TT 70: Graphene: Electronic Properties
(Joint session of DS, DY, HL, MA, O and TT organized by O)

Time: Thursday 10:30–12:45   Location: S053

TT 70.1   Thu 10:30   S053
PEEM of epitaxial graphene on silicon carbide — •Richard Hönig, Christoph Keutner, Cornelis Hilscher, Ulf Berges, and Carsten Westphal — Experimentelle Physik I, TU Dortmund, Otto-Hahn-Straße 4, 44227 Dortmund, Germany

Graphene is a promising candidate for two-dimensional electronic structures. Especially epitaxial graphene on silicon carbide (SiC) is in the focus of current studies, due to the well-established infrastructure for SiC in the semiconductor-industry.

We present photoemission electron microscopy (PEEM) studies of epitaxial graphene, grown by confinement controlled sublimation (CCS). This technique is a suitable tool for producing large areas of homogeneous graphene. The resulting flake-sizes of graphene exceed the resolution of scanning tunneling microscopy. However, the PEEM-technique provides a better suited resolution up to the mesoscopic scale. Hence, PEEM was chosen to study and characterize these graphene/SiC-samples.

Here, we will demonstrate the first characterization procedures and results. In the future, samples with an adequate amount of graphene will be used for further studies, including the real-time imaging of intercalation-processes.

TT 70.2   Thu 10:45   S053
Graphene growth on structured SiC — •Alexander Stöhr[1], Jens Baringhaus[2], Aleixei Zakharov[3], Christoph Tegenkamp[2], and Ulrich Starke[1] — [1]Max-Planck-Institut für Festkörperforschung, Stuttgart, Deutschland — [2]Leibniz-Universität Hannover, Hannover, Deutschland — [3]MAX IV Laboratory, Lund University, Lund, Schweden

Despite its missing band gap, graphene is reviewd as a potential successor of silicon for applications in logical devices. Nowadays, few techniques are available to introduce a band gap into the band structure of graphene. One of the most promising methods is the confinement of its charge carriers into quasi one-dimensional stripes, so called graphene nanoribbons. Unfortunately, the usual approach to structure graphene by lithography techniques leads to disorder and defects at the edges of the nanoribbons, which then dominat the electronic states of the ribbon. To circumvent this problem, we structure our SiC-crystal prior to the graphene growth. After the growth process a faceting of the sidewalls by 23-28° was observed by AFM. On those areas which are inclined towards the non-structured surface, diffraction spots and a π-band were observed in microscopic LEED and ARPES, respectively. Those experimental findings confirm the growth of ordered graphene on the facets.

TT 70.3   Thu 11:00   S053
A new candidate for silicon carbide (3x3) surface reconstruction — •Jan Kloppenburg[1,3], Lydia Nemec[2,3], Björn Lange[4], Matthias Scheffler[3], and Volker Blum[4] — [1]Université catholique de Louvain — [2]Technische Universität München — [3]FHI Berlin — [4]Duke University

Silicon carbide (SiC) is a primary substrate for high quality epitaxial graphene growth. Graphene growth on SiC(000-1) surface is significantly different from the well controlled monolayer graphene growth on the silicon face. On the carbon face, a (3x3) surface as a precursor phase precedes graphene growth changing the thermodynamics compared to the Si-face[1]. Despite more than a decade of research the precise atomic structure of the (3x3) surface reconstruction of SiC(000-1) is still not clear. Here, we employ an *ab initio* random structure search (AIRSS) based on van-der-Waals corrected PBE density functional theory (DFT) to identify the reconstruction in the C-rich range. Our search reveals a new lowest energy surface reconstruction model for the C-rich SiC(000-1) face that was not previously reported[2] and that would explain the very different graphitization behaviour compared to the Si-face. Simulated STM images are in excellent agreement with previously reported experimental findings[3,4].
[1] Nemec et al, *Phys. Rev. Lett.* **111**, 065502, 2013
[2] Nemec et al, *Phys. Rev. B* **91**, 161408, 2015
[3] Hiebel et al, *Phys. Rev. B* **80**, 235429, 2009
[4] Hiebel et al, *Phys. Rev. B* **45**, 154003, 2011

TT 70.4   Thu 11:15   S053
Characterisation of Graphene Electrodes — •Markus Manz[1], Martin Lottner[1], Martin Stutzmann[1], and Jose Garrido[1,2] — [1]Walter Schottky Institut, Technische Universität München, Garching, Germany — [2]Catalan Institute of Nanoscience and Nanotechnology, Barcelona, Spain

The biocompatibility and flexibility of graphene devices allow for long-term in vivo detection of action potentials [1]. Thus, graphene has a serious advantage over former approaches [2] using other materials, which are rigid or brittle. Furthermore, the transparency of graphene micro electrodes allows for simultaneous optical stimulation/imaging and electrical recording [1]. While graphene has a high in plane conductivity, the out of plane conductivity of undoped single layer graphene (SLG) is rather low. This is a major drawback for the detection of neurotransmitters through their respective redox reactions. Therefore, various methods have been developed to increase the out of plane conductivity and 'activate' [3] the SLG electrodes. We investigated two methods of graphene 'activation', namely ozonization and doping with nitric acid. We characterized the modified electrodes using cyclic voltammetry, impedance spectroscopy, and Raman spectroscopy. We then compared the sensitivity of the untreated and 'activated' electrodes towards the neurotransmitters norepinephrine and dopamine.
[1] Kuzum, D. et al., Nat. Commun. 5:5259doi: 10.1038/ncomms6259 (2014). [2] Kwon, K. Y. et al. in Biomedical Circuits and Systems Conference (BioCAS), 2012 IEEE 164-167 (2012). [3] Kasry, A. et al., ACS Nano 4, 3839-3844 (2010).

TT 70.5   Thu 11:30   S053
Ultraclean Freestanding Graphene by Pt-metal catalysis — •Jean-Nicolas Longchamp, Conrad Escher, and Hans-Werner Fink — Physics Department of the University of Zurich, Winterthurerstrasse 190, CH-8057 Zürich, Switzerland

When using graphene as a substrate in electron microscopy, the presence of residues is obstructive because the latter are often of the same size as the object under study. While the growth of defect-free single-layer graphene by means of chemical vapor deposition (CVD) is nowadays a routine procedure, easily accessible and reliable techniques to transfer graphene to different substrates in a clean manner are still lacking. We have discovered a method for preparing ultraclean freestanding graphene using the catalytic properties of platinum metals. Complete catalytic removal of a sacrificial PMMA layer only requires annealing in air at a temperature between 175°C and 350°C. Here, we will describe in detail the preparation process for obtaining ultraclean freestanding graphene by Pt-metal catalysis. The presentation of low-energy electron holography and TEM investigations will demonstrate that areas of ultraclean freestanding graphene as large as 2 microns square can now routinely be prepared.

TT 70.6   Thu 11:45   S053
Nano-scaled graphene solution-gated field-effect transistors — •Peter Knecht[1], Benno Martin Blaschke[1], Karolina Stoiber[1], Martin Letter[1], Simon Drieschner[1], and Jose Antonio Garrido[2] — [1]Walter Schottky Institut, TU München, Garching, Germany — [2]Catalan Institute of Nanoscience and Nanotechnology, Barcelona, Spain

Graphene solution-gated field-effect transistors (SGFETs) are a promising biosensing platform, due to their unique properties such as high charge carrier mobility, low electronic noise, good electrochemical performance and an excellent biocompatibility. The recording of cell action potentials using graphene SGFETs has already been demonstrated. However, the sensing area of several hundred square micrometer is not small enough to resolve potential changes on a subcellular level. In this work, we present the fabrication of nano-scaled graphene SGFETs where the transistor area is reduced to 0.01 square micrometer. The dependence of the transistor's transconductance and the electronic low frequency noise on size and shape of the sensing area is studied. In addition, we investigate if the reduced device size leads to a more pronounced dependence of the device's performance on the graphene quality. Finally, the recording of cell action potentials using the nano-scaled devices is demonstrated and compared to micro-scaled graphene SGFETs.

TT 70.7 Thu 12:00 S053

Graphene wrinkles: their conductivity, crystallinity, and reactivity — ●Raul D. Rodriguez[1,2], Tao Zhang[3], Jana Kalbacova[1,2], Devang Parmar[1], Akhil Nair[1], Zoheb Khan[1], Mahfujur Rahaman[1], Ihsan Amin[2], Jacek Gasiorowski[1], Evgeniya Sheremet[1], Rainer Jordan[2], Michael Hietschold[1], and Dietrich R.T. Zahn[1,2] — [1]Institut für Physik, Technische Universität Chemnitz, Chemnitz 09107, Germany — [2]Center for Advancing Electronics Dresden (cfaed), Germany — [3]Professur für Makromolekulare Chemie, Department Chemie, Technische Universität Dresden, Mommsenstrasse 4, 01062 Dresden, Germany

Wrinkles appear to be unavoidable in graphene produced by chemical vapor deposition (CVD) on copper. Despite its generality, isolating the role of wrinkles on overall electrical conductivity, crystallinity, and chemical reactivity of CVD-grown graphene remains an open issue. We investigate the reactivity of basal planes and wrinkles in graphene with polystyrene bromide (PSBr) and correlate it with electrical conductivity, defect concentration, and doping with a special resolution from the micro- to the nano-scale. We show that wrinkles dominate the chemical reactivity of CVD graphene, and moreover, that doping with the same functionality can yield opposite electronic type to the basal plane regions (n- vs. p-type). These results expand our understanding of wrinkles in CVD graphene towards engineering for novel applications.

TT 70.8 Thu 12:15 S053

Conversion of pyrrolyl-thiophenol self-assembled monolayers (SAMs) into carbon nanomembranes (CNMs) and graphene — ●Christof Neumann[1], Matthias Füser[2], Michael Mohn[3], Ute Kaiser[3], Andreas Terfort[2], and Andrey Turchanin[1] — [1]Institute of Physical Chemistry, Friedrich Schiller University Jena, 07743 Jena — [2]Institute of Inorganic and Analytical Chemistry, Goethe University Frankfurt, 60348 Frankfurt — [3]Electron Microscopy Group of Materials Science, Ulm University, 89081 Ulm

The conversion of aromatic self-assembled monolayers (SAMs) into carbon nanomembranes (CNMs) and graphene presents a promising pathway to the production of a broad variety of functional 2D materials [1]. The properties of these materials can be flexibly tuned via an appropriate choice of the molecular building units for SAMs. Here we investigate the conversion of 4-(1H-pyrrol-1-yl)thiophenol and 4-(2,5-dimethyl-1H-pyrrol-1-yl)thiophenol SAMs on polycrystalline copper foils into CNMs via the electron induced crosslinking. Furthermore, we study the pyrolytic transformation of these CNMs into graphene at temperatures up to 800 °C. We characterize these different conversion steps and the resulting physical and chemical properties of CNMs and graphene by a number of complementary experimental techniques including X-ray photoelectron and Raman spectroscopy, high-resolution transmission electron and helium ion microscopy as well as by electric transport measurements. [1] P. Angelova et al.,: A Universal Scheme to Convert Aromatic Molecular Monolayers into Functional Carbon Nanomembranes, ACS Nano 7, 6489 (2013)

TT 70.9 Thu 12:30 S053

Extracellular stimulation of electrogenic cells using graphene devices — ●Karolina Stoiber[1], Martin Lottner[1], Markus Manz[1], Simon Drieschner[1], Benno Blaschke[1], Martin Stutzmann[1], and José A. Garrido[1,2] — [1]Walter Schottky Institut, Technische Universität München, Garching, Germany — [2]Catalan Institute of Nanoscience and Nanotechnology, Barcelona, Spain

Graphene is a highly conductive, chemically stable, flexible and biocompatible material. Therefore, Graphene microelectrode arrays (GMEAs) are a promising bio-sensing and cell stimulation platform in neural implants. In this work, the electrical stimulation of HEK293 and HL1 cells through extracellular voltage trains by GMEAs is presented. Further, the investigation of the biocompatibility of graphene foam and its capability for extracellular stimulation is discussed.

GMEAs with circular electrodes were fabricated using standard photo-lithography techniques. For the characterization of the devices Raman-spectroscopy and cyclic voltammetry were used. The cell membrane potential of HEK293 cells was monitored during extracellular stimulation via patch-clamping. HL1 cells, a cardiomyocyte-like cell line, were dyed with a calcium-sensitive fluorophore and the modulation of their firing frequency upon stimulation was recorded.

Graphene foam devices were fabricated as previously described. The devices were characterized electrochemically and their capability for extracellular stimulation of HL1 cells tested.