HL 15: C/diamond I

Time: Tuesday 9:30–13:00 Location: POT 51

HL 15.1 Tue 9:30 POT 51

Subtractive combination modes in the intermediate frequency region of the Raman spectrum of carbon nanotubes — •Daniel Niesner, Jonas Röhrl, Ralf Graupner, and Martin Hundhausen — Lehrstuhl für Technische Physik, Universität Erlangen-Nürnberg, Erwin-Rommel-Strasse 1, 91058 Erlangen, Germany

Raman spectroscopy has become a widely used tool for the investigation of carbon nanotubes. The Raman spectrum of carbon nanotubes is dominated by the prominent features in the high and low frequency region. Apart from those in the intermediate frequency region between 400 and 1000 cm^{-1} several less intense Raman modes are observed which result from higher order scattering. By measuring the temperature dependence of the intensity of these modes we identified subtractive combination modes which result from processes in which one phonon is created and another one is annihilated. From our measurements we estimate the frequencies of the phonons involved in the process.

HL 15.2 Tue 9:45 POT 51

Characterization of Peapods synthesis from CVD grown Carbon Nanotubes — •Christian Spudat, Carola Meyer, Karin Goss, Paul Kögerler, and Claus M. Schneider — Forschungszentrum Jülich, Institut für Festkörperforschung, Electronic Properties (IFF-9), 52425 Jülich

Because of their ballistic conductance Carbon Nanotubes (CNTs) are a promising material for spintronic devices. Their magnetic and electronic properties can be altered by functionalization. This can be done by side groups sticking on the outside or the inside of the CNTs or by filling the inner hollow of CNTs with guest molecules. When C_{60} is used as a guest molecule the resulting structure is called a "peapod". In this talk we present a characterization of the different step towards peapods synthesized from CVD grown CNTs using HRTEM measurements. But even at electron energies as low as $E = 80\ keV$ individual CNTs and especially C_{60} molecules are destroyed during electron irradiation indicated by the collapse of sidewalls and coalescence of interior C_{60}. Therefore we use Raman spectroscopy as a non-destructive method to characterize nanotubes during different steps of the peapod synthesis and correlate these measurements with our microscopic results. This comparison between spectroscopy and microscopy allows us to investigate changes in the Raman spectra during different synthesis steps and allocate them to the microscopic images to get a better understanding of different changes in the Raman spectra of CNTs during peapod synthesis.

HL 15.3 Tue 10:00 POT 51

A comparison of the temperature-dependent charge carrier dynamics in naturally grown graphite and HOPG probed by time-resolved THz spectroscopy — •Konrad von Volkmann[1], Martin Scheuch[1], Luca Perfetti[2], Tobias Kampfrath[1], Christian Frischkorn[1], and Martin Wolf[1] — [1]Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin — [2]Laboratoire des Solides Irradiés, Ecole polytechnique, 91128 Palaiseau cedex, France

The ultrafast charge carrier dynamics of naturally grown graphite and Highly Oriented Pyrolytic Graphite (HOPG) have been investigated by time-resolved THz spectroscopy in the range of 10 to 30 THz. For both samples, we present temperature dependent measurement of the scattering rates between 10 K and 300 K and give a comparison of the static dielectric function. While HOPG displays a clear rise of the scattering rate with temperature this behavior is hardly noticeable - if at all present - in the case for naturally grown graphite. A discussion of possible origins of this discrepancy will be given.

HL 15.4 Tue 10:15 POT 51

Development of ultra nanocrystalline diamond (UNCD) growth rate and surface roughness: a simulation study — •Hadwig Sternschulte[1,2] and Ulrich Stimming[1,2] — [1]nanotum, Technische Universität München, D-85748 Garching — [2]Physik Department E19, Technische Universität München, D-85748 Garching

The growth of ultra nanocrystalline diamond (UNCD) with grain sizes of 10 nm and less was simulated by a simple geometrical model: diamond spheres with a fixed diameter are statistically distributed over a flat substrate surface. The number of spheres spread by each simulation cycle are defined by the secondary nucleation rate. Before each start of the simulation, the substrate was covered with diamond seeds whose concentration is described by the primary nucleation rate. The probability to attach a diamond sphere to the bare substrate was set to zero. Distributed diamond spheres which are in contact with yet deposited diamond or with seed nuclei are attached with a probability of one. Two variations of the model are discussed: i) the diamond spheres are attached at the first point of contact (ballistic deposition) resulting in the formation of many voids, and ii) the newly attached diamond spheres are located at the minimum possible z position (solid on solid model) minimising the formation of voids. In this work, a comparison of the early stages of the UNCD growth will be presented. Especially, the development of the minimal film thickness for a continuous closed layer in dependence of the primary nucleation rate, the development of the growth rate with time and of the surface roughness will be discussed with both models and compared with experimental data.

HL 15.5 Tue 10:30 POT 51

Raman Spectroscopy on folded Graphene — •Robert Panknin, Philipp Klar, Cinzia Casiraghi, and Stephanie Reich — Fachbereich Physik, Freie Universität, Berlin

Raman spectroscopy is a non-destructive technique able to identify graphene from graphite, to probe the doping level of graphene and determine the amount of defects [1-3].

Here we investigate the effect of the interaction between graphene layers and their stacking order by Raman spectroscopy. The stacking order affects the second order Raman spectrum, as shown in graphite (AB stacking) and turbostratic (random stacking) graphite [4].

Graphene and few graphene layers are obtained by micromechanical cleavage. Folded flakes are then selected. We show that the folding changes the electronic structure of graphene and this can be uniquely probed by Raman spectroscopy.

[1] Ferrari, A. C. et al., Phys. Rev. Lett. **97**, 187401 (2006)
[2] Pisana, S. et al., Nature Mater. **6**, 198-201 (2007)
[3] Casiraghi, C. et al., Appl. Phys. Lett. **91**, 233108 (2007)
[4] Lespade P. et al., Carbon **22**, 375 (1984)

HL 15.6 Tue 10:45 POT 51

The non-linear optical properties of single and multilayer graphene — •Rainer Stöhr[1], Roman Kolesov[1], Fedor Jelezko[1], Jens Pflaum[2], and Jörg Wrachtrup[1] — [1]3rd Physics Institute, Stuttgart University, D-70659 Stuttgart — [2]Julius-Maximilians-University of Würzburg, Institute of Physics, Experimental Physics VI, D-97074 Würzburg and Bavarian Centre for Applied Energy Research e.V. (ZAE Bayern), D-97074 Würzburg

By optically exciting graphene flakes with pico- and femtosecond pulses of different wavelengths and with pulse power densities in the order of GW/cm^2 we can not only observe the well known G-line and D'-line but also the anti-Stokes G line. In addition, a broad background can be detected which peaks at the excitation wavelength and which extends by about 3000 wavenumbers into the red and about 2500 wavenumbers into the blue. Both, the anti-Stokes G line and the background were found to be of cubic dependence with respect to incident laser power.

We can explain the occurrence of the anti-Stokes G line as a result of a stimulated Raman process due to the pulsed laser excitation.

It will be evidenced that simple heating effects of the flakes cannot account for the broad continuum radiation; however this feature can be assigned to an electron-hole scattering mechanism which depends primarily on the number of excited charge carrier pairs.

As a possible application we show that the continuum radiation can be used to significantly improve the contrast of a confocal image compared to that mapped at the Raman lines and thereby will pave the way of a detection mechanism of high sensitivity.

HL 15.7 Tue 11:00 POT 51

Weak Localization and Transport Gap in Graphene Antidot Lattices — •Jonathan Eroms and Dieter Weiss — Institut für Experimentelle und Angewandte Physik, Universität Regensburg

We have performed transport experiments in antidot lattices in single

layer graphene. After mechanical exfoliation from natural graphite, suitable single layer flakes were patterned into antidot lattices using electron beam lithography and plasma etching. The lattice periods varied between 90 nm and 400 nm.

When the lattice period is reduced, the quantum Hall effect gradually disappears owing to the geometrical condition that a cyclotron orbit has to fit through the constrictions between the antidots. Samples with narrow channels between the antidots can be regarded as a network of graphene nanoribbons and correspondingly show a transport gap of a few mV at low temperatures.

In the magnetotransport curves we observe a pronounced weak localization effect. The strong visibility is due to intervalley scattering at the antidot edges. By a careful examination of the temperature and geometry dependence we conclude that our short-period antidot lattices are best described as an array of phase-coherent cavities.

HL 15.8 Tue 11:15 POT 51

Adsorbates on graphene: Impurity states and electron scattering — •Tim Wehling[1], Mikhail Katsnelson[2], and Alexander Lichtenstein[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstrasse 9, 20355 Hamburg — [2]Institute for Molecules and Materials, Radboud University of Nijmegen, Heijendaalseweg 135, 6525 AJ Nijmegen, The Netherlands

Sources of electron scattering in graphene are being controversially debated to date. Midgap states and / or charged impurites are considered as possible factors determining graphene's electronic transport properties. We present ab-initio studies of impurites on graphene and elucidate the role of the SiO_2 substrate. We show that water and ethanol adsorbates strongly affect the coupling of graphene's electrons to impurity bands in the substrate. Covalently and ionically bond impurities on free standing graphene are considered and characteristic desorption energies are discussed. Covalently bond impurities are shown to cause midgap states which are strongly coupled to the graphene bands.

15 min. break

HL 15.9 Tue 11:45 POT 51

Graphene on various substrates — •Ulrich Stöberl, Ursula Wurstbauer, Werner Wegscheider, Dieter Weiss, and Jonathan Eroms — Institut für Experimentelle und Angewandte Physik, Universität Regensburg, 93040 Regensburg, Germany

So far nearly all transport experiments on graphene have been carried out using silicon dioxide (SiO_2) as a substrate. Therefore it is interesting to study electrical transport in graphene on substrates other than SiO_2. To clarify the influence of the substrate on visibility, morphology and transport properties of graphene and few layer graphene (FLG), we study graphene on molecular beam epitaxy (MBE) grown (001)-GaAs-, manganese p-doped (001) GaAs- and InGaAs-substrates. We combine scanning electron microscopy (SEM) and atomic force microscopy (AFM) to detect, pattern, and study the morphology of the graphitic layers on different substrate materials. The MBE grown substrates can be tailored in terms of morphology, polarity as well as doping and are all equipped with back-gate electrodes. From morphology and flexibility measurements we learned that graphene is quite flexible and follows continuous textures. Thin layers of carbon have the capacity to follow the morphology of the substrate from the nm- to the μm range. Low-temperature magnetotransport measurements of graphene on these substrates reveal normal electric field dependence via back gate voltages as known from reports of transport on suspended graphene or layers on SiO_2. In further studies, the influence of the substrate on position and sharpness of the Dirac-Point, intrinsic carrier density and mobility will be investigated.

HL 15.10 Tue 12:00 POT 51

Raman Spectroscopy of Graphene and Few Layer Graphene in Different Dielectric Environments — •Philipp Klar, Robert Panknin, Cinzia Casiraghi, and Stephanie Reich — Fachbereich Physik, Freie Universität, Berlin, Germany

Graphene is the two-dimensional prototype for carbon allotropes. Recently, graphene has attracted a lot of interest because it shows ballistic transport at room temperature along with chemical and mechanical stability [1]. Raman spectroscopy is a powerful tool to identify graphene and to probe its doping level [2-4]. It has been shown that charged-impurities can strongly affect the electronic properties of graphene, in particular they can limit its mobility [5]. Here we use Raman spectroscopy in order to investigate the effect of different dielectric environments and substrates on the electronic structure of graphene and few layer graphene. Graphene and graphene layers have been obtained by micro mechanical cleavage of graphite and placed on different substrates (silicon covered with 300 nm silicon oxide, glass and calcium fluoride) and in different media with high dielectric constant.

[1] A.K. Geim et al., Nat. Mater. **6**, 183 (2007)
[2] A.C. Ferrari et al., PRL **97**, 187401 (2006)
[3] S. Pisana et al., Nat. Mater. **6**, 198 (2007)
[4] C. Casiraghi et al., APL **91**, 233108 (2007)
[5] J.H. Chen et al., Nat. Phys. **4**, 377 (2008)

HL 15.11 Tue 12:15 POT 51

Ab initio calculations of the phonon spectra of graphene nanoribbons — •Roland Gillen, Marcel Mohr, Janina Maultzsch, and Christian Thomsen — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin

During the past decades, graphite-related materials of nanoscale, such as nanotubes, have been subject to scientific research. Their remarkable optical and electronical properties make them promising for use in future nanotechnology. Recently, another type of nanoscale materials, narrow strips of graphene (single layer graphite), have been fabricated and investigated regarding their electronical and transport properties. Those graphene nanoribbons correspond to "unrolled" carbon nanotubes, i.e. the model system used in zone-folding calculations of carbon nanotube properties. We use DFT calculations to obtain the bandstructures and phonon dispersions of nanoribbons of various shapes and widths. Group theory was applied to classify the resulting phonon modes. We show that most of the phonon modes can be interpreted as "overtones" of a few "fundamental modes" and that these overtones can be understood from zone folding the phonon dispersions of graphene. Shape and size dependences are found. Similarities between nanoribbons and carbon nanotubes will be discussed.

HL 15.12 Tue 12:30 POT 51

Bound states and magnetic field-induced valley splitting in gate-tunable graphene quantum dots — •Patrik Recher[1,2], Johan Nilsson[1], Guido Burkard[3], and Björn Trauzettel[2] — [1]Instituut-Lorentz, Universiteit Leiden, P.O. Box 9506, 2300 RA Leiden, The Netherlands — [2]Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany — [3]Department of Physics, University of Konstanz, 78457 Konstanz, Germany

The magnetic field dependence of energy levels in gapped single- and bilayer graphene quantum dots (QDs) defined by electrostatic gates is studied analytically in terms of the Dirac equation. Due to the absence of sharp edges in these types of QDs, the valley degree of freedom is a good quantum number. We show that its degeneracy is efficiently and controllably broken by a magnetic field applied perpendicular to the graphene plane. This opens up a feasible route to create well-defined and well controlled spin- and valley-qubits in graphene QDs. We also point out the similarities and differences in the spectrum between single- and bilayer graphene quantum dots. Striking in the case of bilayer graphene is the anomalous bulk Landau level (LL) that crosses the gap which results in crossings of QD states with this bulk LL at large magnetic fields in stark contrast to the single-layer case where this LL is absent. We discuss the applicability of such QDs to control and measure the valley isospin and their potential use for hosting and controlling spin qubits.

HL 15.13 Tue 12:45 POT 51

Graphene-based nanoelectronics — •Soeren Neubeck, Frank Freitag, L. A. Ponomarenko, Rui Yang, A. K. Geim, and K. S. Novoselov — Department of Physics, University of Manchester, Manchester M13 9PL, UK

Graphene, a monolayer of Carbon atoms arranged in a honeycomb-lattice, holds strong promise for microelectronic applications in the post-Silicon age. Still, a current technological problem is, that graphene remains conducting even in the limit of virtually zero carrier concentration.

Recent theoretical and experimental work has shown, that it is possible to introduce an energy gap in graphene by confining its geometrical dimensions.

Here, we use an atomic force microscope (AFM) to manipulate graphene films on a nanoscopic length scale. By means of local an-

odic oxidation with an AFM-tip we are able to structure isolating trenches into single-layer graphene flakes, down to a trench size of less than 30nm in width. Using this technique, we demonstrate the fabrication of a single-layer graphene quantum dot. The device consists of a nanometre-sized graphene island, that is coupled to source and drain electrodes via two narrow constrictions. Low-temperature transport measurements of this device reveal Coulomb blockade, and Coulomb diamonds, characteristic of quantum dots, have been measured. A charging energy of the dot of 10meV could be extracted, which corresponds to the geometric dimensions of the dot structure formed.