, when the carrier system is highly anisotropic. We observe that Coulomb-scattering prefers processes of carriers with parallel momentum corresponding to a relaxation dynamics carried out directly toward the Dirac point. In contrast, the emission of phonons leads efficiently and quickly to an isotropic carrier distribution in the states one phonon energy beneath the exciting energy. Accordingly, for large scattering angles Coulomb- and phonon-induced relaxation dynamics complement each other, whereas in the case of narrow scattering angles there is a direct competition [1]. We demonstrate how the combination of all relaxation channels results in an ultrafast thermalization, followed by a slower energy dissipation.

[1] E. Malic, T. Winzer, E. Bobkin, and A. Knorr, Phys. Rev. B 84, 205406, (2011)

O 86.7 Fri 12:00 MA 041

Sheet plasmon dispersion in epitaxial graphene and graphene nanostructures — •Jens Baringhaus, Thomas Langer, Herbert Pfnür, and Christoph Tegenkamp — Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany

The dispersion of the two-dimensional sheet plasmon in epitaxial graphene on SiC substrates has been investigated by means of angle resolved high resolution electron energy loss spectroscopy. The dispersion shows a characteristic point of inflection whose position in phase space depends on the interface (Si-face, C- face, H-intercalation). The plasmon dispersions can be quantitatively described by the model of a nearly free electron gas assuming in addition a resonant coupling to long-lived electron-hole pairs. As the characteristic point appears

when entering the interband regime, the effect is related to the chemical potential of the graphene film, i.e. the interface structure. This is in agreement with experiments where the chemical potential has been shifted both by adsorption of F4-TCNQ on epitaxial monolayer graphene and heating of quasi freestanding monolayer graphene films. In undoped or barley doped graphene sheets such as graphene on C-face SiC a point of inflection is not visible at all. Furthermore, the uniaxial dispersion on self-assembled multilayer graphene nanoribbons with an average width of 100 nm has been studied as well. In perpendicular direction a strong damping of the plasmon is observed which can be attributed to the roughness of the ribbons whereas in parallel direction the plasmon dispersion is shifted to higher energies. This shift has its origin in the multilayer characteristic of the ribbons.

O 86.8 Fri 12:15 MA 041

Screening of charges by graphene layers — Daniel Niesner[1], Marko Kralj[2], and •Thomas Fauster[1] — [1]Lehrstuhl für Festkörperphysik, Universität Erlangen-Nürnberg, Staudtstr. 7, D-91058 Erlangen, Germany — [2]Institut za fiziku, Bijenička 46, HR-10000 Zagreb, Croatia

The screening of external charges by a two-dimensional electron gas is studied by spectroscopy of loosely bound electrons on graphene grown on various substrates. The charge transfer from the substrate to the graphene layer (doping) is correlated with the work function and the energy of the Dirac point in good agreement with theoretical predictions [1]. The spectroscopy of the unoccupied states by two-photon photoemission reveals that the long-range image potential applies only for energies close to the vacuum level. The lowest state is found at 3.7 eV above the Dirac point independent of the substrate. This indicates that for this state the screening is dominated by the electronic structure of the graphene layer.

[1] P. A. Khomyakov *et al.,* Phys. Rev. B **79**, 195425 (2009).

O 86.9 Fri 12:30 MA 041

Anisotropic quantum Hall effect in graphene on stepped SiC(0001) surfaces — •Timo Schumann, Klaus-Jürgen Friedland, Myriano H. Oliveira Jr., J. Marcelo Lopes, and Henning Riechert — Paul-Drude-Institut für Festkörperelektronik, 10117 Berlin

The synthesis of epitaxial graphene on SiC by surface thermal decomposition is a promising route for future applications, since it produces high-quality and large-area layers directly on an insulating substrate. By this method, a regularly stepped graphene surface is formed with terrace widths in the order of μm and step heights of about 10 nm. Here we report on an anisotropic behavior in the magnetoresistance measured at high magnetic fields for narrow Hall bars patterned on stepped surfaces. The devices morphology and structural quality has been studied by atomic force microscopy and Raman spectroscopy. If the Hall bar is aligned parallel to the terraces, a quantum Hall effect with negative magnetoresistance is observed due to the condensation of the carriers in the Landau levels, away from the Fermi energy. In contrast, a positive magnetoresistance arises if the current crosses many steps (Hall bar perpendicular to the terraces). We tentatively explain this behavior by proposing a model, which is based on the opening of new conducting channels at both edges of the Hall bar in the surface region close to the steps. These additional channels enable the possibility of electron backscattering from one channel to another on the opposite side, since the spatial separation between the additional edge channels is reduced, resulting in a positive magnetoresistance.

O 86.10 Fri 12:45 MA 041

Transmission electron microscopy of biological samples on nanocrystalline graphene support films — •Daniel Rhinow[1], Matthias Büenfeld[2], Nils-Eike Weber[2], André Beyer[2], Armin Gölzhäuser[2], Werner Kühlbrandt[1], and Andrey Turchanin[2] — [1]Max-Planck-Institut für Biophysik, 60438 Frankfurt, Deutschland — [2]Universität Bielefeld, Fakultät für Physik, 33615 Bielefeld, Deutschland

Electron cryo-microscopy (cryoEM) of vitrified biological specimens is a powerful method for the analysis of macromolecular structures. Although theory indicates that atomic resolution should be attainable routinely, resolutions obtained with most ice-embedded specimens are significantly worse. Biomolecules are phase objects and image contrast is degraded by radiation damage, inelastic scattering, electrostatic charging, and specimen movement. Amorphous carbon, used routinely as support film in biological cryoEM, has several disadvantages such as low electrical conductivity at low temperature and mechanical instability below a film thickness of ~ 20 nm. We have tested nanocrystalline graphene as support film for transmission electron microscopy of ice-embedded biological specimens. Nanocrystalline graphene was synthesized by pyrolysis of molecular nanosheets, obtained by cross-linking of self-assembled biphenyl precursors. Due to their transparency, mechanical strength, and conductivity nanocrystalline graphene supports match all requirements for cryoEM of biological specimens.