

HL 101: Graphene: Preparation and characterization II (O, jointly with HL, TT)

Time: Friday 10:30–13:00

Location: H17

HL 101.1 Fri 10:30 H17

Engineering of 2D-Nanomaterials by Swift Heavy Ion Irradiation — ●OLIVER OCHEDOWSKI, HANNA BUKOWSKA, SEVILAY AKCÖL-TEKIN, and MARIKA SCHLEBERGER — Universität Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg

Two dimensional (2D) nanomaterials prepared from layered crystal materials have attracted a great amount of interest in multiple fields of science. These nanomaterials can be metallic (e.g. graphene), semi-conducting (MoS₂) or insulating (Mica) with properties often different from their bulk counterparts. Here, we will demonstrate how the morphology of several 2D-nanomaterials can be modified by swift heavy ion (SHI) irradiation in the MeV regime under glancing incidence angle. The induced modifications are investigated by means of atomic force microscopy. In the case of graphene we will show by Kelvin probe force microscopy how SHIs can be used to alter the electronic structure and induce doping of the graphene.

HL 101.2 Fri 10:45 H17

Fabrication of laterally structured graphene/carbon nanomembrane hybrids — ●ANDREAS WINTER¹, STEFAN WUNDRACK², RAINER STOSCH², and ANDREY TURCHANIN¹ — ¹Universität Bielefeld, 33615 Bielefeld — ²Physikalisch-Technische Bundesanstalt, 38116 Braunschweig

Laterally structured free-standing micro- and nanostructures of single-layer graphene (SLG) embedded into dielectric sheets with a thickness comparable to graphene are of great interest for applications in electronic or optoelectronic devices. However, their fabrication is not a trivial task at present. Here, we demonstrate how such hybrids can be engineered using electron-irradiation-induced crosslinking of graphene micro-/nanostructures with carbon nanomembranes (CNMs). CNMs are a dielectric 2D carbon material with the thickness of about 1 nm consisting of cross-linked randomly oriented benzene rings. We show scalable production of well-defined laterally patterned CNM-SLG hybrids of various architectures and characterize their structural, chemical and electronic quality by complementary spectroscopic and microscopic techniques including helium ion microscopy and Raman spectroscopy. Application areas of the generated hybrids will be discussed.

HL 101.3 Fri 11:00 H17

Non-destructive chemical functionalization of single-layer graphene for electronic applications — MIROSLAW WOSZCZYNA¹, MIRIAM GROTHE¹, ANDREAS WINTER², ANNIKA WILLUNAT¹, STEFAN WUNDRACK¹, RAINER STOSCH¹, FRANZ AHLERS¹, THOMAS WEIMANN¹, and ●ANDREY TURCHANIN² — ¹Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — ²Faculty of Physics, University of Bielefeld, 33615 Bielefeld, Germany

Chemical functionalization of single-layer graphene (SLG) is of key importance for implementations of this material in functional electronic devices such as, e.g., field effect transistor (FET) based nanosensors. However, the electronic quality of graphene typically degrades after the functionalization with presently employed methods, significantly restricting the application areas. Here, we present a route to non-destructive chemical functionalization of graphene via engineering of carbon nanomembrane (CNM)/SLG hybrids. We employ SLG, grown by methane CVD on Cu foils, and amino-terminated 1 nm thick CNMs, generated by electron-beam-induced crosslinking of aromatic self-assembled monolayers, to fabricate hybrid CNM/SLG FETs on oxidized silicon wafers. Structural, chemical and electronic properties of these devices are characterized by Raman spectroscopy, X-ray photoelectron spectroscopy and electrical transport measurements. We unambiguously show that the intrinsically high electronic quality of pristine SLG is preserved in the amino-functionalized hybrids opening broad avenues for their use in graphene-based FETs.

HL 101.4 Fri 11:15 H17

Etching Nanoscale tunnels into graphite- a new route to produce suspended graphene — ●MAYA LUKAS¹, VELIMIR MEDED¹, ARAVIND VIJAYARAGHAVAN^{1,2}, LI SONG^{3,4}, PULICKEL M. AJAYAN⁴, KARIN FINK¹, WOLFGANG WENZEL¹, and RALPH KRUPKE^{1,5} — ¹Karlsruhe Institute of Technology (KIT), Institute of Nanotechnology, D-76021 Karlsruhe — ²School of Computer Science, The University of Manchester, UK — ³Research Center for Exotic Nanocarbons,

Shinshu University, Nagano, Japan — ⁴Department of Mechanical Engineering & Materials Science, Rice University, Houston, TX, USA — ⁵Department of Materials and Earth Sciences, Technische Universität Darmstadt, D-64287 Darmstadt

Catalytic hydrogenation of graphite, although known since the 1970s, has recently attracted renewed attention, as a route for nanopatterning of graphene and to produce graphene nano-ribbons. These reports show that metallic nanoparticles etch surface layers of graphite or graphene anisotropically along the crystallographic zigzag <11-20> or armchair <1010> directions.

We report the sub-surface etching of highly oriented pyrolytic graphite (HOPG) by Ni nanoparticles, to form a network of tunnels, as seen by SEM and STM. The layers on top of tunnels which are only a few layers below the surface bend inward, while their local density of states remains fundamentally unchanged. Our work opens a new route to produce suspended graphene for the study of fundamental mechanical and electronic properties. M. Lukas, V. Meded *et al.*, *Nat. Commun.* accepted for publication

HL 101.5 Fri 11:30 H17

Direct e-beam writing of single-layer graphene nanostructures — ●NILS-EIKE WEBER¹, HENNING VIEKER¹, STEFAN WUNDRACK², RAINER STOSCH², and ANDREY TURCHANIN¹ — ¹Fakultät für Physik, Universität Bielefeld — ²Physikalisch-Technische Bundesanstalt, Braunschweig

We demonstrate direct writing of single-layer graphene nanostructures employing electron irradiation of aromatic self-assembled monolayers (SAM) and subsequent annealing. The process consists of the following technological steps: (i) formation of an aromatic SAM on a Cu substrate; (ii) electron-beam-irradiation of the SAM resulting in locally cross-linked SAM areas; (iii) conversion of these areas into single-layer graphene via annealing. In this way graphene nanostructures of various architectures are directly defined in the SAM by electron beam lithography reducing several manufacturing steps, which are typically applied for the patterning of two-dimensional sheets including graphene (baking and developing electron-beam resist, plasma etching, resist striping). The formed nanostructures were characterized by Raman spectroscopy, scanning electron and helium ion microscopy. We demonstrate their successful transfer from the original copper foils onto oxidized silicon wafers, where they can directly be integrated into electronic devices.

HL 101.6 Fri 11:45 H17

Understanding of the imaging contrast in STM/NC-AFM of graphene on metals — ●ELENA VOLOSHINA¹, EDOARDO FERTITTA¹, ANDREAS GARHOFER², FLORIAN MITTENDORFER², MIKHAIL FONIN³, TORBEN HAENKE⁴, OLIVER SCHAFF⁴, THORSTEN KAMPEN⁴, ANDREAS THISEN⁴, and YURIY DEDKOV⁴ — ¹Physikalische und Theoretische Chemie, Freie Universität Berlin, 14195 Berlin, Germany — ²Institute of Applied Physics, Vienna University of Technology, Gusshausstr. 25/134, 1040 Vienna, Austria — ³Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany — ⁴SPECS Surface Nano Analysis GmbH, Voltastraße 5, 13355 Berlin, Germany

Realization of graphene moiré superstructures on the surfaces of 4d and 5d transition metals offers templates with periodically modulated electron density, which is responsible for a number of fascinating effects, including the formation of quantum dots and the site selective adsorption of organic molecules or metal clusters on graphene. Here, applying the combination of scanning probe microscopy/spectroscopy and the density functional theory calculations, we gain a profound insight into the electronic and topographic contributions to the imaging contrast of the epitaxial graphene/Ir(111) system. We show directly that in STM imaging the electronic contribution is prevailing compared to the topographic one. In the force microscopy and spectroscopy experiments we observe a variation of the interaction strength between the tip and high-symmetry places within the graphene moiré supercell, which determine the adsorption sites for molecules or metal clusters on graphene/Ir(111).

HL 101.7 Fri 12:00 H17

Precise imaging of graphene — ●THOMAS HOFMANN, ALFRED J. WEYMOUTH, JOACHIM WELKER, and FRANZ J. GIESSBL — Institut

für Experimentelle und Angewandte Physik, Universität Regensburg
Atomic imaging of graphene with a scanning probe microscope is challenging due to its small atomic lattice. We show that metallic tips, which have been characterized prior to the measurement, cannot truthfully image the graphene surface due to their large, non-spherical electron density [1]. Calculations predict that the metal tip atom strongly interacts with the graphene surface [2]. Carbon oxide front atom identification (COFI) [2] shows that contact of a clean metal tip with graphene can lead to graphene flakes attaching to the tip apex. This results in blurred images and multi-valley force versus distance curves. As a solution we use a metal tip, functionalized with an inert carbon monoxide molecule as suggested by Gross et al. [3]. The closed-shell nature of the CO drastically reduces the attraction between tip and graphene. Additionally, the small size of the CO allows truthful imaging of the graphene surface.

[1] *J. Welker, and F. J. Giessibl, *Science* 336, 6080 (2012)

[2]*M. Ondráček, P. Pou, V. Rozsival, C. González, P. Jelínek, and R. Pérez, *PRL* 106, 176101 (2011)

[3]*L. Gross, F. Mohn, N. Moll, P. Liljeroth, and G. Meyer, *Science* 325, 5944 (2009)

HL 101.8 Fri 12:15 H17

Role of substrate-molecular interactions in arrangement and collective motion of fullerene islands on graphene — ●MARTIN SVEC¹, PABLO MERINO², YANNICK DAPPE³, CESAR GONZALEZ¹, ENRIQUE ABAD⁴, PAVEL JELINEK¹, and JOSE-ANGEL MARTIN-GAGO⁵ — ¹Institute of Physics, ASCR, Prague, CZ — ²CAB INTA-CSIC, Madrid, ES — ³CEA, IRAMIS, SPCSI, FR — ⁴UAM, Madrid, ES — ⁵ICMM-CSIC, Madrid, ES

Fullerenes interacting with graphene are a model system, that should be entirely driven by van der Waals (vdW) interactions. We concentrate on the interactions occurring between fullerenes and the single-layer graphene grown on SiC(0001) [1]. By using a VT-STM at 40K, regular islands of fullerenes were found. The particular orientation of the fullerenes in the islands, which occupy 4x4 graphene unit cells each, is critically evaluated by a comparison of STM measurements to extensive STM simulations with realistic fullerene-terminated tips. The determined orientation of fullerenes is independently confirmed by complex theoretical calculations of several adsorption configurations, taking into account the vdW interaction between the constituents of this system. Furthermore, islands of fullerenes were found collectively moving on the graphene. Surprisingly, according to the theory, the cohesion among the fullerenes is weaker than adhesion to the surface. Nevertheless, cohesion is a decisive factor in the collective motion, thanks to a low diffusion barrier of fullerenes on graphene.

[1] M. Švec et al., *Phys. Rev. B* 86 121407(R)(2012)

HL 101.9 Fri 12:30 H17

XPS Analysis of Wet-Chemically Prepared Graphene Oxide

— ●OLE LYTKEN, MICHAEL RÖCKERT, JIE XIAO, CHRISTIAN PAPP, HANS-PETER STEINRÜCK, SIEGFRIED EIGLER, MICHAEL ENZELBERGER, STEFAN GRIMM, PHILIPP HOFMANN, WOLFGANG KROENER, CHRISTOPH DOTZER, PAUL MÜLLER, and ANDREAS HIRSCH — Universität Erlangen-Nürnberg

Graphene is one of the most studied materials of the last few years, but large scale production of high-quality graphene remains a challenge. One approach to a large scale production of graphene is the oxidation of graphite to graphite oxide, which can be exfoliated to graphene oxide and subsequently reduced to graphene. The challenge of this method is to keep the carbon structure intact during oxidation. We report on the XPS analysis of graphene oxide produced by a mild synthesis method that keeps the carbon structure intact and allows the reduction back to high-quality graphene. Only carbon with a single bond to one neighboring oxygen atom is observed (e.g. alcohols, expoxides or ethers), but no carbonyl (C=O) or carboxyl (-COOH) groups are found. Some common problems related to the interpretation of graphene oxide XPS spectra in the presence of charging and sulfur impurities will be touched upon.

Support by the SFB 953 and the Alexander-von-Humboldt Foundation is gratefully acknowledged.

HL 101.10 Fri 12:45 H17

Morphological and Electronic Study of Moiré Patterns due to Dislocated Graphene on HOPG — ●DILEK YILDIZ¹, ŞENER ŞEN², OĞUZ GÜLSEREN², and OĞUZHAN GÜRLÜ¹ — ¹Istanbul Technical University, Istanbul, Turkey — ²Bilkent University, Ankara, Turkey

Highly oriented pyrolytic graphite (HOPG) is widely used as a calibration sample for scanning tunneling microscopy (STM) studies. It is also used as a substrate in surface science because of its smooth surface. HOPG is composed of stacked two dimensional hexagonal lattices formed by carbon atoms, popularly named as graphene layers. Because of the weak van der Waals bonding between the graphene layers, the topmost layer may be shifted or rotated on HOPG. Due to the rotation of the top layer, super-periodic structures called as Moiré patterns form on HOPG. These formations were investigated in numerous studies; however, they are rediscovered in graphene research and their origin is still not understood. In this study we used different solvents to see their effects on HOPG samples and the formation of super-periodic structures on these surfaces. We investigate the morphological and electronic properties by using scanning tunneling microscopy and spectroscopy (STM and STS) under ambient conditions. We compared electronic properties of Moiré patterns due to their periodicities. In order to shed light onto the observed electronic structures we also performed ab initio calculations on these super periodic structures. (Supported by TUBITAK 109T687 and ITU-BAP 33263).