# MA 20: Graphene: Characterization and devices (HL, jointly with DS, MA, O, TT)

Time: Wednesday 9:30–13:00 Location: H17

MA 20.1 Wed 9:30 H17

**Polarization dependence of phonon modes in graphene nanoribbons** — •Felix Kampmann[1], Nils Scheuschner[1], Bernat Terrés[2,3], Christoph Stampfer[2,3], and Janina Maultzsch[1] — [1]Institut für Festkörperphysik, TU Berlin, Hardenbergstraße 36, 10623 Berlin, Germany, EU — [2]JARA-FIT and II. Institute of Physics B, RWTH Aachen University, Aachen, Germany, EU — [3]Peter Grünberg Institute (PGI-6/8/9), Forschungszentrum Jülich, Jülich, Germany, EU

Polarization dependent Raman spectroscopy has lately been used to investigate the edge states of few layer graphene revealing insight into the selection rules of their Raman modes.

Here we report polarization dependent Raman measurements on single-layer graphene nanoribbons with varying width down to 30 nm.

We show that the $\cos^2(\theta)$ behavior of the intensity ratio I(D)/I(G) can be reproduced as it has already been known for the graphene edge states. Furthermore we found a similar behavior for I(D′)/I(G) and discuss the dependence on the nanoribbon width.

MA 20.2 Wed 9:45 H17

**Manifestation of charged and strained graphene layers in the Raman response of graphite intercalation compounds** — Julio Chacon-Torres[1], •Ludger Wirtz[2], and Thomas Pichler[1] — [1]Faculty of Physics, University of Vienna, Austria — [2]Physics and Material Sciences Unit, University of Luxembourg, Luxembourg

We present recent Raman measurements together with a detailed analysis of potassium graphite intercalation compounds (GICs): stage II to stage VI (where stage n means one intercalant layer after every nth graphene layer). By ab-initio calculations of the charge densities and the electronic band dispersions, we demonstrate that most (but not all) of the charge donated by the K atoms remains on the outer graphene layers, i.e., the once adjacent to the intercalant layer. This leads to an electronic decoupling of the inner (uncharged) from the outer (charged) layers and consequently also to a decoupling of the corresponding Raman spectra: The G-line splits into two peaks and the 2D line is entirely due to the uncharged inner layers while the 2D line of the outer layers is suppressed due to the strong charging. The quantitative interpretation of the peak positions requires that the internal strain of the graphene layers is taken into account. This allows to unambiguously identify the Raman response of strained charged and uncharged graphene layers and to correlate it to the in-plane lattice constant. Raman spectroscopy is thus a very powerful tool to identify internal strain in single and few-layer graphene as well as to to identify the strain in nanoelectronic and optoelectronic devices or the local interfacial strain in other graphene composites.

MA 20.3 Wed 10:00 H17

**C–axis transport in graphite and few–layered–graphene** — •Ole Pfoch, Yuri Koval, Michael Enzelberger, and Paul Müller — Department of Physics and Interdisciplinary Center for Molecular Materials, Universität Erlangen

Electrical transport in single or few layered graphene was intensively investigated during the last decade. However, most experiments were performed with electronic transport in the plane. Measurements in perpendicular direction are rare and the results are rather sensitive to materials properties. For instance, the literature data for the anisotropy of the electrical conductivity in plane and along the c–axis varies between 100 and 10 000. One of the reasons for the wide spread of anisotropy data might be a significant influence of structural defects. We reduce the influence of these defects by decreasing the cross section of the measured structures down to $2 \times 2\,\mu m^2$. Mesa type structures were prepared by e–beam lithography and $O_2$–plasma etching. The influence of the mesa size on the c–axis conductivity and its temperature dependence were investigated. We have found that the c–axis conductivity is rather sensitive to the prehistory of the sample and to the origin of the graphite material. We present our recent results and discuss the mechanism of c–axis electrical transport.

MA 20.4 Wed 10:15 H17

**Electronic transport of metallic thin films and islands on graphene with scanning tunneling spectroscopy** — •Anne Holtsch, Hussein Shanak, Haibin Gao, and Uwe Hartmann — Institute for Experimental Physics, Saarland University, P.O. Box 151150, 66041 Saarbrücken

Electronic properties of graphene without and with metallic thin films and islands on top are investigated. The graphene layers are epitaxially grown on rhodium using a chemical vapor deposition (CVD) method. In a second step, metallic thin films and islands (Au) are deposited onto the surface of the graphene layer. Investigations are performed by using scanning tunneling spectroscopy (STS). An introduction to a method for an automated comparison and characterization of different spectroscopic curves is the focus of this presentation. This method will be used to clarify which impact the metallic thin films and islands have on the electronic properties of graphene. Therefore a comparison between the results obtained from graphene samples without and with metalic thin films and islands is presented.

MA 20.5 Wed 10:30 H17

**Fano-Profiles in HOPG and graphene flakes.** — •Matthias Städter, Matthias Richter, and Dieter Schmeisser — Brandenburg University of Technology, Cottbus, Germany

We investigated the electronic structure of the valence and conduction band of HOPG by 2D resonant photoemission spectroscopy. Our aim is to understand the electronic structure of defects and inhomogeneities in graphene and related materials in more detail. From our measurements we find that the transition from the $\sigma$-band to the $\pi^*$-band at the M-point shows a characteristic Fano-Profile. A Fano-Profile occurs as the result of the interference of the band to band transition and a parallel transition to a discrete energy level within the band gap.The theory of Fano enables us to determine the energetic location of these discrete level. It is found to be several meV above the Fermi-Energy. Additional measurements on graphene flakes lead to similar results for the $\sigma$- to $\pi^*$-band transition and the location of the discrete energy state. With this we not only can determine the energetic states of defects but also get a better understanding of the origin of the Fano profile which is a particular detail of the resonant absorption process.

MA 20.6 Wed 10:45 H17

**Multiple Auger Decay at resonant photo-excitation In carbon thin films** — •Matthias Richter, Matthias Städter, Ioanna Paloumpa, and Dieter Schmeisser — Brandenburg University of Technology Cottbus, Applied Physics and Sensors, K.-Wachsmann-Allee 17, 03046 Cottbus, Germany

We use resonant photoemission at the C1s edge to study the electronic structure of HOPG, graphene flakes and monolayer graphene. We find remarkable differences in the profile of the Auger decay channels, which we attribute to an additional multiple-Auger with a three-hole final state. A prerequisite for the appearance of this decay mechanism is the existence of localized excitonic states, which cause the appearance of the multiple Auger decay. Defects (pits, holes, steps and kinks) can act as localized excitonic states. We use those effects to identify the existence and the quantity of such defect states within the $\pi^*$-band regime in carbon thin films, because the intensity of the three-hole Auger decay is varying with the defect density of the carbon films. The defect-excitonic states can be either localized in the band-gap at the M-point or in case of surface defects like steps, kinks or pits even at the K-point by losing the pure $sp^2$ character of the films. We find that the appearance of the multiple Auger decay is different for multilayer and monolayer graphene. In particular the interaction of impurities leads to broadening of the C1s core levels. The three-hole Auger decay spectroscopy is a new method to detect such contaminations with a high sensitivity.

MA 20.7 Wed 11:00 H17

**Characterization of large-scale graphene CVD with far-infrared radiation** — •Christian Cervetti[1], Boris Gorshunov[1,4,5], Elena Zhukova[1,4,5], Martin Dressel[1], Klaus Kern[2,3], Marko Burghard[2], and Lapo Bogani[1] — [1]1. Physikalisches Institut, Universität Stuttgart — [2]Max Planck Institut für Festkörperforschung — [3]Institute de Physique de la Matière Condensée, Ecole Polytechnique de Lausanne, Switzerland — [4]A.M.Prokhorov General Physics Institute, Russian Academy of Sciences, Russia — [5]Moscow Institute of Physics and Technology (State University), Russia

We use monochromatic terahertz (THz) spectrometer and standard Fourier-transform spectrometer to measure the conductance of large scale single layer graphene obtained by chemical vapor deposition. We demonstrate the extreme sensitivity of the THz conductance to copper particles produced on graphene during the transfer process, making THz spectroscopy a powerful tool for monitoring the removal of unwanted leftovers during the production of large scale graphene samples.

**Coffee break**

MA 20.8 Wed 11:30 H17

**Terahertz generation in freely suspended graphene** — •Andreas Brenneis[1], Leonhard Prechtel[1], Helmut Karl[2], Dieter Schuh[3], Werner Wegscheider[4], Li Song[5], Pulickel Ajayan[6], and Alexander W. Holleitner[1] — [1]Walter Schottky Institut and Physik-Department, TU München, Germany — [2]Institute of Physics, University of Augsburg, Germany — [3]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany — [4]Laboratorium für Festkörperphysik, ETH Zürich, Switzerland — [5]University of Science and Technology of China — [6]Rice University, Houston, Texas, USA

We report on THz generation and picosecond photocurrents in freely suspended bilayers of graphene [1]. The graphene layers are connected to coplanar strip lines which serve as source and drain contacts. A pump laser pulse excites charge carrier in the graphene. The resulting charge carrier dynamics couple to the strip line circuit and propagate along the strip line. With a probe laser pulse focused onto an on-chip photo switch, the propagating signal is read out via a third contact with a picosecond time resolution. By varying the delay of the probe pulse relative to the pump pulse, the optoelectronic signal can be measured time-resolved. We discuss the generation of THz radiation, ultrafast displacement currents, and thermoelectric currents within the optically excited graphene. Financial support by the ERC-grant NanoREAL is acknowledged.

References: [1] L. Prechtel, L. Song, D. Schuh, P. Ajayan, W. Wegscheider, A.W. Holleitner, Nature Comm. 3, 646 (2012).

MA 20.9 Wed 11:45 H17

**Broadband THz detection with graphene flakes** — •Martin Mittendorff[1,2], Stephan Winnerl[1], Josef Kamann[3], Jonathan Eroms[3], Harald Schneider[1], and Manfred Helm[1,2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Universität Dresden, Germany — [3]Universität Regensburg, Germany

We demonstrate a broadband THz detector based on graphene flakes, which are produced by scotch-tape method on $SiO_2/Si$, combined with a logarithmic periodic antenna. The antenna is coupled to the graphene flake with an interdigitated comb-like structure in the center. The detectors were characterized at roomtemperature using the free-electron laser FELBE at the Helmholtz-Zentrum Dresden-Rossendorf. The responsivity is above 1 nA/W for wavelengths from $30\mu m$ to $220\mu m$. The rise time of the measured signals is below 100 ps and their length is in the range of 200 ps, while the pulse duration of the FEL pulses is around 20ps. The effect of the antenna coupling could be confirmed via polarization dependent measurements. Due to the spectral bandwidth combined with high temporal resolution and simple handling these detectors can be very useful for timing purposes of short laser pulses.

MA 20.10 Wed 12:00 H17

**Electrostatic force and Raman spectroscopy measurements on graphene replicating water layers on mica** — •Vitalij Scenev, Philipp Lange, Nikolai Severin, and Jürgen P. Rabe — Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Deutschland

Recently it has been argued that graphenes exfoliated onto mica become hole-doped by the substrate and that the doping level can be blocked by molecular water interlayers confined during sample preparation [1]. We use Scanning Probe Microscopy (SPM), Electrostatic Force Microscopy (EFM) and Raman Spectroscopy to investigate both the structure and the electronic properties of graphene conforming to molecular water layers on the mica surface. The layers are fluid, since variation of ambient humidity allows to control in-situ the layer thicknesses in the range of a monolayer [2]. Our data imply that graphene is hole-doped by the water layers with the doping level increasing with the water layer thickness.

1. Shim, J., et al., Water-Gated Charge Doping of Graphene Induced by Mica Substrates. Nano letters, 2012. 12(2): p. 648-654.

2. Severin, N., et al., Reversible dewetting of a molecularly thin fluid water film in a soft graphene-mica slit pore. Nano letters, 2012. 12(2): p. 774-779.

MA 20.11 Wed 12:15 H17

**Tailoring the graphene/silicon carbide interface for monolithic wafer-scale electronics** — •Stefan Hertel[1], Daniel Waldmann[1], Johannes Jobst[1], Andreas Albert[1], Matthäus Albrecht[1], Sergey Reshanov[2], Adolf Schöner[2], Michael Krieger[1], and Heiko B. Weber[1] — [1]Chair for Applied Physics, Erlangen, Germany — [2]ACREO AB, Kista, Sweden

The vision of graphene as future material for electronic devices is derived from impressive material parameters. However, it is evident that graphene will not readily take over the role of a semiconductor. In particular, an efficient switch is lacking due to graphene's missing bandgap.

By focusing not only on the graphene layer, but considering the silicon carbide (SiC) substrate as an essential part of the system, we developed an easy scheme to fabricate transistors with high ON/OFF ratio - suited for logic - by tailoring the interface between SiC and the graphene layer [1]. Therefore we currently work with two graphene materials on SiC: as grown monolayer graphene (MLG) and hydrogen intercalated quasi-freestanding bilayer graphene (QFBLG). We proved the high-quality ohmic contact of MLG to n-type SiC and also characterized the Schottky-like behavior of QFBLG.

Using these components we are currently able to demonstrate transistors with ON/OFF ratios exceeding 104 at room temperature in normally-on and normally-off operation mode. We present a concept for inverters using a resistor-transistor logic scheme.

[1] S. Hertel *et al.*, Nature Communications **3**, 957 (2012)

MA 20.12 Wed 12:30 H17

**Electrical interfacing of cells with graphene field effect transistors** — •Felix Rolf, Lucas H. Hess, Tobias Schneider, Benno Blaschke, Moritz Hauf, and Jose A. Garrido — Walter Schottky Institut, TU München

The next generation of neuroprosthetic devices will need novel solid-state sensors with improved performance. Increased signal detection capability, better mechanical and physiological compatibility with living tissue, and in general a higher stability in biological environments are among the main requirements. Due to its electronic and electrochemical characteristics, as well as its physico-chemical properties, graphene is one of the most suitable candidates to meet these demanding requirements.

In this talk, we will report on arrays of graphene solution-gated field effect transistors (G-SGFETs) which are able to detect the electrical activity of electrogenic cells. It will be discussed how the combination of high carrier mobilities in graphene and the large interfacial capacitance at the graphene/electrolyte interface results in such high signal sensitivities. Thereby it is possible for instance, to show the generation and propagation of action potentials in cardiomyocyte-like HL-1 cell cultures. Another application is the single cell-transistor coupling using Human Embryonic Kidney (HEK293) cells. In the latter case the response of the G-SGFETs to electrical activity as well as the cell chemical activity will be discussed. Our results confirm that G-SGFETs are able to outperform state-of-the-art devices, suggesting that G-SGFETs can play an important role in future bioelectronic systems.

MA 20.13 Wed 12:45 H17

**Exploring the electronic performance of graphene FETs for bio-sensing** — •Lucas Hess, Benno Blaschke, Max Seifert, and Jose Garrido — Walter Schottky Institut, TU München

For medical applications such as neuroprostheses and for fundamental research on neuronal communication, it is of utmost importance to develop a new generation of electronic devices which can effectively detect the electrical activity of nerve cells. The outstanding electronic and electrochemical performance of graphene hold great promise for bioelectronic applications. For instance, we have reported on arrays of CVD-grown graphene solution-gated FETs (SGFETs) for cell interfacing, demonstrating their ability to transduce with high resolution the electrical activity of individual electrogenic cells.

In this contribution, we will present a detailed discussion on the suitability of CVD-grown graphene SGFETs for in-electrolyte operation, together with a study of the effect of electrolyte composition on the device performance. The sensitivity of SGFETs is dominated by two characteristic parameters: transconductance and electronic noise,

which will be analyzed in this talk by in-electrolyte Hall-effect experiments and low-frequency noise characterization. Finally, we will briefly report on the pH and ion sensitivity of graphene devices, highlighting the influence of the chosen substrate for the device fabrication, as well as the effect of surface contamination from the fabrication technology.

This work demonstrates the potential of graphene to outperform state-of-the-art Si-based devices for biosensor and bioelectronic applications.