

## TT 97: Graphene: Structure (jointly with O, HL)

Time: Thursday 10:30–13:00

Location: MA 041

TT 97.1 Thu 10:30 MA 041

**Manganese Intercalation in Graphene/Ir(111): a structural study** — ●STEFAN BÖTTCHER<sup>1</sup>, HENDRIK VITA<sup>1</sup>, YURIY S. DEDKOV<sup>2</sup>, and KARSTEN HORN<sup>1</sup> — <sup>1</sup>Fritz-Haber Institute, Faradayweg 4-6, 14195 Berlin — <sup>2</sup>SPECS Surface Nano Analysis GmbH, Voltastrasse 5, 13355 Berlin

The graphene/substrate interaction is of interest for a many applications, and to understand and classify the interaction mechanism as such. For example, the 3d transition metals Fe, Co and Ni on the one hand, and Cu on the other suggest that a classification into strongly and weakly interacting systems may be possible, as judged by criteria such as the survival of the Dirac cone or the crystallographic structure of the graphene layer. Here we present a structural study, through LEED and STM, of manganese intercalation on graphene/Ir(111), a system that has so far not been studied. We follow the stages of the intercalation process, from the deposition of Mn on top through the formation of the intercalated phase. Manganese is found to be arranged pseudomorphically to the Ir(111) substrate underneath graphene. While several criteria for a weak interaction are fulfilled, the graphene/Mn/Ir(111) system also shows structural evidence for a strong interaction between the graphene and the Mn layer, e.g. a lower separation between graphene and the intercalated layer, a conclusion that is further supported by ARPES. Manganese intercalation may therefore be special because it fills the gap between the strongly and weakly interacting transition metals. In addition, at higher intercalation temperatures a new, possibly surface alloyed phase is observed.

TT 97.2 Thu 10:45 MA 041

**Manganese Intercalation in Graphene/Ir(111): electronic structure** — ●HENDRIK VITA<sup>1</sup>, STEFAN BÖTTCHER<sup>1</sup>, YURIY DEDKOV<sup>2</sup>, and KARSTEN HORN<sup>1</sup> — <sup>1</sup>Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — <sup>2</sup>SPECS Surface Nano Analysis GmbH, Berlin, Germany

Transition metal surfaces are ideal templates for the growth of high quality graphene films. The system graphene/Ir(111) shows rather weak interaction between substrate and the graphene layer. It is well known that transition metals such as Ni and Co, intercalated under graphene/Ir(111), show a rather strong interaction with graphene, yielding massive modifications of the graphene  $\pi$ -band. The intercalation of Mn thin films underneath graphene seems interesting in this context, since Mn has a half filled 3d shell, and the graphene sheet may act as an inert, passivating cover. Here we investigate graphene/Mn/Ir(111) by deposition on top of graphene/Ir(111), and follow the intercalation process by annealing at moderate temperatures using XPS. Investigating the band structure by high resolution ARPES, the Dirac cone is preserved, and we observe a trigonal suppression of the replica Dirac cones, probably due to an enhanced corrugation of the graphene film. A totally different situation occurs if the intercalation process is performed at much higher temperatures. Drastic changes in the band structure emerge, with a shifted  $\pi$ -band to higher binding energies, and a chemical shift of the C1s core level. Additionally, a restructuring of the intercalated Mn thin film is observed by LEED.

TT 97.3 Thu 11:00 MA 041

**Atomically Resolved Graphitic Surfaces in Air by Atomic Force Microscopy** — ●DANIEL S. WASTL, ALFRED J. WEYMOUTH, and FRANZ J. GIESSIBL — University of Regensburg, Universitätsstrasse 31, 93053 Regensburg, Germany

Imaging at the atomic scale with atomic force microscopy in biocompatible environments is an ongoing challenge. We demonstrate here atomic resolution of graphite and hydrogen-intercalated graphene on SiC in air. The main challenges arise from the overall surface cleanliness and the water layers which form on almost all surfaces. To further investigate the influence of the water layers, we compare data taken with a hydrophilic bulk-silicon tip to a hydrophobic sapphire tip. While atomic resolution can be achieved with both tip materials at moderate interaction forces, the strong differences in force versus distance spectra can be related to the water layers on the tips and samples. Imaging at very low tip-sample interaction forces results in the observation of large terraces of a naturally-occurring stripe struc-

ture on the hydrogen intercalated graphene[1]. This structure has been previously reported on graphitic surfaces that are not covered with disordered adsorbates in ambient conditions (i.e. on graphite and bilayer graphene on SiC[3], but not on monolayer graphene on SiC). Both these observations indicate that hydrogen-intercalated graphene is close to an ideal graphene sample in ambient environments.

[1] Wastl, Weymouth, Giessibl, ACS Nano 8, 5233 (2014).

[2] Wastl Weymouth, Giessibl, Phys. Rev. B 87, 245415 (2013).

[3] Wastl et al., ACS Nano 7, 10032 (2013).

TT 97.4 Thu 11:15 MA 041

**A route to free-standing graphene by removal of the Ni substrate by a gas phase reaction** — ●ANN-KATHRIN HENSS<sup>1</sup>, PATRICK ZELLER<sup>1</sup>, MICHAEL WEINL<sup>2</sup>, MATTHIAS SCHRECK<sup>2</sup>, and JOOST WINTTERLIN<sup>1</sup> — <sup>1</sup>Ludwig-Maximilians-Universität, Munich, Germany — <sup>2</sup>Universität Augsburg, Augsburg, Germany

An essential step for the use of graphene in electronic devices is the removal of the underlying metal substrate after graphene growth. We have tested a new route to free-standing graphene grown on thin single crystalline Ni(111) films. The 150 nm thick metal films were epitaxially grown on a Si(111) wafer separated by a 120 to 150 nm thick yttria-stabilized zirconia (YSZ) buffer layer. Aligned monolayer graphene was grown by chemical vapor deposition using ethylene as precursor gas under ultra high vacuum conditions. The graphene quality was monitored by scanning tunneling microscopy and low energy electron diffraction. The subsequent removal of the nickel substrate was performed in a pure gas phase reaction. In the so called Mond process, a chemical transport reaction, nickel reacts with carbon monoxide to gaseous nickel tetracarbonyl at 350 K. By applying a temperature gradient in the reaction furnace the formed carbonyl complex is transported to areas with higher temperature leaving graphene on the isolating YSZ buffer layer of the substrate. X-ray photoelectron spectroscopy, scanning electron microscopy and Raman spectroscopy were used to study the samples after this process.

TT 97.5 Thu 11:30 MA 041

**Freestanding lateral nanostructures of two-dimensional carbon materials** — ●ANDREAS WINTER<sup>1</sup>, YASIN EKINCI<sup>2</sup>, RAINER STOSCH<sup>3</sup>, THOMAS WEIMANN<sup>3</sup>, JOHANNES BISKUPEK<sup>4</sup>, UTE KAISER<sup>4</sup>, and ANDREY TURCHANIN<sup>1</sup> — <sup>1</sup>Faculty of Physics, Bielefeld University, 33615 Bielefeld, Germany — <sup>2</sup>Laboratory for Micro- and Nanotechnology, Paul Scherrer Institut, 5232 Villigen, Switzerland — <sup>3</sup>Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — <sup>4</sup>Electron Microscopy Group of Materials Science, Ulm University, 89081 Ulm, Germany

Two-dimensional (2D) carbon materials like graphene, hexagonal boron nitride or carbon nanomembranes (CNMs) have recently attracted enormous interest due to their potential use in electronics, chemical and biological sensors, nanofilters, hybrid materials etc. Most applications require a lithographic patterning of these 2D materials. Here we present various micro- and nanostructures of graphene and CNMs as well as their in-plane heterostructures fabricated via optical, e-beam and EUV interference lithography. The preparation of these structures on supporting substrates as well as large area freestanding nanomembranes with patterns varying from ca. 100  $\mu\text{m}$  to 50 nm will be shown. Via electron irradiation, graphene and dielectric CNMs can be stitched together, forming electrically heterogeneous ultrathin 2D carbon sheets. We characterize their properties employing X-ray photoelectron and Raman spectroscopy, helium ion microscopy and high-resolution TEM.

TT 97.6 Thu 11:45 MA 041

**Graphene Membranes as Electron Transparent Windows for Photoelectron Spectroscopy** — ●JÜRGEN KRAUS<sup>1</sup>, ROBERT REICHEL<sup>1</sup>, SEBASTIAN GÜNTHER<sup>1</sup>, LUCA GREGORATTI<sup>2</sup>, MATTEO AMATI<sup>2</sup>, MAYA KISKINOVA<sup>2</sup>, ALEXANDER YULAEV<sup>4</sup>, IVAN VLASSIOUK<sup>3</sup>, and ANDREI KOLMAKOV<sup>4</sup> — <sup>1</sup>TU München Chemie Department, Lichtenbergstr. 4, D-85748 Garching — <sup>2</sup>Sincrotrone Trieste, Area Science Park, 34149 Trieste, Italy — <sup>3</sup>Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA — <sup>4</sup>Center for Nanoscale Science and Technology, NIST, Gaithersburg, MD 20899, USA

The high mechanical stability of graphene (g) allows the construction

of ultrathin gas tight membranes. Transferred few layer thick g covering the orifice of an environmental cell could be used to seal a water droplet inside the cell from the surrounding vacuum of the ultra-high vacuum chamber into which the cell was introduced. The used membranes were transparent even for slow photoelectrons (PEs), so that the sealed water could be characterized by x-ray photoelectron spectroscopy (XPS). We also measured the electron attenuation length of monolayer g on Cu for PEs of 200-1000 eV kinetic energy. We were able to produce free standing monolayer g by locally electrochemically etching the Cu-substrate underneath the as-grown g. After deposition of gold on the membrane backside and acquiring Au 4f PEs from the opposite site, we proved that  $< 1\%$  of a monolayer Au can be detected through the suspended g membrane. This pushes the applicability of our membrane based XPS technique towards surface characterization under ambient conditions.

TT 97.7 Thu 12:00 MA 041

**Irradiation of Graphene-FETs with highly charged Ions** — ●PHILIPP ERNST<sup>1</sup>, ROLAND KOZUBEK<sup>1</sup>, OLIVER OCHEDOWSKI<sup>1</sup>, JENS SONNTAG<sup>2</sup>, AXEL LORKE<sup>2</sup>, and MARIKA SCHLEBERGER<sup>1</sup> — <sup>1</sup>Universität Duisburg-Essen, AG Schleberger, Duisburg, Germany — <sup>2</sup>Universität Duisburg-Essen, AG Lorke, Duisburg, Germany

We have studied the influence of ion bombardment on the properties of graphene field-effect transistor (FET) structures. We used highly charged ions (HCI) with different potential energies at roughly the same kinetic energy (charge state  $\text{Xe}^{32+}$  and  $\text{Xe}^{25+}$  with  $E_{\text{kin}} = 220$  keV and  $E_{\text{kin}} = 195$  keV). Electrical transport measurements, Raman spectroscopy, and atomic force microscopy were used to investigate the electrical and structural modifications of the graphene-FETs induced by the ion irradiation. The electrical analysis was performed *in-situ* in the ultra-high vacuum set up used for the irradiation. For all investigated fluences, the experiments show a reduction of the mobility, which scales with the potential energy of the ions. Remarkably, the influence of the impact of highly charged ions is already measurable at extremely low fluences  $< 15$  ions/ $\mu\text{m}^2$ . As a consequence of the irradiation, a p-doping effect could be observed. Further experiments at lower kinetic energies ( $< 50$  keV) are planned to clarify how the potential energy of the impinging HCIs will affect the observed irradiation effects in graphene.

TT 97.8 Thu 12:15 MA 041

**Increasing the mobility of holes in graphene FETs by irradiation with swift heavy ions** — ●TOBIAS FOLLER, PHILIPP ERNST, OLIVER OCHEDOWSKI, ROLAND KOZUBEK, LUKAS MADAUSS, and MARIKA SCHLEBERGER — Fakultät für Physik and CeNIDE, Universität Duisburg-Essen, 47048 Duisburg, Germany

In this work graphene field-effect transistors (FETs) are modified by irradiation with swift heavy ions (SHI,  $\text{Xe}^{23+}$  with  $E_{\text{kin}} = 91$  MeV). Graphene FETs are prepared by exfoliation of a HOPG crystal followed by deposition of metal contacts via Photolithography. They allow to investigate the mobility of charge carriers in graphene. Current measurements, Raman spectroscopy and atomic force microscopy have been used to investigate the electrical and structural modifications of graphene due to the ion irradiation. By irradiation with swift heavy ions under perpendicular incidence with small fluences ( $\approx 2500$  ions/ $\mu\text{m}^2$ ), we have succeeded in almost doubling the mobility of holes compared to the unirradiated sample. On the other hand irradiation

under glancing incidence ( $\leq 2^\circ$ ) with fluences of 10 ions/ $\mu\text{m}^2$  have revealed that, despite the rather small changes in the ( $I_D/I_G$ )-ratio in the Raman spectrum, the charge carrier mobility is significantly reduced.

TT 97.9 Thu 12:30 MA 041

**Structure, strain distribution and energetics of basal-plane dislocations in bilayer graphene** — ●KONSTANTIN WEBER and BERND MEYER — Interdisciplinary Center for Molecular Materials and Computer-Chemistry-Center, FAU Erlangen-Nürnberg

A recent TEM study [1] demonstrated that substrate-grown graphene bilayers are typically not perfect in registry, but contain a high concentration of basal-plane dislocations. Using atomistic simulations based on the registry-dependent potential of Kolmogorov and Crespi [2] and the classical AIREBO potential we investigated the atomic structure and the properties of the 4 different types of dislocations with shortest possible Burgers vector in bilayer graphene, the thinnest imaginable crystal that can host such 1D defects. We find that each of the 4 different dislocations splits into two partial dislocations. The partials are equally spaced due to the absence of a stacking fault energy, a peculiar property of bilayer graphene. Furthermore, partials with a step component give rise to a pronounced buckling of the graphene bilayer. An analysis of the atomic structure, local strain distribution, disregistry and dislocation energy of the dislocations will be given and we will highlight how their properties differ from textbook examples of dislocations in 3D crystals.

- [1] B. Butz, C. Dolle, F. Niekel, K. Weber, D. Waldmann, H.B. Weber, B. Meyer, E. Spieker, *Nature* **505**, 533 (2014).  
 [2] A. Kolmogorov, V. Crespi, *Phys. Rev. B* **71**, 235415 (2005).

TT 97.10 Thu 12:45 MA 041

**Plasma-enhanced chemical vapor deposition of graphene on metallic substrates** — ●NICOLAS WÖHRL<sup>1</sup>, OLIVER OCHEDOWSKI<sup>2</sup>, STEVEN GOTTLIEB<sup>2</sup>, STEPHAN SCHULZ<sup>1</sup>, and VOLKER BUCK<sup>2</sup> — <sup>1</sup>Faculty of Chemistry and CeNIDE, University Duisburg-Essen, 47057 Duisburg, Germany — <sup>2</sup>Faculty of Physics and CeNIDE, University Duisburg Essen, 47057 Duisburg, Germany

In this work we present the synthesis of graphene on copper and nickel substrates by microwave Plasma-enhanced Chemical Vapor Deposition (PE-CVD) process. The special construction of the plasma source allows the deposition at a wide range of different process parameters giving a fast and inexpensive method to synthesize graphene. Additional advantages of the plasma deposition of graphene are lower substrate temperatures compared with thermal CVD processes. In contrast to the thermal CVD the gaseous precursors are already decomposed in the plasma and the plasma parameters are varied to investigate the influence on the nucleation and growth of graphene and on the defect density in the graphene layers. Optical emission spectroscopy is used to characterize the plasma properties while Raman spectroscopy and AFM measurements are used as nondestructive tools for the characterization of the synthesized graphene films. Especially Raman spectroscopy is used as a suitable tool to determine the number of graphene layers, the disorder and the defect density. We present a possible way to produce large area of monolayer graphene on metallic substrates with the prospect to make graphene available for industrial applications.