O 65: Poster: Graphene (HL jointly with MA, O)

Time: Wednesday 17:00–20:00 Location: P1

O 65.1 Wed 17:00 P1

Semi-empirical phonon calculations for graphene on different substrates — •Henrique Miranda, Alejandro Molina-Sanchez, and Ludger Wirtz — Physics and Materials Science Research Unit, UNIVERSITÉ DU LUXEMBOURG, Luxembourg

We investigate the graphene-substrate interaction via changes in the phonon dispersion of graphene. Ab-initio calculations on these systems are of high computational cost due to the non-commensurability of the unit cells of graphene and the substrate. This leads to the formation of Moiré patterns with accordingly large supercell sizes. We use a semi-empirical force constant model for the calculation of phonons of graphene on different metallic and insulating substrates. The interaction of graphene with the substrate is described via suitably chosen spring constants. The phonon dispersion in the primitive unit cell of graphene is obtained via an "unfolding procedure" similar to the ones used for the discussion of ARPES (angular resolved photo-emission spectroscopy) of graphene on incommensurate substrates.

O 65.2 Wed 17:00 P1

Bilayer graphene: topological phases and entanglement spectrum — •Sonja Predin and John Schliemann — Institute for Theoretical Physics,University of Regensburg, D-93040 Regensburg, Germany

We present a calculation of the entanglement spectrum of fermions in bilayer graphene. In particular, a non-trivial topological order of the Abelian phase of the time-reversal symmetry breaking d-wave state is studied. We show that the entanglement spectrum is gapped, additionally we show that edge excitations in the entanglement spectrum form doublet Dirac fields around every K point.

O 65.3 Wed 17:00 P1

Ultrafast dynamics and photoluminescence of hot carriers in graphene — •Thomas Danz, Andreas Neff, Reiner Bormann, Sascha Schäfer, and Claus Ropers — IV. Physical Institute, University of Göttingen, 37077 Göttingen, Germany

The ultrafast dynamics of optically excited carriers in graphene can be monitored by pump-probe spectroscopy [1,2]. Furthermore, it was recently shown that the thermalization of hot carriers leads to photoluminescence at wavelengths far away from the exciting pump [3,4]. Here, we present the implementation of an experimental setup which combines transient spectroscopy with sub-15-fs temporal resolution with hot carrier photoluminescence detection under the same excitation conditions. With this approach, we aim at a comprehensive picture of the ultrafast carrier response and the disentanglement of the timescales underlying different relaxation pathways. First experimental results will be presented.

[1] J. M. Dawlaty *et al.*, Appl. Phys. Lett. **92**, 042116 (2008)
[2] M. Breusing *et al.*, Phys. Rev. B. **83**, 153410 (2011)
[3] C. H. Lui *et al.*, Phys. Rev. Lett. **105**, 127404 (2010)
[4] W. Liu *et al.*, Phys. Rev. B. **82**, 081408 (2010)

O 65.4 Wed 17:00 P1

Electron spin resonance of ion-irradiation induced single vacancies on monolayer graphene characterized by scanning tunneling spectroscopy — •Sven Just[1], Stephan Zimmermann[2], Vladislav Kataev[2], Marco Pratzer[1], Bernd Büchner[2], and Markus Morgenstern[1] — [1]II. Physikalisches Institut B, RWTH Aachen — [2]Leibniz-Institut für Festkörper- und Werkstoffforschung, Dresden

Single vacancies with densities of $0.003/\mathrm{nm}^2 - 3/\mathrm{nm}^2$ are prepared on HOPG and on single layer graphene on SiO_2 produced by chemical vapour deposition using Ar ions with 50 eV kinetic energy. The vacancies exhibit a peak at E_F in scanning tunneling spectroscopy, which survives 3 h of air exposure, afterwards a small broadening of the peak is observed. Electron spin resonance shows a peak corresponding to g = 2.0022, if the defect density is above $0.3/\mathrm{nm}^2$, and a peak width of 10 G with an anisotropy below 0.5 G between in-plane and out-of-plane magnetic field. The peak width hardly depends on temperature, while the peak intensity decreases with increasing temperature in the range of 4 K - 20 K.

O 65.5 Wed 17:00 P1

Enhancing the Raman signal of graphene on SiC(0001) by using a solid immersion lens in *top-down* geometry — •Felix Fromm[1], Martin Hundhausen[2], Michl Kaiser[3], Julia Krone[1], and Thomas Seyller[1] — [1]TU Chemnitz, Institut für Physik — [2]FAU Erlangen-Nürnberg, Lehrstuhl für Laserphysik — [3]FAU Erlangen-Nürnberg, Lehrstuhl für Werkstoffwissenschaften

We present a study of epitaxial graphene by recording Raman spectra from the backside through the silicon carbide (SiC) substrate. In that *top-down* geometry we profit from the fact, that the graphene layer emits approximately 96 % of the Raman intensity into the SiC [1]. However, we only observe an intensity enhancement of approximately a factor of 4 compared to the conventional *top-up* geometry. This is because the solid angle of detection is decreased by refraction at the SiC/air interface and is limited by the total internal reflection. To further improve the detection efficiency, we use a high refractive index solid immersion lens (SIL) made of cubic zirconia combined with a suitable immersion liquid. By that, the angle of total internal reflection, as well as the solid angle of detection are increased. We eventually observe an increase of the detected Raman intensity towards the *top-up* geometry to a factor of 25. As an additional advantage, the background signal of the two-phonon Raman modes of the SiC is suppressed to a large extent.

[1] F. Fromm et al., New J. Phys. 15, 113006 (2013)

O 65.6 Wed 17:00 P1

Growth of graphene on 6H-SiC(0001) under ammonia/argon atmosphere — •Christian Raidel, Felix Fromm, Samir Mammadov, Martina Wanke, and Thomas Seyller — TU Chemnitz, Insitut für Physik, Germany

In this work we investigated the nitrogen incorporation into epitaxial grown monolayer graphene by using ammonia as process gas within argon flow during thermal decomposition of SiC. The growth parameters as temperature and ammonia concentration were studied by various surface sensitive methods as XPS, LEED, RAMAN, AFM, and STM. ARPES shows that the ammonia grown graphene shows more p-type doped graphene than undoped graphene on SiC(0001). Due to the dissociation of ammonia during the growth process etch pits are produced. Vacancy associated nitrogen incorporation was observed by XPS and STM.

O 65.7 Wed 17:00 P1

Characterization and transfer of 2D dichalcogenides produced by anodic bonding — •Philipp Nagler, Gerd Plechinger, Christian Schüller, and Tobias Korn — Institut für Experimentelle und Angewandte Physik, Universität Regensburg, 93040 Regensburg, Germany

Atomically thin MoS_2 and WS_2 structures have attracted growing attention as promising 2D semiconductors. As monolayers, both materials exhibit a direct bandgap and therefore are suitable candidates for future opto-electronical devices. We produced singlelayer MoS_2 and WS_2 by means of anodic bonding. In this process, the material is bonded by electrostatic forces on a borosilicate glass substrate. Compared to mechanical exfoliation, this technique usually yields larger flakes. Anodic bonded MoS_2 flakes were characterized by Raman and photoluminescence (PL) spectroscopy. Performing low-temperature PL measurements, we observed similar behaviour as in SiO_2-supported MoS_2. Furthermore, PL measurements for anodic bonded WS_2 are presented. By applying the wedging transfer technique, we transferred anodic bonded monolayer WS_2 from the glass to a SiO_2 substrate. Additionally, using this method, heterostructures consisting of various 2D materials could be produced and characterized.

O 65.8 Wed 17:00 P1

Graphene nanostructures produced from transfered layers — •Christopher Belke, Dmitri Smirnov, Johannes C. Rode, Hennrik Schmidt, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, D-30167 Hannover, Germany

Graphene consists of carbon atoms, which are arranged in a two-dimensional honeycomb lattice. It has unique electronic properties, which can be examined in high quality samples [1]. These are often

prepared by mechanical exfoliation on a silicon wafer with silicon dioxide on top. This substrate has a strong influence on the transport properties due to charge traps and surface roughness [2]. To reduce these effects or to produce novel complexe layersystems, graphene sheets can be stacked by a transfer methode e. g. onto other substrates or one upon the other to fabricate twisted flakes. The latter has been done and was under examination with magnetotransport measurements. Graphene is exfoliated on a thin PMMA layer, which can be detached from the silicon wafer. This layer is then placed on another graphene mono- or bilayer flakes. The samples were characterized at low temperatures and in dependence of a magnetic field. Magnetic field independent oscillations could be observed in a multilayer system.

[1] K. S. Novoselov et al. Science **306**, 666 (2004)
[2] P. Barthold et al. NJP **13**, 0433020 (2011)

O 65.9 Wed 17:00 P1

Twisted graphene bilayers, folded via atomic force microscope — •Johannes C. Rode, Dmitri Smirnov, Christopher Belke, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover

Naturally occurring double-layer graphene consists of two hexagonal lattices in Bernal stacking. We investigate the folding of single-layer graphene via atomic force microscope (AFM) and the electronic properties of thusly created bilayers. The crystal lattices of these are twisted against each other which affects the interlayer coupling, giving rise to interesting electronic properties like a screening effect and reduced Fermi velocities at higher twist angles. Furthermore, the influence of a moiré-superlattice or twist induced van-Hove-singularities can be expected at lower twist angles. Our samples are obtained by micromechanical cleavage of natural graphite and placed on a silicon substrate with a top layer of silicon dioxide. The atomic force microscope then serves as a tool to mechanically manipulate the sample by programmed tip movements. We show AFM-induced folding of graphene on a μm-scale which can afterwards be contacted via e-beam lithography. Magnetotransport measurements over the folded areas show interesting signatures like multiple origins of landau fans in the charge carrier concentration.

O 65.10 Wed 17:00 P1

The Effect of the Chemical Potential of Graphene on THz Detection — •Markus Göthlich[1], Fathi Gouider[1], André Müller[2], Yuri B. Vasilyev[3], and Georg Nachtwei[1] — [1]Institut für Angewandte Physik, Technische Universität Braunschweig, Mendelssohnstraße 2, D-38106 Braunschweig — [2]Physikalisch Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig — [3]A.F.Ioffe Physical Technical Institute, RU-194021 St.Petersburg, Russia

One particular fact about graphene is its remarkable Landau quantization $E_n = \mathrm{sgn}(n)\sqrt{\Delta^2 + 2\hbar e v_F^2 |n|B}$ with n being the Landau level (LL) index. This would allow a transition at 2.4 THz (corresponding to an energy of about 10 meV) to happen at a magnetic field as low as 0.2 T. But theoretical investigations show the opening of a bandgap and a high chemical potential in epitaxial graphene on Si-face SiC due to graphene–substrate interactions. On the other hand our calculations—based on Gusynin et al. Phys. Rev. Lett. 98, 157402 (2007)—show that at high chemical potential the photoresponse can only be observed at higher magnetic fields of some Tesla. Gating is difficult due to the insolating behaviour of SiC substrate on the one hand and THz intransparency of top gates on the other hand. Therefore our aim is to design a new sample geometry that allows the manipulation of the chemical potential of the graphene while not blocking the THz radiation before reaching the detector.

O 65.11 Wed 17:00 P1

Gate-controlled STM study of magnetic impurities on a graphene surface — •Paul Punke[1], Christian Dette[1], Roberto Urcuyo[1], Christopher Kley[1], Sören Krotzky[1], Rico Gutzler[1], Marko Burghard[1], Soon Jung Jung[1], and Klaus Kern[1,2] — [1]Max-Planck-Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany — [2]Institut de Physique de la Matière Condensée, Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

Graphene has been regarded as an ideal material for post silicon electronic application due to its unique electronic properties. To realize a field effect transistor for logic applications out of graphene, there has been a lot of effort to understand the gating effect on the charge-carrier-density-dependent properties of graphene, such as electronic scattering, spin based phenomena and collective excitations. We have designed a gatable low temperature scanning tunneling microscope (STM) by adding contacts to the sample holder. To prepare the gate-tunable graphene devices, we use graphene grown by chemical vapor deposition (CVD), transferred with or without a supporting layer of polymethylmethacrylate (PMMA) or polystyrene (PS), on an insulating layer of SiO2 or hexagonal boron nitride (h-BN) on SiO2. We also grow the graphene on h-BN directly on Ni substrate by CVD method. The quality of these samples will be compared by means of optical microscopy, atomic force microscopy (AFM), Raman spectroscopy and STM. Finally, we will present the gate-controlled electronic structure of graphene.

O 65.12 Wed 17:00 P1

Ion Implantation of Graphene - Toward IC Compatible Technologies — •H. Hofsäss[1], U. Bangert[2,3], W. Pierce[2], D. M. Kepaptsoglou[3], Q Ramasse[3], R Zan[1], M. H. Gass[3,4], J.A. van den Berg[5], C. Boothroyd[6], and J Amani[1] — [1]II. Physikalisches Institut, Georg-August-Universität Göttingen, Göettingen, Germany — [2]School of Materials, The University of Manchester, Manchester, United Kingdom — [3]SuperSTEM Laboratory, Daresbury, United Kingdom — [4]AMEC, Walton House, 404 The Quadrant, Birchwood, United Kingdom — [5]School of Computing, Science and Engineering, University of Salford, Salford, United Kingdom — [6]Ernst Ruska-Centre for Microscopy and Spectroscopy, Juelich Research Centre, Juelich, Germany

Doping of graphene via ultra low energy ion implantation could open possibilities for fabrication of nanometer-scale patterned graphene-based devices as well as for graphene functionalization compatible with large-scale integrated semiconductor technology. Using advanced electron microscopy/spectroscopy methods, we show for the first time directly that graphene can be doped with B and N via ion implantation of mass selected ions at energies of 20 - 30 eV and that the retention is in good agreement with predictions from calculation-based literature values. Atomic resolution high-angle dark field imaging (HAADF) combined with single-atom electron energy loss (EEL) spectroscopy reveals that for sufficiently low implantation energies ions are predominantly substitutionally incorporated into the graphene lattice with a very small fraction residing in defect-related sites.