O 44: Graphene: Electronic Properties, Structure and Substrate Interaction

Time: Tuesday 18:15–20:30 Location: Poster E

O 44.1 Tue 18:15 Poster E

Effect of electron-density inhomogeneities on the electronic band structure of single-layer graphene — •Trevor Clarke[1,2], Peter Kot[1,2], Jon Parnell[1,2], Sina Habibian[1,2], Klaus Kern[1,3], and Christian R. Ast[1] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]University of British Columbia, Vancouver, Canada — [3]École Polytechnique Fédérale de Lausanne, Switzerland

In an ideal graphene sheet, the density of electrons is uniformly distributed throughout the two-dimensional lattice. However, in experimental contexts, graphene sheets are routinely subject to electron-density inhomogeneities. Such inhomogeneities, or charge puddles, are thought to arise from charged impurities located on the substrate on which the graphene is deposited. To investigate the effects of charge puddles on the electronic properties of single-layer graphene, we simulate fluctuating potential landscapes that model charge inhomogeneities via two methods: the diamond-square algorithm, and fractional Brownian motion (with Perlin noise). Each method produces randomly fluctuating (but smooth and continuous) potential landscapes with unique features and characteristics. These potential landscapes are used to perturb the on-site energies of the carbon atoms in the lattice. The band structure of the perturbed lattice is then calculated using a tight-binding model. We present calculations exploring a range of parameter values, and indicate results produced from values which generate potentials that most closely resemble empirical findings.

O 44.2 Tue 18:15 Poster E

Robust ballistic transport phenomena in epitaxial graphene nanoribbons — •Johannes Aprojanz, Jens Baringhaus, Maren Wehr, Felix Klösel, and Christoph Tegenkamp — Leibniz Universität Hannover, Institut für Festkörperphysik, 30167 Hannover, Germany

Graphene nanoribbons (GNRs) are of particular importance for future carbon-based electronics. Their outstanding electronic properties, especially the presence of topologically protected ballistic transport channels, make them a prime candidate for a new class of fully coherent devices. However, the large amount of defects introduced by conventional lithography processes prevents the formation of such edge channels. The self-assembling growth of GNRs on the sidewalls of SiC mesa structures overcomes this obstacle leading to the observation of exceptional ballistic transport properties. With local transport experiments by means of a 4-tip STM, two fundamentally different ballistic modes can be identified. One is thermally activated and exhibits a mediocre mean free path in the order of several hundred nm, the other is temperature independent and shows an exceptionally long mean free path larger than 10 μm [1]. The roughness of the underlying SiC substrate is identified as a major source for electronic scattering. Consequently, the mean free path is shown to be directly dependent on the width of the substrate terraces [2].

[1] Baringhaus et al., Nature **506**, 349 (2014)
[2] Baringhaus et al., APL **106**, 043109 (2015)

O 44.3 Tue 18:15 Poster E

A bottom-up approach to synthesize graphene nanoribbons on Ru(0001) by chemical vapor deposition — •Ann-Kathrin Henss and Joost Wintterlin — Ludwig-Maximilians-Universität, Munich, Germany

The synthesis of defined graphene nanoribbons is of great interest for future applications due to their tunable band gaps. We have tested a bottom-up approach to synthesize graphene nanoribbons by chemical vapor deposition (CVD) of hydrocarbons on a prestructured Ru(0001) single crystal under ultra high vacuum conditions. The structuring of the substrate was achieved by aluminum deposition at elevated sample temperatures to decorate the step edges of the Ru(0001) surface. A subsequent oxidation step led to the formation of ordered stripes of aluminum oxide along the step edges which are to act as barriers between which graphene could grow in form of nanoribbons. Graphene was grown by CVD using ethylene as a precursor gas at 850°C and a pressure of 3×10^{-9} Torr. Scanning tunneling microscopy and Auger electron spectroscopy were used to monitor the synthesis steps. After the graphene growth no ordered structures of aluminum oxide were present on the surface anymore. Hydrogen forming during the decomposition of ethylene was found to reduce the aluminum oxide to metallic aluminum, which is no longer a growth barrier for graphene.

O 44.4 Tue 18:15 Poster E

Twisted graphene layers on metals investigated by scanning tunneling microscopy — •Sabina Simon, Philipp Leicht, Julia Tesch, Luca Gragnaniello, and Mikhail Fonin — Department of Physics, University of Konstanz, 78457 Konstanz, Germany

Epitaxial growth on metal substrates is known to be one of the most powerful approaches in producing large-scale high-quality monolayer graphene, yet it remains a major challenge to realize the growth of multilayers.

This work is devoted to the investigation of multilayered graphene systems epitaxially grown on metallic substrates. Firstly, we discuss the local electronic properties of twisted graphene flakes on Au(111). The electronic properties of such twisted bilayer graphene areas show an increased accessibility of atomically resolved graphene features, a shift of the Dirac energy closer to E_F with a residual doping of 85 meV and a reduced Fermi velocity of $(0.8\pm0.1)\cdot10^6$ m/s. Secondly, we present the results of the investigation of growth of large scale graphene bilayers on Ir(111) and report on their structure and electronic properties.

O 44.5 Tue 18:15 Poster E

Graphene formation on Ag(001) by liquid precursor deposition — •Jens Uwe Neurohr, Samuel Grandthyll, Karin Jacobs, and Frank Müller — Saarland University, 66041 Saarbruecken, Germany

Chemical vapor deposition (CVD) is the standard method for epitaxial growth of graphene on many transition metal surfaces, but for a very weakly interacting substrate such as Ag(001) the CVD-process fails. However, epitaxial graphene on Ag(001) can be obtained by liquid precursor deposition (LPD) - an alternative synthesis route that was successfully demonstrated on many transition metals in previous studies [1]. Graphene growth on Ag(001) was investigated by X-ray photoelectron spectroscopy (XPS), low energy electron diffraction (LEED), and Fermi surface mapping (FSM), revealing a monolayer coverage of arbitrarily rotated domains [2], similarly to the growth of boronitrene (i.e., h-BN monolayers) on the Ag(001) [3].

References:
[1] S. Grandthyll, S. Gsell, M. Weinl, M. Schreck, S. Hüfner and F. Müller J. Phys. : Condens. Matter 24 (2012) 314204
[2] S. Grandthyll, K. Jacobs and F. Müller Phys. Status Solidi B, 252: 1695-1699
[3] F. Müller, S. Grandthyll Surface Science 617 (2013) 207-210

O 44.6 Tue 18:15 Poster E

Lifting Graphene from Substrates by Scanning Tunneling Microscopy — •Anne Holtsch, Anne Holtsch, Wolf-Rüdiger Hannes, and Uwe Hartmann — Universität des Saarlandes, Saarbrücken

Graphene as a two-dimensional crystal is only stable because of the formation of so-called ripples. Such ripples are thus called intrinsic and have been identified both by transmission electron microscopy [1] and scanning tunneling microscopy (STM) [2].

Here we study graphene grown via CVD and transferred onto copper foils, which may cause corrugations either before, during or after transfer. We find, however, that the corrugations appear very similar to those of free-standing membranes [2]. We report on the lifting of the graphene from the copper substrates using the attractive forces of a STM tip as previously reported for graphene on silicon dioxide [3].

Since metallic substrates electronically bind to the adsorbing graphene, higher bias voltages for lifting are generally required than in the case of free-standing membranes. Other features of Z(V) spectroscopy curves such as reversible flipping processes with hysteric behavior are also analyzed. It is discussed wether interaction strengths between graphene and particular types of substrates can be deduced from such measurement.

[1] J. C. Meyer et al., Nature 446, 60 (2007) [2] R. Dan et al., Nanoscale 4, 3065 (2010) [3] T. Mashoff et al., Nano Lett. 10, 461

(2010)

O 44.7 Tue 18:15 Poster E

Flipping ripples of freestanding graphene membranes using Scanning Tunneling Microscopy — •Bernd Uder, Wolf-Rüdiger Hannes, and Uwe Hartmann — Fachrichtung Experimentalphysik, Universität des Saarlandes, Germany

Measurement and control of the elastic properties of two-dimensional materials is a prerequisite for their development into nanoelectromechanical systems. So far atomic force microscopy has been the only tool used to determine elastic moduli and breaking strength of freestanding graphene membranes [1]. This method usually does not allow a thorough characterization in terms of defect concentration and other sample parameters. Here we report on the deformation of graphene membranes using the attractive forces of a scanning tunneling microscope tip. The method poses challenges since membrane and tip instabilities are easily induced. We have been able to initiate flipping processes, which are reversible but show a hysteresis. Cascade like flipping and metastable membrane states are also observed. Possible relations with local elastic properties of the rippled membrane structure are discussed within a simple model.

[1] C. Lee, X. Wei, J. W. Kysar, J. Hone, Science 321, 385 (2008)

O 44.8 Tue 18:15 Poster E

Local transport measurements in Graphene on SiO2 using Kelvin Probe Force Microscopy — Philip Willke[1], Christian Möhle[1], •Anna Sinterhauf[1], Hak Ki Yu[2,3,4], Alec Wodtke[2,3], and Martin Wenderoth[1] — [1]IV. Physical Institute, University of Göttingen, 37077 Göttingen, Germany — [2]Institute for Physical Chemistry, University of Göttingen, 37077 Göttingen, Germany — [3]Max Planck Institute for Biophysical Chemistry, 37077 Göttingen, Germany — [4]Department of Materials Science & Engineering, Ajou University, Suwon 443-749, Korea

By using Kelvin Probe Force Microscopy with an additional applied electric field we investigate the local voltage drop in graphene on SiO2 under ambient conditions. We are able to quantify the variation of the local sheet resistance and to resolve localized voltage drops at line defects. Our data demonstrates that the resistance of line defects has been overestimated so far. Moreover, we show that different types of wrinkles have the largest resistance. Temperature-dependent measurements show that the local monolayer sheet resistance reflects the macroscopic increase in resistance with temperature while the defect resistance for folded wrinkles is best described by a temperature-independent model which we attribute to interlayer tunneling. This work was supported by the Deutsche Forschungsgemeinschaft (DFG) priority program 1459 Graphene.

O 44.9 Tue 18:15 Poster E

Epitaxial graphene via flash annealing of SiC studied by VT-STM — •Ismail Baltaci, Malte Schulte, Eugenia Wodopian, Harry Ritter, and Carsten Westphal — Experimentelle Physik 1, TU Dortmund, Otto-Hahn-Strasse , 44227 Dortmund, Germany

Graphene has a charge carrier mobility which is two magnitudes larger than in SiC. Therefore graphene is of particular relevance for the semiconductor industry, e.g. as a new material for transistors.

There are different methods which should yield large and homogeneous graphene layers. Here we concentrate on an epitaxial growth based on cyclic heating of SiC, known as flash annealing. The hydrocarbon contaminations are desorbed during degasing SiC at 600° C. Heating up to 1400° C leads to a sublimation of Si. The remaining carbon atoms reconstruct in a hexagonal structure forming large graphene layers.

In addition to the flash annealing we are using hydrogen etching to achieve a high quality and flat SiC surface prior to the annealing steps. A Si- or Ar-flux during the annealing reduces the Si-sublimation and thus increases the graphene quality. In order to optimize the procedure multiple parameters have to be taken in account. Imaging the surface of SiC/Graphene is achieved by VT-STM.

O 44.10 Tue 18:15 Poster E

STM characterization of epitaxial graphene produced by confinement controlled sublimation of SiC — •Hermann Kromer[1], Cornelis Hilscher[1], Richard Hönig[1], Christoph Keutner[1,2], and Carsten Westphal[1,2] — [1]Experimentelle Physik 1 - Technische Universität Dortmund, Otto-Hahn-Str. 4, D-44221 Dortmund, Germany — [2]DELTA - Technische Universität Dortmund, Maria-Goeppert-Mayer-Str. 2, D-44221 Dortmund, Germany

Graphene electronics imposes great demands on the material and material processing. The realization of graphene-based electronics requires a homogeneous, controllable and reproducible growth of large-domain graphene layers.

In this study we are focusing on the growth of epitaxial graphene on the Si-face of silicon carbide (SiC). Our aim is to achieve a well controlled growth of high quality graphene layers on a large scale. Therefore we are using the confinement controlled sublimation (CCS) method under ultra high vacuum (UHV) conditions, as well as in an argon atmosphere.

After the preparation, these samples are characterized by scanning tunneling microscopy (STM). STM is an excellent tool to study this system, since its high resolution enables us to examine surfaces down to the atomic level.

O 44.11 Tue 18:15 Poster E

Graphene growth on SiC(11$\bar{2}$0) — •Stefanie Rumbke, Florian Speck, and Thomas Seyller — Professur für Technische Physik, TU Chemnitz, Reichenhainer Str. 70, D-09126 Chemnitz, Germany

Epitaxial growth of graphene on SiC(0001) surfaces leads to the formation of the so-called buffer layer, a monolayer of carbon atoms partially bonded to the substrate [1]. This layer is known to be detrimental for the electronic transport properties of graphene [2]. We present a study of graphene growth on SiC(11$\bar{2}$0) surfaces on which, according to previous work [3], graphene can be grown on top of the substrate without a buffer layer residing at the interface. Prior to graphene growth, samples were hydrogen etched in order to obtain flat surfaces. Systematic studies were carried out to determine the optimal parameters for both hydrogen etching and graphene growth. For hydrogen etching temperature as well as hydrogen flow were varied, for graphene growth temperature and duration of the growth process. The quality of the hydrogen etched surfaces and the graphene layers along with the properties of the graphene were investigated using atomic force microscopy, x-ray photoelectron spectroscopy, low energy electron diffraction and angle-resolved photoelectron spectroscopy. In addition, the impact of hydrogen intercalation on the doping level of graphene on SiC(11$\bar{2}$0) was investigated.

[1] K. Emtsev, et al., Phys. Rev. B **77**, 155303 (2008).
[2] F. Speck, et al., Appl. Phys. Lett. **99**, 122106 (2011).
[3] M. Ostler, et al., Phys. Rev. B **88**, 085408 (2013).

O 44.12 Tue 18:15 Poster E

High quality graphene on boron nitride prepared by polymer free dry transfer and contacting techniques for combined STM and electrical transport measurements — •Tjorven Johnsen, Daniel Montag, Felix Jekat, Martin Grob, Nils Freitag, Peter Nemes-Incze, and Markus Morgenstern — II. Physikalisches Institut B, RWTH Aachen, Otto-Blumenthal-Straße, 52074 Aachen

The charge carrier mobility of graphene is mainly determined by the substrate and adsorbates on the graphene flake. High quality graphene samples are prepared by either suspending the graphene flake or by encapsulating it in hexagonal boron nitride [1,2]. These devices, however, are not accessible for surface sensitive probes like scanning tunnelling microscopy (STM). Here we present a novel transfer technique employing a mica substrate to pick up a boron nitride flake and a graphene flake one after another from SiO_2. The graphene flake is contacted using shadow mask evaporation. Thereby, we eliminate any polymers from the preparation process which are a major source of adsorbates. This is required for combined STM and electrical transport measurements. With these samples we aim to measure symmetry broken states of the quantum hall effect in graphene both with STM and transport measurements.

[1]Du et al., Nat. Nanotechnol. 3, 491 - 495 (2008)
[2]Banszerus et al., Sci. Adv. 1, e1500222 (2015)