

## O 4: Graphene I

Time: Monday 10:30–13:00

Location: MA 041

O 4.1 Mon 10:30 MA 041

**Photoemission Microspectroscopy of Single Layer Graphene on Iridium.** — ●CHRISTIAN WITT, JAN VANIS, MICHAEL HORN-VON HOEGEN, and FRANK-J. MEYER ZU HERINGDORF — University Duisburg-Essen, Faculty of Physics and CeNiDE, Lotharstrasse 1, 47048 Duisburg

Graphene is one of the most investigated materials in modern physics. Especially the differences of the band structure of free standing Graphene and Graphene grown on a substrate is of great interest. A standard method to grow single layer Graphene is chemical vapor deposition using Ethene as a carbon source and heated Iridium crystals as substrate and catalyst. We combined photoemission electron microscopy with various illumination sources to investigate the morphology and band structure of Graphene on Iridium. In our experiments, under illumination with a Helium discharge lamp (photon energy of 21.2 eV) we find the well known energy bands of Graphene. In contrast, under illumination with 200 nm femtosecond laser pulses (photon energy of 6.2 eV) we find a significant density of states at the  $\Gamma$  point.

O 4.2 Mon 10:45 MA 041

**Local Gating of an Ir(111) Surface Resonance by Graphene Islands** — ●SIMON JOHANNES ALTENBURG<sup>1</sup>, JÖRG KRÖGER<sup>2</sup>, TIM WEHLING<sup>3</sup>, BURKHARD SACHS<sup>3</sup>, ALEXANDER LICHTENSTEIN<sup>3</sup>, and RICHARD BERNDT<sup>1</sup> — <sup>1</sup>Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, D-24098 Kiel, Germany — <sup>2</sup>Institut für Physik, Technische Universität Ilmenau, D-98693 Ilmenau, Germany — <sup>3</sup>I. Institut für Theoretische Physik, Universität Hamburg, D-20355 Hamburg, Germany

The influence of graphene islands on the electronic structure of the Ir(111) surface is investigated. Scanning tunneling spectroscopy (STS) indicates the presence of a two-dimensional electron gas with a binding energy of  $-160$  meV and an effective mass of  $-0.18 m_e$  underneath single-layer graphene on the Ir(111) surface. Density functional calculations reveal that the STS features are predominantly due to a hole-like surface resonance of the Ir(111) substrate. Nanometer-sized graphene islands act as local gates, which shift and confine the surface resonance. Funding by the Deutsche Forschungsgemeinschaft via SPP 1459 and SFB 668, the Schleswig-Holstein-Fonds as well as computer time at HLRN are acknowledged.

O 4.3 Mon 11:00 MA 041

**Direct observation of electron confinement in epitaxial graphene nanoislands** — SOO-HYON PHARK<sup>1</sup>, JEROME BORME<sup>1,2</sup>, ●AUGUSTO LEON VANEGAS<sup>1</sup>, MARCO CORBETTA<sup>1</sup>, DIRK SANDER<sup>1</sup>, and JÜRGEN KIRSCHNER<sup>1</sup> — <sup>1</sup>Max Planck Institute of Microstructure Physics, Weingerg 2, 06120 Halle, Germany — <sup>2</sup>International Iberian Nanotechnology laboratory, Avenida Mestre Jose Veiga, 4715-310 Braga, Portugal

A central question for the future applications of graphene is how the substrate and the lateral confinement of a graphene island affect the electronic properties. In this work we have used scanning tunneling spectroscopy to measure the differential conductance  $dI/dV$  of the graphene nanoisland deposited on Ir(111)[1]. The  $dI/dV$  maps show a spatial modulation, which depends on energy. We ascribe this spatial modulation of the local density of states to quantum confinement. An analysis of the energy dependence of these modulations gives a linear dispersion relation,  $E = E_0 \pm \hbar v_F |k|$  with  $E_0 = -90 \pm 20$  meV and a Fermi velocity  $v_F = (6.0 \pm 0.4) \times 10^5$  m/s. These findings are discussed in view of recently published data [2,3].

[1] Soo-Hyon Phark, et al., ACS Nano, 2011, 5 (10), pp 8162-8166.

[2] S. Rusponi, et al., Phys. Rev. Lett. 105 (2010) 246803.

[3] M. Kralj et al., Phys. Rev. B 84, 075427 (2007).

O 4.4 Mon 11:15 MA 041

**Wave function mapping of graphene quantum dots with soft confinement** — ●DINESH SUBRAMANIAM<sup>1</sup>, FLORIAN LIBISCH<sup>2</sup>, YAN LI<sup>3</sup>, CHRISTIAN PAULY<sup>1</sup>, VIKTOR GERINGER<sup>1</sup>, RAPHEL REITER<sup>2</sup>, TORGE MASHOFF<sup>1</sup>, MARCUS LIEBMAN<sup>1</sup>, JOACHIM BURGDÖRFER<sup>2</sup>, CARSTEN BUSSE<sup>4</sup>, THOMAS MICHELY<sup>4</sup>, RICCARDO MAZZARELLO<sup>3</sup>, and MARKUS MORGENSTERN<sup>1</sup> — <sup>1</sup>II. Physikalisches Institut B and JARA-FIT, RWTH Aachen University, D-52074 Aachen, Germany —

<sup>2</sup>Institute for Theoretical Physics, Vienna University of Technology, A-1040 Vienna, Austria — <sup>3</sup>Institute for Theoretical Solid State Physics and JARA-FIT, RWTH Aachen University, D-52074 Aachen, Germany — <sup>4</sup>II. Physikalisches Institut, Universität zu Köln, Zùlpicherstr. 77, D-50937 Köln, Germany

Using low-temperature scanning tunneling spectroscopy, we map the local density of states of graphene quantum dots (QDs) supported on Ir(111). Due to a band gap in the projected Ir band structure around the graphene K point, the electronic properties of the QDs are dominantly graphene-like. Indeed, we compare the results favorably with tight binding calculations on the honeycomb lattice based on parameters derived from density functional theory. We find that the interaction with the substrate towards the edge of the island softly opens a gap in the Dirac cone, which implies soft-wall confinement. Interestingly, this confinement is required for highly symmetric wave functions. Further influences of the substrate are given by the known moire potential and a 10 % penetration of an Ir surface resonance into the graphene layer.

O 4.5 Mon 11:30 MA 041

**Adsorption effects on the electronic and magnetic properties of nanosized Graphene structures on the Ir(111) Surface** — ●YAN LI<sup>1</sup>, DINESH SUBRAMANIAM<sup>1</sup>, NICOLAE ATODIRESEI<sup>2</sup>, PREDRAG LAZIC<sup>3</sup>, VASILE CACIUC<sup>2</sup>, MARCUS LIEBMAN<sup>1</sup>, MARCO PRATZER<sup>1</sup>, CHRISTIAN PAULY<sup>1</sup>, ALEXANDER GEORGI<sup>1</sup>, RICCARDO MAZZARELLO<sup>1</sup>, STEFAN BLUGEL<sup>2</sup>, and MARKUS MORGENSTERN<sup>1</sup> — <sup>1</sup>RWTH Aachen, Aachen, Germany — <sup>2</sup>Forschungszentrum Jùlich, Jùlich, Germany — <sup>3</sup>MIT, Massachusetts, USA

We have studied the structural, electronic and magnetic properties of graphene nanoribbons and flakes grown on the Ir(111) surface by *ab initio* simulations and low-temperature scanning tunneling spectroscopy. The calculated formation energy and the experimental STM images indicate that in zigzag terminated flakes each C atom at the edge is saturated by one hydrogen atom. Due to the interplay between a) the strong interaction between Ir atoms and C atoms at the edge and b) the lattice mismatch, a superstructure consisting of alternating regions of strongly bound, *sp*<sup>3</sup>-hybridized C atoms and weakly bound, *sp*<sup>2</sup>-hybridized C atoms is formed at the edge. As a result of the interaction with the surface, no magnetic edge state near the Fermi level exists in the supported ribbon: this conclusion is corroborated by both calculation and experiments. We also studied theoretically the electronic structure of unsaturated nanoribbons on the same surface. No magnetic edge state was obtained in this system either.

O 4.6 Mon 11:45 MA 041

**SPA-LEED study of strain state of single layer graphene on Ir(111): hysteretic behaviour of lattice parameter and wrinkle formation** — ●C. KLEIN<sup>1</sup>, H. HATTAB<sup>1</sup>, A. T. N'DIAYE<sup>2</sup>, D. WALL<sup>1</sup>, G. JNAWALI<sup>1</sup>, J. CORAUX<sup>3</sup>, C. BUSSE<sup>2</sup>, R. VAN GASTEL<sup>4</sup>, B. POELSEMA<sup>4</sup>, T. MICHELY<sup>2</sup>, F.-J. MEYER ZU HERINGDORF<sup>1</sup>, and M. HORN-VON HOEGEN<sup>1</sup> — <sup>1</sup>Department of Physics, Universität Duisburg-Essen — <sup>2</sup>II. Physikalisches Institut, Universität zu Köln — <sup>3</sup>Institut Néel, CNRS-UJF, Grenoble Cedex 9, France — <sup>4</sup>Physics of Interfaces and Nanomaterials, MESA+ Institute for Nanotechnology, University of Twente, Enschede, The Netherlands

Employing high resolution low energy electron diffraction (SPA-LEED) the lattice parameter of single layer graphene on Ir(111), prepared by thermal decomposition of ethylene at 1530 K, was studied. We analyzed the strain state and the wrinkle formation kinetics as function of temperature. Using the moiré spot separation as a magnifying mechanism for the difference in the lattice parameters between Ir and graphene, we achieved an unrivalled relative precision of ca. 0.1 pm for the graphene lattice parameter. Our data reveals a characteristic hysteresis of the graphene lattice parameter which is explained by the interplay of reversible wrinkle formation and film strain. We show that epitaxial graphene on Ir(111) always exhibits residual compressive strain at room temperature, and provide important guidelines for strategies to avoid wrinkling.

Hattab et. al., Nano Letters (under revision, Nov. 2011)

O 4.7 Mon 12:00 MA 041

**Morphology-dependent corrugation of Graphene/Ir(111):**

**An XSW study** — •SVEN RUNTE<sup>1</sup>, CHI VÕ VÂN<sup>2</sup>, JOHANN CORAUX<sup>2</sup>, JÖRG ZEGENHAGEN<sup>3</sup>, THOMAS MICHELY<sup>1</sup>, and CARSTEN BUSSE<sup>1</sup> — <sup>1</sup>II. Phys. Inst., Universität zu Köln, Germany — <sup>2</sup>Institut Néel, Grenoble, France — <sup>3</sup>European Synchrotron Radiation Facility, Grenoble, France

Graphene grown on metal substrates often shows a superperiodic moiré structure due to the lattice mismatch. In the resulting large unit cells varying local registries between the carbon and the metal atoms are found, leading to a local variation of the respective bond strength. Hence the graphene layer is not flat but significantly corrugated [1].

We performed X-ray Standing Wave (XSW) measurements for graphene/Ir(111) using (111)- and (222)-crystal reflections to determine the height distribution of the carbon atoms. We show that the peak-to-peak corrugation for a fully closed film is 1 Å and about half this value for small graphene flakes. This can be rationalized by postulating different strain states resulting from the cool-down from high growth temperatures and different thermal expansion coefficients of graphene and its substrate. These measurements also clarify the open question of the real shape of the corrugated layer from scanning probe experiments [2,3]. Finally, the influence of intercalated atoms and metal clusters on graphene's corrugation is shown.

[1] C. Busse *et al.*, Phys. Rev. Lett. **107**, 036101 (2011).

[2] A. T. N'Diaye *et al.*, New J. Phys. **10**, 043033 (2008).

[3] Z. Sun *et al.*, Phys. Rev. B **83**, 081415 (2011).

O 4.8 Mon 12:15 MA 041

**Minigap isotropy and broken chiral symmetry in graphene with periodic corrugation** — •JAIME SÁNCHEZ-BARRIGA, A. VARYKHALOV, D. MARCHENKO, M. R. SCHOLZ, and O. RADER — Helmholtz-Zentrum Berlin

The chirality of charge carriers in graphene determines its peculiar scattering properties and in particular the avoided backscattering, predicted to be observable as the closing of minigaps in periodically corrugated graphene. By angle-resolved photoemission we show that the corrugated graphene layer that forms on Ir(111) exhibits isotropic minigaps which close nowhere in k-space, as expected for non-chiral particles. Artificially introducing an extra periodic superpotential by deposition of clusters with different compositions confirms the minigap isotropy indicating that the origin of this behavior is directly connected to the breaking of the chiral symmetry in the system.

O 4.9 Mon 12:30 MA 041

**Extrinsic spin-orbit splitting in graphene on Ir(111) ad-justable by interface chirality** — •DMITRY MARCHENKO, J. SÁNCHEZ-BARRIGA, M. R. SCHOLZ, O. RADER, and A. VARYKHALOV — Helmholtz-Zentrum Berlin

By means of spin- and angle-resolved photoemission we reveal a giant Rashba-type spin-orbit splitting in the  $\pi$ -band of graphene grown on Ir(111). We demonstrate that the magnitude of the splitting depends on the strength of the chemical interaction between graphene and iridium and can be regulated through the mutual rotational displacement of the graphene layer and the Ir(111) substrate.

O 4.10 Mon 12:45 MA 041

**Ion Beam induced Defects in Graphene** — •SEBASTIAN STANDOP<sup>1</sup>, GEORGIA LEWES-MALANDRAKIS<sup>1</sup>, CHARLOTTE HERBIG<sup>1</sup>, OSSI LEHTINEN<sup>2</sup>, ARKADY V. KRASHENINNIKOV<sup>2</sup>, THOMAS MICHELY<sup>1</sup>, and CARSTEN BUSSE<sup>1</sup> — <sup>1</sup>II. Physikalisches Institut, Universität zu Köln — <sup>2</sup>Materials Physics Division, University of Helsinki, Finland

We explore ion irradiation as a tool to intentionally create defects in graphene. Defects not only alter graphene's structure, but were predicted to significantly affect its electronic properties [1]. Ion irradiation of graphene grown epitaxially on Ir(111) was conducted at room temperature with 1-15 keV noble gas ions (He, Ne, Ar, Xe) at an angle of 75° with respect to the surface normal. While for low energies and light ions only single holes or the absence of defect patterns are observed, for ion energies beyond a few keV and heavier ions pronounced damage patterns in great variety are observed as surface damage in scanning tunneling microscopy. These patterns consist of sequences of holes in graphene, some of them decorated by bright protrusions, with a maximum length exceeding 40 nm. We interpret the holes as to result from multiple scattering of the ions in between graphene and the Ir(111) surface. The protrusions are assumed to show Ir adatoms under the graphene layer created by the energy deposition of the ion to the substrate. Our interpretation is supported by corresponding molecular dynamics simulations of ion impacts in conjunction with ab initio density function theory calculations as well as annealing studies performed *in situ*. [1] M. M. Ugeda *et al.*, PRL 104, 096804 (2010)