

## DS 35: Graphen

Time: Thursday 9:30–13:00

Location: H 0111

DS 35.1 Thu 9:30 H 0111

**Graphene Growth and Isotope Engineering** — ●MICHAEL HILKE<sup>1,2</sup>, ERIC WHITEWAY<sup>1</sup>, WAYNE YANG<sup>1</sup>, and VICTOR YU<sup>1</sup> — <sup>1</sup>McGill University, Montreal, Kanada — <sup>2</sup>FU Berlin, Berlin, Deutschland

Graphene is grown by chemical vapor deposition (CVD) on copper using different relative concentrations of C12 and C13 isotopes. This allows us to measure the dynamics of the growth and extract important growth parameters, in particular in relation to regular and fractal graphene (graphlocons) growth. Further, the use of different isotopes, opens the door to new phonon properties such as phonon Anderson localization, phonon waveguides and more generally phonon engineering.

DS 35.2 Thu 9:45 H 0111

**Synthesis of long-range ordered crystalline Graphene by chemical vapor deposition over Iridium (111) films on Sapphire** — ●ARTI DANGWAL PANDEY and ANDREAS STIERLE — Deutsches Elektronen-Synchrotron, Hamburg, Germany

High-quality and large-area Graphene is in demand to exploit its unique physical properties for various applications, including future electronic devices and sensors. Large-area epitaxial graphene have been deposited successfully by CVD on transition metal single crystals. These substrates are of high quality, but very expensive. This drives the search for other alternatives to use cheaper substrates. Ir has low carbon solubility, and so Ir thin film is a good choice for growing Graphene on it. Only single article is published till date for preparing epitaxial graphene on single crystal Ir film. [1] We have synthesized long-range ordered crystalline Graphene over few nanometer thick Ir films deposited on sapphire. Ethylene is used as a carbon source for depositing graphene by CVD and Ir films are grown by physical vapor deposition. LEED reveals the long-range crystallinity of graphene and Ir films, and XPS measurements confirmed the high purity of Ir films. Influence of growth parameters on the quality of Ir film, and thus on Graphene, will be discussed in Detail.

[1] Chi Vo-Van et al. App. Phys. Lett. 98 (2011) 181903.

DS 35.3 Thu 10:00 H 0111

**Rotated domain network in graphene on cubic-SiC(001)** — ●VICTOR ARISTOV<sup>1,2,3</sup>, ALEXANDER CHAIKA<sup>1,4</sup>, OLGA MOLODTSOVA<sup>2</sup>, ALEXEI ZAKHAROV<sup>5</sup>, DMITRY MARCHENKO<sup>6</sup>, JAIME SÁNCHEZ-BARRIGA<sup>6</sup>, ANDREI VARYKHALOV<sup>6</sup>, SERGEY BABENKOV<sup>2</sup>, MARC PORTAIL<sup>7</sup>, MARCIN ZIELINSKI<sup>8</sup>, BARRY MURPHY<sup>4</sup>, SERGEY KRASNENKOV<sup>4</sup>, OLAF LUEBBEN<sup>4</sup>, and IGOR SHVETS<sup>4</sup> — <sup>1</sup>ISSP RAS Chengolovka, Russia — <sup>2</sup>DESY Hamburg, Germany — <sup>3</sup>Uni Hamburg, Germany — <sup>4</sup>Trinity College Dublin, Ireland — <sup>5</sup>MAX-lab Lund, Sweden — <sup>6</sup>BESSY Berlin, Germany — <sup>7</sup>CNRS-CRHEA Valbonne, France — <sup>8</sup>NOVASiC Le Bourget du Lac, France

The atomic structure of the cubic-SiC(001) surface during UHV graphene synthesis has been studied using PES, STM and LEED. The studies prove the synthesis of a uniform, millimeter-scale graphene overlayer consisting of nanodomains rotated by  $\sim 13.5^\circ$  relative to the  $\langle 110 \rangle$ -directed boundaries. The preferential directions of the domain boundaries coincide with the directions of carbon atomic chains on the SiC(001)-c(2x2) reconstruction, fabricated prior to graphene synthesis. The presented data show the correlation between the atomic structures of the SiC(001)-c(2x2) surface and the graphene /SiC(001) rotated domain network and pave the way for optimizing large area graphene synthesis on low cost cubic SiC(001)/Si(001) wafers. Acknowledgments: This work was supported by the RAS, RFBR grants No 140200949 and 140201234, by the BMBF-Project No. 05K12GU2, PSP-Element No. U4606BMB1211, by a Marie Curie IIF grant No 12/IA/1264, by SPP 1459 of DFG.

DS 35.4 Thu 10:15 H 0111

**Investigation of atomic-scale strain variations in graphene as a function of applied strain** — ●STEFAN E. HUBER<sup>1</sup>, GERARD VERBIEST<sup>2</sup>, CHRISTOPH STAMPFER<sup>2</sup>, and KARSTEN REUTER<sup>1</sup> — <sup>1</sup>Technische Universität München — <sup>2</sup>RWTH Aachen

Graphene exhibits unique electronic and mechanical properties. The very high electron mobilities that can be reached in state-of-the-art devices suggest this material to revolutionize present-day electronics.

The demand for high mobilities raises the question what actually limits these in graphene. Recent experiments provide evidence that most likely nanometer-scale strain variations are the mechanism responsible for the limitation of the charge carrier mobility [1,2].

Homogeneously straining graphene is expected to reduce local strain fluctuations and thus to increase the electron mobility. We address this issue with atomistic simulations of two distinct mechanisms that may give rise to nanometer-scale strain variations in the presence of overall strain. Using (and comparing) a series of interatomic potentials to describe graphene, we study (i) the effect of surface defects in a hexagonal boron-nitride substrate deduced from first-principles DFT calculations as well as (ii) thermally induced fluctuations. In both respects, we discuss the effective suppression of out-of-plane distortions already at moderate global strains of a few per cent. In stark contrast, in-plane deformations are enhanced upon the application of global strain, a result clearly beyond the limitations of linear elasticity theory.

[1] N.J.G. Couto et al., Phys. Rev. X 4, 041019 (2014)

[2] S. Engels *et al.*, Phys. Rev. Lett. 113, 126801 (2014)

DS 35.5 Thu 10:30 H 0111

**Uniformity of the pseudo-magnetic field in strained graphene** — ●GERARD VERBIEST, SASCHA BRINKER, and CHRISTOPH STAMPFER — JARA-FIT and 2nd Institute of Physics, RWTH Aachen University, 52074 Aachen, Germany

Graphene is a very promising candidate as active material in future electronic applications. However, its electrical properties are very sensitive to mechanical disturbances, as graphene is only one atomic layer thick. This coupling theoretically gives rise to a so-called "pseudo-vector field", and consequently to a "pseudo-magnetic field".

The pseudo-magnetic field can, just as a real magnetic field, induce Landau levels in graphene, if the field is strong enough. In order to utilize, i.e. measure this effect, one needs (i) a high sample quality and (ii) a large uniformity of the pseudo-magnetic field.

Here we present numerical simulations of the pseudo-magnetic field in graphene with a hexagonal shape as a function of tri-axial strain. We defined a radius of uniformity, as the radius for which the standard deviation from the pseudo-magnetic field in the center reaches 1%. For a hexagon with sides of 100 nm and a strain of 10%, the pseudo-magnetic field strength is  $\sim 40$  T and is uniform within a diameter of 34 nm. For a hexagonal sample size with sides of 1 micron with a strain of 3.5%, the maximum pseudo-magnetic field is reduced to  $\sim 1.2$  T, but it is uniform within a diameter of 540 nm.

DS 35.6 Thu 10:45 H 0111

**Nanopores in Silicon Nitride Membranes, Graphene and CNM: Milling and Imaging Techniques at the Helium Ion Microscope** — ●DANIEL EMMRICH<sup>1</sup>, EMANUEL MARSCHEWSKI<sup>1</sup>, ACHIM NADZEYKA<sup>2</sup>, FRANK NOUVERTNÉ<sup>2</sup>, ARMIN GÖLZHÄUSER<sup>1</sup>, and ANDRÉ BEYER<sup>1</sup> — <sup>1</sup>Physics of Supramolecular Systems, Bielefeld University, 33615 Bielefeld, Germany — <sup>2</sup>Raith GmbH, Konrad Adenauer Allee 8, 44263 Dortmund, Germany

The Helium Ion Microscope (HIM) is a charged particle microscope employing Helium ions for probing the sample. In the low dose regime, the HIM operates as microscope, high doses enable material modification and sputtering. Compared to conventional focussed ion beams (FIB) using metal ions like Gallium, the HIM offers a very small focal spot size down to 0.35 nm and a strongly localized sputter interaction with the material. We employ the HIM for both milling nanopores in free standing membranes as well as for the inspection of pores. The He<sup>+</sup> beam with its unique properties overcomes the resolution limit of conventional FIB tools as we show in a comparison with a high resolution Ga-FIB. We achieve smallest He-milled nanopores with a diameter of about 4 nm in all investigated membranes: 30 nm thick Silicon Nitride, Graphene and 1 nm thick carbon nanomembranes (CNM) made from aromatic self-assembled monolayers by electron-induced cross-linking. Different strategies for the characterization of pores with the HIM will be discussed. In particular, we compare the feasibility of the ion generated secondary electron signal to the He<sup>+</sup> transmission signal.

DS 35.7 Thu 11:00 H 0111

**Doping of graphene on SiO<sub>2</sub> with N<sup>+</sup> and B<sup>+</sup> ions by low-energy ion irradiation.** — ●STEFFEN WEIKERT, JULIAN ALEXAN-

DER AMANI, and HANS CHRISTIAN HOFSSÄSS — II. Physikalisches Institut, Georg-August-Universität Göttingen, Deutschland

Its unique electrical properties make graphene a promising candidate for future electronic devices. An important milestone, especially for the industrial production of those devices, is the realization of a method for large-scale doping of graphene. A potential method for controlled doping of graphene, while minimizing the damage inflicted upon the sample, is low-energy ion irradiation.<sup>[1–3]</sup>

This work shows experiments on the irradiation of monolayer graphene on SiO<sub>2</sub> by N<sup>+</sup> and B<sup>+</sup> ions at 25 eV. For the experimental realization a mass-selected ion beam deposition system was used. <sup>[4]</sup> The irradiation was also simulated using the Monte Carlo program SDTrimSP. In addition to the irradiation of the graphene, I-V measurements were made before and after the irradiation.

[1] U. Bangert, W. Pierce, D. M. Kepaptsoglou, Q. Ramasse, R. Zan, M. H. Gass, J. A. Van den Berg, C. B. Boothroyd, J. Amani, and H. C. Hofssäss, *Nano Lett.* 2013, 13, 4902-4907.

[2] E. H. Åhlgren, J. Kotakoski, and A. V. Krashennnikov, *Phys. Rev. B* (2011), 83, 115424.

[3] Y. Xu, K. Zhang, C. Brüsewitz, X. Wu, and H. C. Hofssäss, *AIP Advances* (2013), 3, 072120.

[4] H. Hofssäss, H. Binder, T. Klumpp and E. Recknagel, *Diam. Relat. Mater.* (1994), 3, 137.

### 15 min. break.

DS 35.8 Thu 11:30 H 0111

**Field induced enhancement of refractive index and conductivity - a substrate effect in graphene** — ●MATTHIAS VAUPEL<sup>1</sup>, ANKE DUTSCHKE<sup>1</sup>, ULRICH WURSTBAUER<sup>2</sup>, and FRANK HITZEL<sup>3</sup> — <sup>1</sup>Carl Zeiss Microscopy GmbH, Königsallee 9-21, 37081 Göttingen, Germany — <sup>2</sup>Dept. of Physics, Columbia University New York, NY 10027, USA — <sup>3</sup>DME Nanotechnologie GmbH, D-38106 Braunschweig, Germany

We study the effect of different substrates, conductive Si vs. isolating SiO<sub>2</sub>, on the electro-optic properties of graphene layers. To this end phase profiles of graphene layers were recorded by total interference contrast (TIC) microscopy, while atomic force microscopy measured the topography of the layers [1]. An optical model consistent with the measured height and phase profile of graphene yields the refractive index  $N$  and conductivity of graphene. Extraordinary high  $N = 3.9 + 9.2i$  is obtained for the graphene on conductive substrate. The optical conductivity is 38 fold increased with respect to the reference value obtained on isolating substrate by TIC [1] and by ellipsometry [2]. These observations are mathematically consistent with the dielectric Drude function, which describes a damped harmonic electron oscillation with zero eigenfrequency and nonzero effective electron mass. The model applies for FETs and electro-optic devices made of graphene.

[1] M. Vaupel, A. Dutschke, U. Wurstbauer, F. Hitzel, A. Pasupathy, *J. Appl. Phys.* 114, (2013) 183107 [2] U. Wurstbauer, C. Röling, U. Wurstbauer, W. Wegscheider, M. Vaupel, P.H. Thiesen, D. Weiss, *Appl. Phys. Lett.* 97, (2010) 231901

DS 35.9 Thu 11:45 H 0111

**Charge and spin transport in graphene nanoribbons with adatoms and defects** — ●FLAVIANO JOSÉ DOS SANTOS<sup>1,2</sup>, FILIPE SOUZA MENDES GUIMARÃES<sup>1,2</sup>, and ROBERTO BECHARA MUNIZ<sup>1</sup> — <sup>1</sup>Institute of Physics, Universidade Federal Fluminense, Niterói, Brazil — <sup>2</sup>Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Several features of spintronic systems are related to the spin-orbit coupling (SOC). Since SOC is relatively small in carbon atoms, several studies have been conducted in order to obtain a way to increase SOC in graphene (e.g., via adsorption of impurities on the graphene surface), which would allow to employ graphene as a basic material for spintronic devices. We have studied the charge and spin transport in graphene nanoribbons, in the linear response regime, affected by the presence of defects (vacancies and edge constrictions) and adatoms. We used effective models for light and heavy adsorbed impurities, some of them inducing enhancement of the SOC [1]. The results are obtained through a combination of analytical and numerical derivations. We investigated the impact of impurity concentration on the establishment of topologically protected edge states giving rise to a spin polarized current flux through the sample. In addition to conductance, local densities of states and current distribution calculations, we also simulate maps of real space local conductance properties for dual-probe Scanning Tunneling Microscope [2] setups on these systems. [1] C.

Week *et al.*, *Phys. Rev. X* 1, 021001 (2011). [2] M. Settnes *et al.*, *Phys. Rev. Lett.* 112, 096801 (2014). Funding: Capes and CNPq (Brazil).

DS 35.10 Thu 12:00 H 0111

**Electronic properties of Co atoms on Graphene / Ir(111) by photoelectron spectroscopy** — ●MICHAEL HEBER<sup>1</sup>, MARKUS SCHOLZ<sup>1</sup>, ADRIAN BENZ<sup>1</sup>, DENIZA CHEKRYGINA<sup>1</sup>, MICHAEL MARTINS<sup>1</sup>, and WILFRIED WURTH<sup>1,2</sup> — <sup>1</sup>Physics Department and Center for Free-Electron Laser Science, Univ. Hamburg, 22761 Hamburg, Germany — <sup>2</sup>DESY Photon Science, 22607 Hamburg, Germany

Despite of the enormous achievements in our understanding of the interaction of deposited metal atoms with the underlying substrates, they still bear a variety of unexplored features. Recently, Graphene grown on metal substrates has proven to be a versatile template to create ordered arrays of adsorbed metal atoms. It was shown, that the electronic properties of adsorbed transition metal atoms strongly depend on the hybridization between the transition metal d-orbitals and the graphene  $\pi$ -band. The graphene  $\pi$ -band itself can hybridize with the valence states of the metal substrates. This opens a gateway to manipulate the adsorbate-Graphene interface itself and thus the electronic properties. We present core and valence level photoemission measurements of Co atoms deposited on Graphene/Ir(111) to obtain a detailed picture of the hybridization effects on the electronic structure of the metal atoms. This work is supported by the SFB 668 "Magnetism from single atoms to nanostructures"

DS 35.11 Thu 12:15 H 0111

**hydration of bilayered graphene oxide** — ●BITA REZANIA<sup>1</sup>, NIKOLAI SEVERIN<sup>1</sup>, ALEXANDR V TALYZIN<sup>2</sup>, and JÜRGEN P RABE<sup>1</sup> — <sup>1</sup>Humboldt University, Berlin, Germany — <sup>2</sup>Umeå University, Umeå, Sweden

Recently, it has been shown that graphene oxide (GO) membranes show remarkable selectivity in permeation of water molecules. This was attributed to the hydration of the membranes - the key to understand the water permeation mechanism. We investigated the change of the interlayer distance in bilayer GO as function of humidity and in liquid water using SFM [1]. The increase of relative humidity from 2 to \*80% results in gradual expansion of interlayer distance by approximately 1 Å. The immersion into liquid water results in increase of the interlayer distance by another 3 Å. Our results are in good agreement with the averaged distance measured by X-ray diffraction on multilayered graphite oxides, which is commonly explained with an interstratification model. However, our experimental design excludes effects connected to interstratification. We find that the hydration is a continuous process of incorporation of water molecules into various sites within the GO layers, while liquid water inserts as a monolayer. The similarity of hydration for our bilayer and previously reported multilayered materials implies GO few and even bilayers to be suitable for selective water transport.

[1] Rezania, B., *et al.* *Nano Lett.* 2014, 14, 3993.

DS 35.12 Thu 12:30 H 0111

**Humidity dependent oxygen transport through single layer graphene oxide** — ●MOHAMMAD FARDIN GHOLAMI, PHILLIP LANGE, NIKOLAI SEVERIN, and JÜRGEN P. RABE — Department of Physics and IRIS Adlershof, Humboldt-Universität zu Berlin, Newtonstr. 15, D-12489 Berlin, Germany

Graphene oxide (GO) is a strongly oxidized and nano-porous single sheet of graphene. Few layer thick GO membranes have been shown to exhibit molecular selective gas transport (H.W. Kim *et al.* and H. Li *et al.*, *Science*, 2013). The molecular selectivity is humidity dependent, which has been attributed to water molecules blocking either GO interlayers or pores. The latter would imply that also single layer GO may exhibit similar properties. Here we used the sensitivity of the fluorescence of thin films of a regioregular poly(3-hexylthiophene-2,5-diyl) to photo-oxidation in order to investigate the transport of oxygen through single layer GOs put on the polymer films by following its fluorescence decaying with time (P. Lange *et al.*, *J. Phys. Chem. C*, 2011). For samples exposed to humid mixtures of 80% nitrogen and 20% oxygen with 32% relative humidity we find that the fluorescence of the polymer covered by GO decays two times slower than the uncovered one. We did not observe any difference in the decay rates when the film was exposed to the corresponding dry gas mixture. We attribute the slower fluorescence decay of the polymer film covered by the humidified GO to slower permeation of oxygen molecules through GO pores clogged by the water molecules. This implies that even single layer GO can be

used as a humidity dependent molecular sieve.

DS 35.13 Thu 12:45 H 0111

**In-situ Creation of Reduced Graphene Oxide Paper on Substrates** — PENG LI<sup>1</sup>, MATTHIAS M. L. ARRAS<sup>2</sup>, FUPING DONG<sup>2</sup>, XIN WANG<sup>1,2</sup>, and KLAUS D. JANDT<sup>2</sup> — <sup>1</sup>Department of Materials Science, Key Laboratory of Automobile Materials of MOE, Jilin University, Changchun, 130012, P. R. China — <sup>2</sup>Chair of Materials Science (CMS), Otto Schott Institute of Materials Research, Friedrich Schiller University Jena, Jena, Germany

Generally, the synthesis conditions of reduced graphene oxide pa-

per (rGOP) require special substrates for its fabrication and, thus, it must often be transferred to application-suitable substrates, afterwards. Here, we tested the hypothesis that rGOP can be synthesized in-situ, e.g., on a polymer substrate, by using a mild step-by-step annealing of graphene oxide hydrosol. By applying the step-by-step annealing at 60, 100 and 160°C for 12 h, shiny and non-crimpling rGOP was created on polymer and glass substrates. The rGOP was characterized by Raman, infra red and X-ray photoelectron spectroscopy, as well as by optical and electron microscopy. Based on the results, a simple formation mechanism for the rGOP was proposed. The presented method will allow to equip surfaces with rGOP functionality directly and is also suitable for a patterned functionalization.