O 51: Graphene III

Time: Wednesday 15:00–17:15 Location: WIL B321

O 51.1 Wed 15:00 WIL B321

A graphene phase transition induced by compressing nanomembranes using STM. — •Alexander Georgi[1], Dinesh Subramaniam[1], Christian Pauly[1], Torge Mashoff[1], Ludger Wirtz[2], Viktor Geringer[1], Marcus Liebmann[1], Marco Pratzer[1], and Markus Morgenstern[1] — [1]II. Physikalisches Institut B, Otto-Blumenthal-Straße, RWTH Aachen University and JARA-FIT, 52074 Aachen — [2]IEMN, Dept. ISEN, B.P. 60069, 59652 Villeneuve d'Ascq Cedex.

The variety of the different carbon allotropes is due to the energetic similarity between the sp^2 and sp^3 band. Even a metastable 3d structure of sp^2 bands called K_4 has been proposed [1].
Applying forces to a graphene flake exfoliated on SiO_2 using an STM-tip the valleys of the intrinsic rippling can be lifted [2]. The induced compression during lifting leads to a transition from flat hexagonal graphene to a triangular appearence probably representing a buckled hexagonal structure resembling a diamond-like arrangement of the atoms. Further lifting leads to a reduction of the compression and a corresponding switch-back to the unbuckled phase. For valleys with 1.5 nm^2, a buckling amplitude of 5 pm has been deduced, which is only 10% of the buckling within a 2d-diamond crystal. The phase transition cannot be reproduced by DFT Calculations so far.
[1] Itoh *et al.*, Phys. Rev. Lett. **102**, 055703 (2009).
[2] Mashoff *et al.*, Nano Lett. **10**, 461 (2010).

O 51.2 Wed 15:15 WIL B321

Local transport measurements on folding graphite and multilayer graphene on SiO2 by a four-probe scanning tunneling microscope — •Shiro Yamazaki, Tobias Spitz, Oswald Pietzsch, and Roland Wiesendanger — Institute of Applied Physics, University of Hamburg, Germany

Unique electrical transport properties of carbon-based materials such as graphite and graphene have attracted great research interest over a long period of time [1,2]. Mechanically-exfoliated microscopic graphite and multi-layer graphene on SiO2 exhibit sub- micron-scale unique structural defects such as various kinds of layer folding. We have measured the local electrical resistance at folding sites, using a variable-temperature UHV-based four-probe scanning tunneling microscope equipped with a high-resolution UHV scanning electron microscope. We have succeeded in detecting the electrical current flowing along a graphite folding sheet. The folding part exhibits a higher resistance than flat areas. We changed a square-like folding to a triangle-like one by mechanically pushing the tip toward the folding part. The electrical resistance has been compared before and after the manipulation of the folding. [1] K. Krishnan et al., Nature 144, 667 (1939); [2] K. S. Novoselov et al., Nature 438, 197 (2005).

O 51.3 Wed 15:30 WIL B321

Raman spectroscopy on graphene on insulator surfaces — •Hanna Bukowska, Florian Meinerzhagen, Sevilay Akcöltekin, Markus Neubert, Volker Buck, and Marika Schleberger — Universität Duisburg-Essen, Fakultät für Physik, Lotharstraße 1, 47058 Duisburg, Germany

Raman spectroscopy is a powerful nondestructive method to investigate graphene sheets. We prepare graphene on different substrates: SiO_2 as well as the insulators $SrTiO_3$, TiO_2, and Al_2O_3. We measure the Raman spectra of all those samples for single-, bi-, fewlayer graphene and graphite. The 2D peak of the Raman spectrum evolves clearly with the number of layers. It reflects the changes in the electronic structures and any substrate-induced changes. The D peak is solely activated by presence of morphological defects - here we verify the quality of our graphene. We compare virgin and modificated graphene which was irradiated with swift heavy ions. Finally, in the future we want to study graphene transistors prepared on two of the above mentioned substrates, where any difference in charge carrier doping should show up in a change of the G peak.

O 51.4 Wed 15:45 WIL B321

Polarized Raman scattering of graphene nanoribbons — •Nils Scheuschner[1], Bernat Terrés[2], Christoph Stampfer[2], and Janina Maultzsch[1] — [1]Institut für Festkörperphysik, TU Berlin, Germany — [2]JARA-FIT, Institute of Bio and Nanosystems, Forschungszentrum Jülich and II. Institute of Physics, RWTH Aachen University, Germany

Understanding the physics of graphene nanoribbons is a key requirement to build novel nanoelectronic devices on the basis of graphene. Resonant Raman spectroscopy is a powerful tool for the investigation of carbon nanomaterials, in particular for studying both their vibrational and electronic properties. Moreover it allows to investigate the electron phonon coupling. Polarization depended Raman scattering can also give information about the edge configuration of graphene nanostructures. We present Raman line scans on lithographically defined and etched single-layer graphene nanoribbons at different incident polarization angles. The length of the nanoribbons is in the range of 1.5-2 micrometer and the width ranges from 100-500 nm. We discuss the dependence of the Raman intensity on the polarization.

O 51.5 Wed 16:00 WIL B321

Illuminating the dark corridor in graphene: polarization dependence of angular resolved photoemission spectroscopy on graphene — •Isabella Gierz[1], Jürgen Henk[2], Hartmut Höchst[3], Christian R. Ast[1], and Klaus Kern[1,4] — [1]Max-Planck-Institut für Festkörperforschung, 70569 Stuttgart, Germany — [2]Max-Planck-Institut für Mikrostrukturphysik, 06120 Halle (Saale), Germany — [3]Synchrotron Radiation Center, University of Wisconsin-Madison, Stoughton, WI 53589, USA — [4]IPMC, Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

We have used s- and p-polarized synchrotron radiation to image the electronic structure of epitaxial graphene near the K-point of the 2D Brillouin zone by angular resolved photoemission spectroscopy (ARPES). Part of the experimental Fermi surface is suppressed due to the interference of photoelectrons emitted from the two equivalent carbon atoms per unit cell of graphene's honeycomb lattice [1]. We will show that by rotating the polarization vector, we are able to illuminate this 'dark corridor' indicating that the present theoretical understanding is oversimplified. Our measurements are supported by first-principles photoemission calculations, which reveal that the observed effect persists in the low photon energy regime.

[1] E. L. Shirley, L. J. Terminello, A. Santoni, and F. J. Himpsel, Phys. Rev. B **51**, 13614 (1995)

O 51.6 Wed 16:15 WIL B321

Plasmon electron − hole resonance in epitaxial graphene — •Thomas Langer[1,2], Jens Baringhaus[1], Christoph Tegenkamp[1], Herbert Pfnür[1], and Hans Werner Schumacher[2] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, D-30167 Hannover — [2]Physikalisch -Technische Bundesanstalt, D-38116 Braunschweig

The sheet plasmon in epitaxially grown graphene on SiC(0001) has been studied by means of angle resolved high resolution electron energy loss spectroscopy. Most interestingly, the dispersion reveals a dip, which can be assigned to quasiparticle dynamics. The effect is characteristic for pristine graphene and depends on the chemical potential but not on temperature and roughness. By assuming an resonant coupling between the 2d plasmon and an inter-band electron-hole pair excitation (so-called plexciton) the dip in the dispersion can be quantitatively explained using the Drude model of the dielectric function and the nearly free 2d electron gas model of Stern. The relation between this dip and the chemical potential becomes apparent by adsorption experiments performed with F4-TCNQ molecules, which reduces the carrier density and lowers the Fermi level. As expected the dip in the dispersion as well as the signature of the enhanced damping in the FWHM shifts to the lower k_F-values. Remarkably, the average slope of the dispersion remains unchanged, although the electron density at E_F is reduce. Obviously, the coupling of the plasmon mode with the loss channels leads to an effective integration over the electron density around E_F with a width proportional to the measured FWHM of the plasmon mode.

O 51.7 Wed 16:30 WIL B321

Phonon-Plasmon Dispersion of Graphene and Quasi-Freestanding Graphene on 6H-SiC(0001) — •Michael Endlich[1], Roland J. Koch[1,2], Thomas Haensel[1], Thomas Seyller[2], and Juergen A. Schaefer[1,3] — [1]Institut für Physik and Institut für Mikro- und Nanotechnologien, TU Ilmenau, PF 100565,

98684 Ilmenau, Germany — [2]Lehrstuhl für Technische Physik, Universität Erlangen-Nürnberg, Germany — [3]Department of Physics, Montana State University, P.O. Box 173840, Bozeman, MT 59717-3840, USA

We report on a comparison between the strongly coupled phonon-plasmon modes of graphene and hydrogen-intercalated monolayer graphene epitaxially grown on 6H-SiC(0001). The dispersion of these modes have been simulated within a simple dielectric model. As a result, the quasi-freestanding character of the hydrogen-intercalated graphene has been corroborated. From the model it is possible to derive essential values of the graphene such as charge carrier density, effective mass and mobility, which are important for technological applications like high frequency transistors. Furthermore, the existence of silicon-hydrogen and carbon-hydrogen stretching and bending vibrations indicate not only a saturation of Si-dangling bonds at the interface, as it has been previously reported in the literature.

O 51.8 Wed 16:45 WIL B321

Plasmarons in Quasi-Freestanding Doped Graphene Observed through Photoemission — Aaron Bostwick[1], Florian Speck[2], Thomas Seyller[2], •Karsten Horn[3], Marco Polini[4], Reza Asgari[5], Allan McDonald[6], and Eli Rotenberg[1] — [1]ALS, Lawrence Berkeley Lab, USA — [2]Technische Physik, Uni Erlangen, Germany — [3]Fritz Haber Institute, Max Planck Society, Berlin, Germany — [4]CNR and Scuola Normale Superiore Pisa, Italy — [5]Institute of Research in Fundamental Sciences, Teheran, Iran — [6]Department of Physics, University of Texas, Austin USA

The unusual conical band structure of graphene leads to a zero-energy band gap at a single Dirac crossing point. By measuring the spectral function of charge carriers in quasi-freestanding graphene with ARPES, we showe that at finite doping, this well-known linear Dirac spectrum does not provide a full description of the charge-carrying excitations. We observed composite plasmaron particles, which are bound states of charge carriers with plasmons, the density oscillations of the graphene electron gas; such quasiparticles were predicted more than forty years ago, but their experimental confirmation so far has proven elusive. We show that the Dirac crossing point is resolved into three crossings: the first between pure charge bands, the second between pure plasmaron bands, and the third a ring-shaped crossing between charge and plasmaron bands. This observation resolves a controversy about the existence of a gap at the Dirac point in graphene on SiC(0001).

O 51.9 Wed 17:00 WIL B321

Electron spectrum of epitaxial graphene monolayers — •Oleg Pankratov, Stephan Hensel, and Michel Bockstedte — Lst. Theoretische Festkörperphysik, Universität Erlangen, Staudtstr 7B2, 91058 Erlangen.

Epitaxial graphene on SiC possesses, quite remarkably, an electron spectrum similar to that of free-standing samples. Yet, the coupling to the substrate, albeit small, should affect the quasiparticle properties. Whether the graphene-substrate interaction opens an energy gap has been a long debate with experimental estimates ranging from 0 to 0.3 eV [1,2]. Using symmetry analysis, we derive a modified Dirac-Weyl Hamiltonian for graphene epilayers [3]. To determine the numerical values of the Hamiltonian parameters we performed *ab initio* calculations for a model (5×5) comensurable interface structure. We find that for the epilayer on the C-face the Dirac cone remains intact, whereas for epilayers on the Si-face the band splitting is about 30 meV. At certain energies, the Dirac bands are significantly distorted by the resonant interaction with interface states, which should lead to mobility suppression, especially on the Si-face.

[1] T. Seyller *et al.*, Phys. Status Solidi B **245**, 1436 2008
[2] S. Y. Zhou *et al.*, Nature Mater. **6**, 770 (2007).
[3] O. Pankratov, S. Hensel, and M. Bockstedte, Phys. Rev. B **82**, 121416 (2010).