

O 29: Graphene I

Time: Tuesday 11:15–13:00

Location: WIL B321

O 29.1 Tue 11:15 WIL B321

Graphene Growth Kinetics on Ru(0001) as Function of the Termination of Graphene Islands — ●SEBASTIAN DAENHARDT¹, SEBASTIAN GUENTHER², STEFAN SCHMITT³, and JOOST WINTTERLIN¹ — ¹Department Chemie, LMU Muenchen — ²Fachgebiet Phys. Chemie (Katalyse), TU Muenchen — ³SPECS GmbH, Voltastr. 5, 13355 Berlin

For a deeper understanding of the growth kinetics of graphene on metal surfaces it is important to monitor the growth of the islands in situ, at the high temperatures of the CVD process. Here we present the results of an in situ STM investigation of the growth of graphene on Ru(0001) during ethylene decomposition between 650 and 750°C. We have also monitored the removal of the graphene layer by oxidation in situ. We find that the graphene islands are all zig-zag terminated, but that there are still two different island terminations, which are rotated by an angle of 120°, that display different growth velocities. The two terminations also differ with respect to the binding to Ru steps. The slowly growing edges tend to bind to Ru steps during the growth, in contrast to the faster growing edges. The slowly growing edges can also etch into ascending steps, so that the graphene islands can grow on given terraces without crossing the steps. In all of these cases graphene grows in a "quantized" form, i.e., by addition of full unit cells of the moiré structure. The data demonstrate a massive restructuring of the Ru surface under the growth conditions, and they provide insight into the energetics of the graphene-Ru edges.

O 29.2 Tue 11:30 WIL B321

Graphene flakes growth study by ARPES — ●MARIN PETROVIC¹, IVA ŠRUT¹, PETAR PERVAN¹, SVEN RUNTE², CARSTEN BUSSE², THOMAS MICHELY², and MARKO KRALJ¹ — ¹Institut za fiziku, Zagreb, Croatia — ²II. Physikalisches Institut, Köln, Germany

A well established route for the large-scale production of graphene is chemical vapor phase deposition (CVD) growth on various metal substrates [1]. However, in order to obtain highly oriented graphene covering the entire Ir(111) surface one needs to combine the temperature programmed growth (TPG) with CVD [2]. Moreover, by using just the TPG procedure, it is possible to grow graphene flakes of various average sizes, depending on the growth parameters used. The overall area of Ir(111) sample covered with flakes after each TPG cycle is always the same, regardless of the temperature [3]. Here we report a study of graphene flakes obtained by ethene decomposition on Ir(111) using the TPG procedure at various temperatures. As the decomposition temperature of the preadsorbed ethene increases, the average size of the flakes increases as well. Based on angle-resolved photoemission spectroscopy (ARPES), in particular the Dirac cone intensity analysis, we characterise graphene flakes on Ir(111) of varying sizes and compare these results with known STM and XPS data.

[1] X. Li et al., *Science* 324, 1312 (2009)[2] R. von Gastel et al., *Appl. Phys. Lett.* 95, 121901 (2009)[3] J. Coraux et al., *New J. Phys.* 11, 023006 (2009)

O 29.3 Tue 11:45 WIL B321

Growth of graphene on heteroepitaxial Ir(111)-films — ●PATRICK ZELLER¹, SEBASTIAN DÄNHARDT¹, STEFAN GSELL², MATTHIAS SCHRECK², and JOOST WINTTERLIN¹ — ¹LMU München, Department Chemie — ²Universität Augsburg, Institut für Physik

Monolayer graphene was epitaxially grown on thin iridium films by chemical vapor deposition (CVD) of ethylene. The films consist of a 150 nm thick (111)-oriented Ir layer on a Si(111) substrate with a 40 to 100 nm thick buffer layer of yttria-stabilized zirconia (YSZ) in between. The idea is to develop preparation techniques for epitaxial graphene without the need for bulk single crystals. The Ir films display a high crystalline quality with mosaic tilt and twist spreads lower than 0.2° [1]. The growth of graphene on these films was investigated by scanning tunneling microscopy (STM) and low-energy electron diffraction (LEED). We find the same four rotational graphene domains that exist on bulk Ir(111) single crystals, with rotational angles of 0°, 13.9°, 19.1°, and 30° [2,3]. STM data of the 13.9° and the 19.1° phase are reported here for the first time. The quality of the graphene and the formation of the various domains can be controlled by the growth conditions. In summary we demonstrate that the quality of the epitaxial graphene on the Ir films is comparable to Ir(111) single crystals. The

findings may open a new economic route for epitaxial graphene synthesis.

[1] Gsell, S., et al., *Journal of Crystal Growth* 2009, 311, 3731. [2] N'Diaye, A., et al. *New Journal of Physics* 2008, 10, 043033. [3] Logi-nova, E., et al. *Physical Review B* 2009, 80, 085430.

O 29.4 Tue 12:00 WIL B321

Long-Range Ordered Single Crystal Graphene on Heteroepitaxial Ni Thin Films Grown on MgO(111) — ●TAKAYUKI IWASAKI¹, HYE JIN PARK¹, MITSU HARU KONUMA¹, DONG SU LEE¹, ALEXEI ZAKHAROV², JURGEN H. SMET¹, and ULRICH STARKE¹ — ¹Max-Planck-Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany — ²Max Lab, Lund University, Box 118, Lund, S-22100, Sweden

The establishment of graphene-based electronics can be achieved when the size, crystal orientation and number of layers of graphene are controlled on a substrate. Growth of large area graphene has been reported on metal films [1] or foils [2]. The resulting graphene, however, is polycrystalline with rotational disorder and grain boundaries which can scatter carriers and thus impair the device properties. Here, we demonstrate the synthesis of large-size single crystal and uniform monolayer graphene on Ni(111) thin films that were heteroepitaxially grown on MgO substrates [3]. The Ni films have flat terraces and no large grain boundaries, and also the formation of twins is suppressed on the atomic scale. As confirmed by LEED and ARUPS measurements the Ni films as well as the synthesized graphene are single crystalline. The Ni films can be easily etched, so that the transfer of mm-scale single crystal graphene onto an insulating substrate could be achieved. Furthermore, we show the synthesis of twisted bilayer graphene by a combination of catalytic hydrocarbon reaction and carbon segregation. [1] K.S. Kim et al., *Nature*, 457, 706 (2009). [2] X. Li et al., *Science*, 324, 1312 (2009). [3] T. Iwasaki et al., *Nano Lett.*, accepted for publication.

O 29.5 Tue 12:15 WIL B321

Direct graphene growth on insulators: The interaction with the substrate — ●OLAF SEIFARTH, GUNTHER LIPPERT, JAROSLAW DABROWSKI, and GRZEGORZ LUPINA — IHP, Im Technologiepark 25, 15230 Frankfurt, Germany

Strong effort is devoted to grow graphene directly on insulators to create a technological step towards cost effective mass production of high-frequency transistors. We have shown recently, that direct graphene growth can be achieved on silicate substrates by solid carbon source deposition. Here, we present a systematic study on the interaction of the graphene with the insulator by means of Raman and photoelectron spectroscopy. We address temperature dependence, the correlation between graphene quality and the number of layers and unintentional background doping. Special notice is devoted to the agglomeration sites on the substrate.

O 29.6 Tue 12:30 WIL B321

Electrical conductivity of single functionalized graphene sheets measured by Kelvin probe force microscopy — LIANG YAN¹, ●CHRISTIAN PUNCKT², ILHAN A. AKSAY², WOLFGANG MERTIN¹, and GERD BACHER¹ — ¹Werkstoffe der Elektrotechnik und CeNIDE, Universität Duisburg-Essen, Germany — ²Dept. of Chem. and Biolog. Engineering, Princeton University, USA

Functionalized graphene can be produced in bulk amounts by the thermal exfoliation of graphite oxide resulting in a material exhibiting a large fraction of single functionalized graphene sheets (FGSs) which – in contrast to pristine (e.g. "Scotch Tape") graphene – contain a large amount of functional groups and lattice defects. The number density of functional groups and defects can be tuned either by modifying the exfoliation process or by subsequent thermal reduction or annealing. FGSs have been used in various applications ranging from polymer nanocomposites to supercapacitors and batteries. In these applications, both the intrinsic resistance of the FGSs as well as the electrical contact between adjacent sheets limit device performance. By measuring the conductivity of individual FGSs employing Kelvin probe force microscopy, we can eliminate the contribution of contact resistance, analyze the intrinsic sheet conductivity with spatial resolution, and correlate electronic and topographical features. Despite their large

degree of lattice disorder and functionalization, we obtain conductivities on the order of 10^5 S/m for individual sheets. Results are put in perspective with emerging applications and competing materials.

O 29.7 Tue 12:45 WIL B321

Single and double layer graphenes as ultra-barriers for fluorescent polymer films — •PHILIPP LANGE¹, MARTIN DORN¹, NIKOLAI SEVERIN¹, DAVID A. VANDEN BOUT², and JÜRGEN P. RABE¹ —
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²The University of Texas at Austin, Department of Biochemistry and Chemistry, USA

Graphene, with its combined high electrical conductivity, optical transparency and mechanical flexibility, offers great potential for electrodes in flexible organic optoelectronic devices. Since freely suspended graphene is also largely impermeable to gases, it could even serve as

both transparent electrode and effective barrier to protect the device against the ubiquitous degradation by water and oxygen. However, in a working device graphene may be subject to structural degradation. Here we report on the chemical and structural stability of graphene *in-situ* on a conjugated polymer film. Fluorescence and scanning force microscopies were used to probe the degradation of the polymer protected from ambient by graphene. We detected individual permeable point defects in single layer graphene resulting from a rare event structural degradation. Double layer graphene in contrast is stable and protects the polymer most efficiently from degradation. We estimate an upper limit of the water and oxygen transmission rates through graphene in direct contact with the polymer film as low as 5×10^{-6} g m⁻²day⁻¹ and 6×10^{-3} cm³m⁻²day⁻¹, respectively, which is on the order of the technologically required transmission rates. This suggests that graphenes can function as both electrode and barrier layer in future devices.