

O 68: Graphene: Preparation and Characterization I (jointly with HL, MA and TT)

Time: Thursday 10:30–13:15

Location: H17

O 68.1 Thu 10:30 H17

Synthesis of graphene on $(6\sqrt{3} \times 6\sqrt{3})R30^\circ$ reconstructed SiC surfaces by molecular beam epitaxy — ●TIMO SCHUMANN¹, MARTIN DUBSLAFF¹, MYRIANO H. OLIVEIRA JR.¹, MICHAEL HANKE¹, FELIX FROMM², THOMAS SEYLLER^{2,3}, J. MARCELO J. LOPES¹, and HENNING RIECHERT¹ — ¹Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany — ²Lehrstuhl für Technische Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — ³Institut für Physik, Technische Universität Chemnitz, Chemnitz, Germany

We report on the synthesis of graphene on a $(6\sqrt{3} \times 6\sqrt{3})R30^\circ$ reconstructed SiC(0001) surface (a.k.a. *buffer layer*) by means of molecular beam epitaxy (MBE). Raman spectroscopy reveals that the quality of the MBE-grown graphene films increases with growth time and that the average crystallite size exceeds 20 nm. X-ray photoelectron spectroscopy confirms that the thickness of the films increases as a function of the growth time and proves that the buffer layer is preserved during the growth process. In addition, grazing-incidence X-ray diffraction measurements were performed at the beamline ID10 of the ESRF in Grenoble. In-plane reflections of the buffer layer, the SiC, as well as from the MBE-synthesized graphene, were investigated. Strikingly, despite their nanocrystalline nature, it is observed that the graphene films grown by MBE show an in-plane alignment to the substrate, revealing that a conventional epitaxial growth on the buffer layer takes place. The results will be discussed in the context of MBE growth of graphene considering the most recent data reported in the literature.

O 68.2 Thu 10:45 H17

Microscopic characterization of CVD grown graphene suspended on TEM grids — ●FLORIAN STUDENER¹, LUCA BIGNARDI¹, WILLEM VAN DORP¹, STEFFANO GOTTARDI¹, OLEKSIH IVASHENKO¹, PAVEL DUDIN², ALEXEI BARINOV², PETRA RUDOLF¹, and MEIKE STÖHR¹ — ¹Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, 9747 AG Groningen, Netherlands — ²Sincrotrone Trieste S.C.p.A, 34149 Basovizza, Trieste, Italy

We investigated CVD grown graphene, which was transferred and suspended on a TEM grid. Both electronic and structural properties were investigated. The former were investigated with angle resolved photoelectron spectroscopy and microscopy, while the latter were analysed with Raman spectroscopy and transmission electron microscopy. We could observe that CVD grown graphene has comparable characteristics with free standing graphene produced with micro cleavage, e. g. the Fermi velocity of $1 \cdot 10^{-6}$ m/s is close to the theoretically expected value. Despite the polycrystalline nature of the Cu foil used as a substrate for the graphene growth, the obtained graphene exhibits large single-crystalline domains up to tens of microns. Thus, the presented transfer method can be successfully exploited for clean TEM substrates for further investigations.

O 68.3 Thu 11:00 H17

Graphene-enhanced versus Surface-enhanced Raman Scattering — ●FATEMEH YAGHOBIAN, TOBIAS KORN, and CHRISTIAN SCHÜLLER — Institute of Experimental and Applied Physics University of Regensburg D-93040 Regensburg, Germany

Graphene-enhanced Raman scattering (GERS) is emerging as an important method due to the need for highly reproducible, quantifiable and biocompatible active substrates. As a result of its unique two dimensional carbon structure, graphene provides particularly large enhanced Raman signals of molecules at its surface. In this work, it is demonstrated that graphene works as active substrate for enhanced Raman scattering and has a great potential in biosensing because of its ability to quench interfering fluorescence. Obtained GERS signals of different molecules with reproducible enhancement factors are discussed and compared with surface-enhanced Raman scattering (SERS) signals on highly active substrates, covered with spherical silver nanoparticles. We have also observed an upshift in the frequency of the breathing mode of a test molecule, when adsorbed on graphene, in contrast to measurements on silver nanoparticles, where the frequencies remain unchanged.

O 68.4 Thu 11:15 H17

Dynamics of adsorbate layers on freestanding graphene

probed by ultrafast low-energy electron diffraction — ●MAX GULDE¹, SIMON SCHWEDA¹, MANISANKAR MAITI¹, HAKKI YU², SASCHA SCHÄFER¹, and CLAUS ROPERS¹ — ¹Materials Physics Institute and Courant Research Centre, University of Göttingen, Germany — ²Department of Dynamics at Surfaces, Max Planck Institute for Biophysical Chemistry, University of Göttingen, Germany

Ultrafast structural dynamics in solids and nanostructures can be observed by an increasing number of sophisticated electron and x-ray diffraction techniques. Despite successful implementations of ultrafast reflection high-energy electron diffraction (1,2), the diffractive probing of ultrafast structural processes at surfaces remains an experimental challenge. We have implemented ultrafast low-energy electron diffraction (ULEED) to study structural changes with high temporal resolution and ultimate surface sensitivity, at electron energies from 100 eV to 500 eV. Specifically, we utilize nanoscopic needle emitters in an electrostatic lens geometry as high-brightness sources of pulsed electrons. With this approach, the ultrafast melting dynamics of ordered adsorbate structures on freestanding graphene is investigated in transmission with a temporal resolution below 5 ps.

(1) A. Hanisch-Blicharski, A. Janzen, B. Krenzer, S. Wall, F. Klasing, A. Kalus, T. Frigge, M. Kammler, and M. Horn-von Hoegen, *Ultramicroscopy* (accepted) (2012)

(2) S. Schäfer, W. Liang, and A. H. Zewail, *J. Chem. Phys.* 135, 214201 (2011)

O 68.5 Thu 11:30 H17

High-Temperature STM of the Ordering of an Amorphous Carbon Layer into Graphene on Ru(0001) — SEBASTIAN GÜNTHER¹, SEBASTIAN DÄNHARDT², ●MARTIN EHRNSPERGER², PATRICK ZELLER², STEFAN SCHMITT³, and JOOST WINTTERLIN² — ¹Chemie Department, Technische Universität München, Germany — ²Department Chemie, Ludwig-Maximilians-Universität München, Germany — ³SPECS GmbH, Voltastr. 5, D-13355 Berlin, Germany

An amorphous carbon layer was prepared on Ru(0001) by chemical vapor deposition of ethylene at about 650 K. High-Temperature Scanning Tunneling Microscopy (HTSTM), Low Energy Electron Diffraction and Temperature Programmed Desorption measurements were used to characterize the layer and its formation. The obtained carbon layer then served as amorphous precursor in an ordering transition towards graphene. At temperatures between 920 and 950 K the layer transformed into graphene which was indicated by the evolving moiré pattern. The ordering was monitored *in situ* by HTSTM. The observations revealed a unique mechanism involving mobile, small topographic holes that move through the disordered carbon layer leaving graphene behind. The transport of carbon monomers mediated by these holes opens a low-energy pathway for the ordering transition. In a dense packed graphene layer this mechanism is impossible which can explain the problems of healing defects in chemically synthesized graphene.

O 68.6 Thu 11:45 H17

***In situ* LEEM Investigations of the Growth of Graphene on Ni(111)-Films** — ●PATRICK ZELLER¹, MICHAEL WEINL², FLORIAN SPECK³, MARKUS OSTLER³, THOMAS SEYLLER³, MATTHIAS SCHRECK², and JOOST WINTTERLIN¹ — ¹Department Chemie, Ludwig-Maximilians-Universität München — ²Institut für Physik, Universität Augsburg — ³Department für Physik, FAU Erlangen-Nürnberg

We report about low energy electron microscopy (LEEM), scanning tunneling microscopy (STM), auger electron spectroscopy (AES) and x-ray photoelectron spectroscopy (XPS) investigations of graphene grown on single-crystalline Ni(111) films. The films, which may provide an easy and economical way towards a scalable graphene synthesis, consist of 150 nm thick, heteroepitaxially grown Ni(111) layers on a Si(111) wafer with a YSZ-buffer layer. Monolayer graphene was grown by chemical vapor deposition of ethylene and *in situ* LEEM investigations of the graphene growth were performed. Also the formation of nickel carbide and its transformation into graphene were observed. Furthermore we noticed an involvement of the bulk during the reaction. At the beginning of the ethylene dosing the C atoms dissolve in the bulk, and after nucleation segregation of C atoms starts. We could also observe the healing of rotated graphene towards aligned, high quality graphene in a small temperature range. Also a temper-

ature dependent formation and healing of dislocation lines in the Ni films was observed.

O 68.7 Thu 12:00 H17

Growth of graphene on a stepped iridium surface: morphology, domains and electronic fingerprints — ●IVA ŠRUT¹, VESNA MIKŠIĆ TRONTL¹, PETAR PERVAN¹, FABIAN CRAES², THOMAS MICHELY², CARSTEN BUSSE², and MARKO KRALJ¹ — ¹Institut za fiziku, Bijenička 46, 10000 Zagreb, Croatia — ²II. Physikalisches Institut, Universität zu Köln, Zùlpicher Straße 77, 50937 Köln, Germany

A promising route for modification of graphene properties is the growth of graphene on a substrate with a periodic arrangement of steps. We have used scanning tunneling microscopy and spectroscopy (STM/STS) and low energy electron diffraction (LEED) to study the growth of graphene on such periodically stepped Ir(332) surface. We have found that graphene continuously extends over iridium terraces and steps. Moreover, new distinctive mesoscopic features of the underlying surface are formed involving large, flat terraces accompanied by groups of narrower steps [1]. These morphologically different regions are also distinctive by their spectroscopic features found in STS. The distribution of the newly formed terraces as well as the contribution of various graphene orientations is sensitive to the preparation temperature. Below 800°C we find that the terrace width distribution is closer to the intrinsic distribution of clean Ir(332) than for higher temperatures. Additionally, graphene grown at low temperatures has a prominent contribution of a domain rotated by 30° with respect to the substrate. We find that the microscopic shape of steps after graphene formation strongly depends on the orientation of graphene.

[1] I. Šrut, et al., submitted

O 68.8 Thu 12:15 H17

Phonons of graphene on Ir(111) — ●MICHAEL ENDLICH¹, ALEJANDRO MOLINA-SÁNCHEZ², LUDGER WIRTZ², and JÖRG KRÖGER¹ — ¹Institut für Physik, Technische Universität Ilmenau, D-98693 Ilmenau — ²Physics and Material Sciences Research Unit, University of Luxembourg, L-1511 Luxembourg

The phonon dispersion relations of graphene on Ir(111) were determined with angle-resolved inelastic electron scattering. A weak graphene-Ir interaction is inferred from the lifting of the degeneracy of the out-of-plane optical and acoustic dispersion branches at the \bar{K} point of the surface Brillouin zone and from the energy reduction of the out-of-plane optical phonon. Despite this interaction the Kohn anomalies known from graphite of the highest optical phonon branch at $\bar{\Gamma}$ and \bar{K} persist. The experimental dispersion relations are in agreement with density functional calculations.

O 68.9 Thu 12:30 H17

Support restructuring during graphene growth on Cu foils triggers the formation of non flat membranes — ●JÜRGEN KRAUS¹, SEBASTIAN BÖCKLEIN², ROBERT REICHELT¹, BENITO SANTOS³, TEVFIK O. MENTES³, ANDREA LOCATELLI³, and SEBASTIAN GÜNTHER¹ — ¹Technische Universität München Chemie Department, D-85748 Garching — ²Ludwig-Maximilians-Universität, D-81377 München — ³Sincrotrone Trieste, I-34149 Trieste - Basovizza

Meanwhile the growth of single crystalline graphene flakes on Cu foils at a mm-length scale can be achieved, which provides a potential source for high quality graphene. On the other hand, the g-Cu system still suffers from certain inherent defects: during graphene growth sequences

of inclined Cu facets form which are visible in scanning electron microscopy (SEM) images as stripes and which have been observed as well applying atomic force microscopy (AFM) and scanning tunneling microscopy (STM). Since the graphene follows the morphology of the underlying Cu foil the support restructuring leads to the formation of so called nanorippled graphene which persists even if the graphene is transferred on a flat Si wafer. In our study, we identified a sequence of such Cu facets after graphene growth on a Cu foil using low energy electron microscopy (LEEM) and show why the graphene cannot flatten when removed from the support. In addition, we were able to prepare graphene membranes by the local electrochemical removal of the Cu foil underneath the grown graphene. We show that the resulting membranes are exact replicas of the former morphology of the Cu foil during growth, i.e. they are non flat membranes.

O 68.10 Thu 12:45 H17

Graphene on Rh(111) and Ru(0001): combined STM/NC-AFM and DFT studies — ●YURIY DEDKOV¹, TORBEN HAENKE¹, OLIVER SCHAFF¹, ANDREAS THISSEN¹, ELENA VOLOSHINA², and MIKHAIL FONIN³ — ¹SPECS Surface Nano Analysis GmbH, Voltstraße 5, 13355 Berlin, Germany — ²Physikalische und Theoretische Chemie, Freie Universität Berlin, 14195 Berlin, Germany — ³Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany

The electronic and crystallographic structure of graphene moiré on Rh(111) and Ru(0001) is studied via combination of density-functional theory calculations and scanning tunneling and noncontact atomic force microscopy (STM and NC-AFM). Whereas the principal contrast between hills and valleys observed in STM does not depend on the sign of applied bias voltage, the contrast in atomically resolved AFM images strongly depends on the frequency shift of the oscillating AFM tip. The obtained results demonstrate the perspectives of application atomic force microscopy/spectroscopy for the probing of the chemical contrast at the surface.

O 68.11 Thu 13:00 H17

Epitaxial graphene nanoflakes on Au(111): Structure, electronic properties and manipulation — ●MIKHAIL FONIN¹, PHILIPP LEICHT¹, LUKAS ZIELKE¹, ELENA VOLOSHINA², and YURIY S. DEDKOV³ — ¹Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany — ²Institut für Chemie und Biochemie - Physikalische und Theoretische Chemie, Freie Universität Berlin, 14195 Berlin, Germany — ³SPECS Surface Nano Analysis GmbH, 13355 Berlin, Germany

Graphene nanoribbons and graphene dots have been proposed to exhibit such peculiar phenomena like localized edge states or edge magnetism. The aim of the present study is the investigation of structural and electronic properties of epitaxial graphene nanoflakes on the Au(111) surface.

Upon in situ preparation, we observe a formation of two types of nanoflakes, which are either embedded in the gold surface or sit directly on top of Au(111). In all cases, flakes reveal a moiré contrast, which is modulated by the herring-bone reconstruction of the Au(111) surface with the moiré period depending on the orientation of the graphene sheet in relation to the substrate. We show that quasi-free-standing graphene nanoflakes can be easily manipulated by the STM tip regardless of the flake size. The details of the structure and electronic properties of such quasi-free-standing flakes are discussed upon comparison with graphene dots on Ir(111).