

O 65: Graphene V

Time: Thursday 10:30–13:00

Location: MA 041

O 65.1 Thu 10:30 MA 041

The Suitability of Single Crystal Metal Films as Substrates for Graphene Growth — ●PATRICK ZELLER¹, MICHAEL WEINL², MATTHIAS SCHRECK², and JOOST WINTTERLIN¹ — ¹LMU München, Department Chemie — ²Universität Augsburg, Institut für Physik

We report about a project in which thin, single crystal films of various metals are investigated as substrates for the epitaxial growth of graphene. The films consist of 100 to 150 nm thick, epitaxially oriented metal layers grown on Si(111) wafers. 40 to 100 nm thick yttria-stabilized zirconia (YSZ) buffer layers separate the metal from the Si substrate [1]. As metals we have investigated Ir(111), Ru(0001), and Ni(111). All metal films display high crystalline quality with a typical mosaic spread in the range of 0.2 to 0.9°. Ir films have the lowest values down to 0.1°. Graphene was grown on the films by chemical vapor deposition (CVD) of ethylene at elevated temperatures. Methods used were scanning tunneling microscopy (STM), low-energy electron diffraction (LEED), Auger electron spectroscopy (AES), atomic force microscopy (AFM) and scanning electron microscopy (SEM). The topography of the as-grown metal films can be improved by annealing in UHV. Investigations of the thermal stability and dewetting of the films were done. AFM and SEM show the size of the graphene domains. We show that the quality of the graphene layers achieved on these metal films is comparable to epitaxial graphene grown on bulk metal single crystals. [1] Gsell, S., et al., Journal of Crystal Growth 2009, 311, 3731.

O 65.2 Thu 10:45 MA 041

Epitaxial growth of graphene on Ir(111) by liquid precursor deposition — ●SAMUEL GRANDTHYLL¹, FRANK MÜLLER¹, CHRISTIAN ZEITZ¹, KARIN JACOBS¹, STEFAN HÜFNER¹, STEFAN GSELL², and MATTHIAS SCHRECK² — ¹Saarland University, Experimental Physics, D-66041 Saarbrücken, Germany — ²University Augsburg, Institut Phys. D-86135 Augsburg, Germany

The epitaxial growth of graphene on the surface of an Ir/YSZ/Si(111) multilayer substrate via the deposition of a liquid carbon precursor (acetone) was investigated by x-ray photoelectron spectroscopy, x-ray photoelectron diffraction, low-energy electron diffraction (LEED), and Fermi surface mapping. It is shown that the onset of graphene formation starts in a low temperature range around 600 K and that subsequent annealing up to 1000 K finally results in well-ordered graphene monolayers. Comparison of temperature-dependent LEED data with model calculations suggests that the growth of graphene takes place via a backbone-like growth by the formation of a hexagonal network connecting the hcp and fcc configuration sites within the similar to 10x10/9x9 supercell. In LEED, the low intensities of the superstructure related satellite spots give evidence for only small corrugations of the graphene layer due to weak interaction with the Ir(111) surface, making graphene on Ir(111) similar to free-standing graphene with the Fermi surface providing distinct spots at the K points.

O 65.3 Thu 11:00 MA 041

Local tunneling spectroscopy of the Hydrogen-induced impurity state in quasi-freestanding graphene — ●RONNY SCHLEGEL¹, MARTHA SCHEFFLER¹, DANNY HABERER¹, RICO POHLE¹, TORBEN HÄNKE¹, ALEXANDER GRÜNEIS^{1,2}, CHRISTIAN HESS¹, and BERND BÜCHNER¹ — ¹Leibniz Institute for Solid State and Materials Research Dresden — ²University of Vienna, Austria

Graphene has a unique electronic structure, which is expected to exhibit a linear dispersion near the Fermi edge. Usually this peculiar feature is difficult to observe due to proximity effect from the substrate. However, the fabrication of quasi-freestanding graphene on specific multi-layer metal surfaces has recently been demonstrated.

Manipulation of such graphene through selective insertion of impurities may allow to tune the electronic structure and thus to open up new routes towards graphene based device functionalities. Hydrogenation leads to a reversible gap opening at the Fermi edge. Also a dispersionless, hydrogen-induced state appears in the center of this gap.

Here we use scanning tunneling microscopy and spectroscopy (STM/STS) to study graphene samples with an outstanding cleanliness obtained by in-situ preparation under UHV conditions. The surfaces are investigated by STM and atomically resolved images of the pris-

tine graphene as well as the hydrogen adsorbate sites were achieved. STS measurements reveal an enhanced DOS near the Fermi edge after hydrogenation, consistent with theoretical predictions and ARPES experiments.

O 65.4 Thu 11:15 MA 041

Investigation of the electronic structure of bilayer graphene on Ni(111) — ●MARTIN WESER¹, ROLAND KOCH², ELENA VOLOSHINA³, ALEX GENERALOV^{1,4}, HENDRIK VITA¹, THOMAS SEYLLER², KARSTEN HORN¹, and YURIY S. DEDKOV⁵ — ¹Fritz-Haber Institut, Berlin, Germany — ²Universität Erlangen-Nürnberg, Erlangen, Germany — ³Freie Universität, Berlin, Germany — ⁴Technische Universität Dresden, Germany — ⁵SPECS Surface Nano Analysis GmbH, Germany

Among the many proposed applications of graphene in electronic devices, its use as a spin-filter has received attention, because the electronic structure of graphene and that of close-packed surfaces of ferromagnetic metals such as Ni and Co overlap only for the minority spin bands at the Fermi level. The effect was predicted to strongly increase with increasing of the number of graphene layers. We have developed a method for multilayer preparation using pyridine cracking on Ni(111) in ultrahigh vacuum. We characterize our multilayer films using low energy electron diffraction, core and angle-resolved valence level photoelectron spectroscopy. Multilayers are found to grow in a manner where consecutive layers are rotated against each other by well-defined angles, a fact that may lead to a decoupling of layers as found in multilayer growth on the carbon face of SiC(000-1). It was found that twisted stacking occurs for the overlayer, with two favorable rotation angles. In spite of this arrangement, spin filtering may still be possible because of the specific shape of the majority spin states in Ni(111) at EF.

O 65.5 Thu 11:30 MA 041

DFT studies of Graphene on Ni(111) and Surface Nickel Carbide Ni₂C — ●ANDREAS GARHOFER¹, PETER JACOBSEN^{1,2}, BERNHARD STOEGER¹, GARETH S. PARKINSON¹, MICHAEL SCHMID¹, ROMAN CAUDILLO³, FLORIAN MITTENDORFER¹, JOSEF REDINGER¹, and ULRIKE DIEBOLD^{1,2} — ¹Institute of Applied Physics, TU Wien, Austria — ²Tulane University, USA — ³Intel Corporation

Graphene with its unique transport properties supported on ferromagnetic materials is a promising candidate for the fabrication of spin-filtering devices. In order to study the growth of graphene on metal surfaces, graphene on Ni(111) is a perfect system from a structural point of view.

We studied the systems using the DFT program package VASP with the vdW-DF method in the flavor of optB88 to include van der Waals interactions. In our theoretical discussion we analyzed the growth of graphene and Ni₂C on Ni(111). We calculated the stability of the surface carbide phase and the binding energies of rotated and unrotated graphene on Ni(111) as well as on Ni₂C. Graphene and Ni₂C have no epitaxial relationship due to their incommensurate lattices, leading to a spread in grain rotations. The CVD growth of graphene on Ni(111) was also studied with STM. The experiments showed not only perfect aligned (1x1) structures, but also several moiré patterns. They are due to grain rotations of graphene on both Ni(111) and also surface nickel carbide Ni₂C. During CVD growth, carbon atoms segregate into the Ni bulk. With an increasing carbon concentration first the surface carbide and then a graphene layer on top is built.

O 65.6 Thu 11:45 MA 041

Freely spanned graphene membranes from epitaxial graphene — ●DANIEL WALDMANN¹, JOHANNES JOBST¹, KONRAD ULLMANN¹, FELIX FROMM², SEBASTIAN BAUER³, BENJAMIN BUTZ⁴, JAN ENGLERT⁵, THOMAS SEYLLER², PATIRK SCHMUKT³, ERDMAN SPIEKER⁴, and HEIKO WEBER¹ — ¹Lehrstuhl für Angewandte Physik, Universität Erlangen-Nürnberg — ²Lehrstuhl für Technische Physik, Universität Erlangen-Nürnberg — ³Lehrstuhl für Korrosion und Oberflächentechnik, Universität Erlangen-Nürnberg — ⁴Center for Nanoanalysis and Electron Microscopy, Universität Erlangen-Nürnberg — ⁵Zentralinstitut für Neue Materialien und Prozesstechnik, Universität Erlangen-Nürnberg, Germany

We developed a fabrication process for freestanding graphene mem-

branes from high-quality epitaxial graphene on silicon carbide (SiC) by electrochemical removal of the SiC. The membranes with areas up to $700 \mu\text{m}^2$ are freely spanned over holes in the substrate. Thus we can perform measurements on epitaxial graphene without the disturbing influence of the substrate. The homogeneity is controlled by scanning electron microscopy and scanning transmission electron microscopy. Raman measurements display a strongly enhanced signal of the membranes compared to epitaxial graphene on substrate. Using high resolution transmission electron microscopy we imaged the graphene membranes with atomic resolution.

O 65.7 Thu 12:00 MA 041

Transfer methods of large-scale graphene — ●MARCO KRAFT^{1,2}, MARC A. GLUBA², GERALD TROPPEZ², and NORBERT H. NICKEL² — ¹Institut für Physik, Humboldt Universität zu Berlin — ²Helmholtz Zentrum Berlin für Materialien und Energie GmbH

Graphene has attracted significant attention due to its unusual high carrier mobility and low sheet resistivity. It would be desirable to combine these outstanding properties with the already established technology of silicon. Unfortunately, it is not possible to grow large-scale graphene on silicon. Hence, graphene has to be grown on foreign substrates and subsequently transferred to the silicon based device. Different approaches for this transfer process (e.g. by adhesive foils, protective resist, etc.) are compared by means of their transfer efficiency. For this purpose large scale graphene was grown by low-pressure chemical vapor deposition (CVD) on copper using methane as a precursor. Raman spectroscopy on the as-grown graphene revealed characteristic defect modes, which might be due to the non planar surface of the copper foil. Afterwards the graphene layer was transferred on a Si/SiO₂ substrate by using different methods. The transfer process is monitored by raman spectroscopy, atomic force microscopy (AFM) and scanning electron microscopy (SEM) and the resulting graphene layers are compared with samples from mechanical exfoliation on mica muscovite as de facto standard for high quality graphene.

O 65.8 Thu 12:15 MA 041

Conversion of aromatic self-assembled monolayers on Cu substrates into graphene sheets — ●NILS-EIKE WEBER¹, DAN MATEI¹, RAINER STOSCH², ARMIN GÖLZHÄUSER¹, and ANDREY TURCHANIN¹ — ¹Physik supramolekularer Systeme und Oberflächen, Universität Bielefeld — ²Physikalisch-Technische Bundesanstalt, Braunschweig

Aromatic thiol-based self-assembled monolayers (SAMs) on gold can be converted into nanocrystalline graphene sheets via electron irradiation induced cross-linking and thermal annealing [1, 2]. To realize the role of substrate in this process, we study the conversion of biphenylthiol SAMs into graphene on copper substrates. To this end, Low Energy Electron Diffraction, Scanning Tunneling Microscopy, X-ray Photoelectron Spectroscopy and Raman Spectroscopy were employed. The use of copper substrates leads to an increase of the crystallinity of graphene sheets in comparison to those obtained on gold substrates. This result makes it promising to attempt the synthesis of high qual-

ity graphene for electronic applications using the suggested molecular approach.

[1] A. Turchanin et al., Adv. Mater. 21, 1233 (2009)

[2] A. Turchanin et al., ACS Nano 5, 3896 (2011)

O 65.9 Thu 12:30 MA 041

Extreme UV interference lithography of carbon nanomembranes and graphene — ●ANDREAS WINTER¹, ANNIKA WILLUNAT¹, MICHAELA VOCKENHUBER², YASIN EKINCI², ANDRE BEYER¹, ARMIN GÖLZHÄUSER¹, and ANDREY TURCHANIN¹ — ¹Physics of Supramolecular Systems and Surfaces, University of Bielefeld, D-33615 Bielefeld — ²Laboratory for Micro and Nanotechnology, Paul Scherrer Institute, 5132 Villigen, Switzerland

Two-dimensional (2D) carbon materials like graphene, graphene oxide, carbon nanomembranes (CNMs) or ultrathin polymeric films have recently attracted enormous interest due to their potential for use in electronics, chemical and biological sensors, nanofilters, hybrid materials, etc. Most of these applications require lithographic patterning of these 2D carbon materials with the nanoscale resolution. In this respect, Extreme UV Interference Lithography (EUV-IL) provides both large-scale patterning and high resolution with an ultimate limit in the sub-10 nm range. We employ EUV-IL to generate two-dimensional nanopatterns of ca. 1 nm thick CNMs as well as of graphene. We characterize these structures with a Helium Ion Microscope (HIM), which allows imaging of topographic and chemical features of both supported CNMs on insulating substrates, freely suspended CNMs and graphene sheets.

O 65.10 Thu 12:45 MA 041

Layer-by-layer engineering of novel 2D carbon materials with tunable optical, chemical and electrical properties — ●ANDREY TURCHANIN¹, CHRISTOPH NOTTBOHM¹, ANDRÉ BEYER¹, RAINER STOSCH², and ARMIN GÖLZHÄUSER¹ — ¹Physik supramolekularer Systeme und Oberflächen, Universität Bielefeld — ²Physikalisch-Technische Bundesanstalt, Braunschweig

We present a route to the fabrication of novel layered 2D carbon materials with tunable electrical, optical and chemical properties on various substrates and as suspended membranes [1]. These materials are engineered via simple layer-by-layer mechanical stacking of carbon (organic) nanomembranes with a thickness of about 1 nm. We characterize physical and chemical properties of these materials via optical microscopy, UV/Vis reflection spectroscopy, X-ray photoelectron spectroscopy, Raman spectroscopy and electrical measurements. Vacuum annealing of the multilayer stacks results in their conversion into graphene at temperatures above 800 K. The degree of this conversion and the thickness of the resulting layers can be precisely controlled. The suggested route opens broad avenues to the engineering of novel 2D carbon hybrid materials for applications ranging from electronics to biophysics.

[1] C.T. Nottbohm et al., Small 7, 874 (2011)