HL 4: Carbon: Diamond, Nanotubes, and Graphene

Time: Monday 10:15–13:30 Location: POT 251

HL 4.1 Mon 10:15 POT 251

Dynamical Decoupling of a single electron spin at room temperature — •Florian Dolde[1], Boris Naydenov[1], Liam T. Hall[2], Chang Shin[3], Helmut Fedder[1], Lloyd C.L. Hollenberg[2], Fedor Jelezko[1], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut and Research Center SCOPE, University of Stuttgart, Stuttgart 70659, Germany — [2]Centre for Quantum Computer Technology, School of Physics, University of Melbourne, Victoria 3010, Australia — [3])National Biomedical Center for Advanced ESR Technology, Dept of Chemistry and Chemical Biology, Cornell University, Ithaca, NY 14853, USA

The negatively charged Nitrogen-Vacancy center (NV) in diamond attracted a lot of interest lately due to the possibility of optical spin state read out of a single center and the possibility of coherent manipulations with microwaves at room temperature. Due to these unique properties the NV is an excellent candidate for room temperature quantum information processing and very sensitive magnetometry using an atom sized sensor. Here we report the increase of the coherence time T^2 of a NV by using dynamical decoupling. We show that the Carr-Purcell-Meiboom-Gill (CPMG) pulse sequence can prolong the T^2 of a single Nitrogen-Vacancy center in diamond up to 2.44 ms compared to the Hahn echo measurement where $T^2 = 390\ \mu$s. Moreover, by performing spin locking experiments we demonstrate that with CPMG the maximum possible T^2 is reached. An application for detecting low magnetic field is demonstrated, improving the sensitivity by about a factor of two compared to the Hahn echo method.

HL 4.2 Mon 10:30 POT 251

Towards two electronic spin entangelment — •Ingmar Jakobi, Florian Dolde, Boris Naydenov, Helmut Fedder, Fedor Jelezko, and Jörg Wrachtrup — 3 Physikalisches Institut and Research Center SCOPE, University of Stuttgart, Stuttgart 70659, Germany

The negatively charged Nitrogen-Vacancy center (NV) in diamond attracted a lot of interest lately due to the possibility of optical spin state read out of a single center and the possibility of coherent manipulations with microwaves at room temperature. Due to these unique properties the NV is an excellent candidate for room temperature quantum information processing. We conducted a systematic search with ground state depletion measurements (GSD) and double electron electron resonance experiments (DEER) on implanted samples in order to identify NV pairs with a suitable distance with a strong dipolar coupling allowing for entanglement experiments.

HL 4.3 Mon 10:45 POT 251

Controlling the charge state of nitrogen-vacancy centers in diamond — •Moritz Hauf[1], Bernhard Grotz[2], Boris Naydenov[2], Markus Dankerl[1], Magalí Ros[1], Fedor Jelezko[2], Jörg Wrachtrup[2], Martin Stutzmann[1], Friedemann Reinhard[2], and José Garrido[1] — [1]Walter Schottky Institut, TU München, Garching — [2]3rd Physics Institute, University of Stuttgart

Nitrogen-vacancy defects (NV) in the diamond lattice have been extensively studied as they can act as single photon emitters with absolute photo-stability. Furthermore, they have found applications in novel fields like quantum computation and single spin magnetometry. In this context, it is of great interest to understand the effect of diamond surface termination and gain control over the charge state of NV centers in diamond. We have shown that by changing the diamond surface termination from oxygen to hydrogen, the fluorescence of the negatively charged NV (NV$^-$) can be suppressed, depending on the implantation energy and dose used for the creation of NV centers in diamond by low-energy nitrogen implantation. This effect is attributed to the band bending that occurs at hydrogen-terminated diamond surfaces. A two-dimensional hole gas is formed at the surface, converting the NV$^-$ to either neutral or even positively charged NV centers. Self-consistent numerical simulations can reproduce the surface band bending and the concurrent disappearance of the NV$^-$ fluorescence. Finally, we have demonstrated that electrostatic control of the charge state of single NV centers can be achieved by using surface-conductive diamond devices and an external gate electrode.

HL 4.4 Mon 11:00 POT 251

Electron transfer in diamond- and graphene-based hybrid systems — •Roberta Caterino, Franz Fuchs, Andreas A. Reitinger, Martin Stutzmann, Ian D. Sharp, and Jose A. Garrido — Walter Schottky Institut, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

In bioelectronic hybrids, composed of photoreactive proteins on inorganic electrodes, the electron transfer between protein and electrode will largely determine the efficiency of the energy transfer. Electron transfer processes depend on a large variety of parameters, such as substrate density of states, protein orientation, electrode-protein distance, etc. It is thus desirable to develop advanced spectroscopic techniques which can provide spatially and energetically resolved information about electron transfer across the electrode/protein interface. We report on the characterization of functional carbon-based surfaces using standard electrochemical techniques as well as ambient and electrochemical scanning tunnelling microscopy and spectroscopy (STM/STS). We will present our work on the modification and functionalization of both diamond and graphene substrates, reporting on novel protocols to obtain an effective grafting of proteins on these carbon surfaces. We have investigated the electron transfer in these protein/ carbon hybrid structures. Using standard electrochemical spectroscopy and STS, we have been able to study the electron transfer between conductive diamond electrodes and covalently immobilized proteins. In addition, we will study how graphene modifies these interfacial phenomena on graphene/diamond hybrid electrodes.

HL 4.5 Mon 11:15 POT 251

Entwicklung und Simulation von SiC-Thyristoren mit integrierter Amplifying-Gate-Struktur — •Korbinian Kaltenecker und Jens-Peter Konrath — Dt.-Frz. Forschungsinstitut Saint-Louis, 5 rue du General Cassagnou, F-68301 Saint-Louis, France

Siliziumcarbid (SiC) hat als Halbleitermaterial bezüglich seiner elektrischen und physikalischen Eigenschaften viele Vorteile gegenüber Silizium. Aufgrund des höheren Bandabstands, der hohen Durchbruchfeldstärke und der guten Wärmeleitfähigkeit werden SiC-Bauteile besonders im Bereich der Leistungsanwednungen entwickelt. Ein typisches Bauteil aus SiC, an dessen Umsetzung in diesem Gebiet gearbeit wird, ist der Thyristor. Zur Zeit sind Thyristoren mit einer Sperrspannung von bis 6 kV kommerziell verfügbar. Bauteile mit bis zu 12 kV Sperrspannung, die mit Pulsströmen größer 10 kA und Pulsweiten von bis zu mehreren Mikrosekunden betrieben werden können, sind Gegenstand der Forschung. Hinsichtlich der Verbesserung der Qualität und Größe der SiC-Wafer, ist nun die Entwicklung großflächiger Thyristoren möglich geworden. Die Integration einer Amplifying-Gate-Struktur in den Thyristor (AGT) ist für großflächige, auf Silizium basierenden Thyristoren ein standartmäßiges Verfahren, um den notwendigen Gate-Strom zum Anschalten des Bauteils klein zuhalten, die Zündgeschwindigkeit zu erhöhen und eine homogene Zündausbreitung zu erreichen. Dieses Verfahren soll nun auf SiC-Bauteile übertragen werden. Wir stellen hier die Realisierung von AGTs, erste experimentelle Resultate, sowie Ergebnisse der Simulation eines solchen Bauteils vor.

HL 4.6 Mon 11:30 POT 251

Dielectrophoretic assembly of field-effect transistors using sorted semiconducting carbon nanotubes — •Juliane Posseckardt[1], Yann Battie[2], Romain Fleurier[2], and Michael Mertig[1] — [1]TU Dresden, Professur für Physikalische Chemie, Mess- und Sensortechnik, 01062 Dresden, Germany — [2]LEM UMR 104 Onera-CNRS 92322 Châtillon, France

We report on the direct assembly of single-walled carbon nanotube field-effect transistors (SWCNT-FETs) by dielectrophoresis using highly enriched semiconducting carbon nanotubes.

The SWCNTs have been sorted using an improved separation technique by density gradient ultracentrifugation made in two steps. The sorted SWCNTs have been characterized by Raman and UV-vis-IR spectroscopy.

The out-of-solution guided assembly from sorted semiconducting fraction is superior in comparison to conventional assembly from unsorted fractions because of the missing necessity to break down purely metallic current bridges. By this, transistors with a high ON/OFF ratio can be produced in one step.

15 min. break

HL 4.7 Mon 12:00 POT 251

Time-resolved picosecond photocurrents in contacted carbon nanotubes — •Leonhard Prechtel[1], Li Song[2], Stephan Manus[2], Dieter Schuh[3], Werner Wegscheider[4], Nadine Erhard[1], and Alex W. Holleitner[1] — [1]Walter Schottky Institut and Physik-Department, TU München — [2]Fakultät für Physik and Center for NanoScience (CeNS), LMU, München — [3]Institut für Experimentelle und Angewandte Physik, Universität Regensburg — [4]Laboratorium für Festkörperphysik, ETH Zürich

We introduce coplanar stripline circuits to resolve the ultrafast photocurrent dynamics of freely suspended carbon nanotubes (CNTs) in the time-domain. By applying an on-chip pump-probe laser spectroscopy we demonstrate that CNTs, contacted by metal electrodes, exhibit a picosecond photocurrent response. We find a combination of an optically induced ultrafast displacement current, transport of photo-generated charge-carriers at the Fermi velocity to the electrodes, and interband charge-carrier recombination processes to dominate the ultrafast photocurrent of the CNTs.

HL 4.8 Mon 12:15 POT 251

Localized defects in single carbon nanotubes imaged with high-resolution tip-enhanced Raman spectroscopy — •Carsten Georgi and Achim Hartschuh — Department Chemie & CeNS, Ludwig-Maximilians-Universität München, Germany

Raman spectroscopy is a powerful tool to study defects in sp^2 carbon materials including carbon nanotubes, graphite and graphene [1]. Defects in the crystalline structure of these materials activate scattering by large momentum phonons giving rise to the characteristic D-band Raman signal. We imaged the D-band scattering in metallic single-walled carbon nanotubes with a spatial resolution of 15 nm using tip-enhanced Raman spectroscopy (TERS). The spatial extension of the D-band signal in the vicinity of localized defect sites was visualized and found to be about 2 nm. Furthermore, localized defects were intentionally photo-generated using the strong optical near-fields at the tip while simultaneously recording the temporal evolution of the local Raman spectrum. From these experiments, the relation between defect density and Raman D-band intensity could be derived for the investigated nanotubes. This relation is highly relevant for the characterization of carbon nanotubes via Raman spectroscopy [2].

[1] A. C. Ferrari *et al.*, Phil. Trans. R. Soc. Lond. A **362**, 2477 (2004)

[2] C. Georgi, A. Hartschuh, Appl. Phys. Lett. **97**, 143117 (2010)

HL 4.9 Mon 12:30 POT 251

Optical Absorption of Free-standing Monolayer and Bilayer Graphene in the Ultraviolet Regime — •Tobias Utikal[1,2], Dong-Hun Chae[1], Siegfried Weisenburger[1,2], Harald Giessen[2], Markus Lippitz[1,2], and Jurgen Smet[1] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]4th Physics Institute, University of Stuttgart, 70550 Stuttgart, Germany

We present direct measurements of the optical absorption of freestanding graphene and Bernal-stacked bilayer graphene from the infrared to the ultraviolet regime. In the visible part of the spectrum our data show a slowly rising absorption towards the blue spectral region. The absolute values clearly reproduce previous findings and can be attributed to a renormalized fine structure constant [1].

However, in the ultraviolet regime, the spectra show a strong increase of the absorption. Broad peaks appear at 4.55 eV and 4.52 eV for monolayer and bilayer graphene, respectively. Using a simple model we can reproduce the experimental data in the ultraviolet as well as in the infrared regime with nearly perfect agreement. From our findings we conclude that the shape of the absorption spectra is a direct consequence of the unique band structure of graphene and its bilayer.

[1] Nair et al., Science 320, 1308 (2008)

HL 4.10 Mon 12:45 POT 251

Excited state spectroscopy on a bilayer graphene double quantum dot — •Christian Volk[1,2], Stefan Fringes[1], Bernat Terres[1,2], Jan Dauber[1], Stephan Engels[1], Stefan Trellenkamp[2], Uwe Wichmann[1], and Christoph Stampfer[1,2] — [1]JARA-FIT and II. Institute of Physics B, RWTH Aachen, 52074 Aachen, Germany — [2]Institute for Bio- and Nanosystems, Forschungszentrum Jülich, 52425 Jülich, Germany

Graphene double quantum dots are promising candidates for future spin-based quantum information applications. Here, we present tunneling spectroscopy experiments on a bilayer graphene double quantum dot device which can be tuned by five all-graphene lateral gates. The device has been prepared by exfoliation of natural bulk graphite, electron beam lithography and reactive ion etching. The diameter of the quantum dots are roughly 60 nm and the constrictions acting as tunneling barriers are 30 nm in width. Low noise charge stability measurements have been carried out in order to determine the gate lever arms and the addition energies of the two coupled quantum dots. Periodically ordered triple points of high conductance are present on a wide energy range as well as faint co-tunneling lines and excited states inside the triple points. We obtain addition energies of 18 and 23 meV respectively for the two dots. High resolution measurements on individual triple points allow us to resolve the energy spectra of excited states (level spacing 1.8 meV) and the interdot coupling energy (on the order of 2-4 meV).

HL 4.11 Mon 13:00 POT 251

Disorder induced energy gaps in graphene nanoribbons — •Jan Dauber[1], Bernat Terrés[1,2], Christian Volk[1,2], Stefan Trellenkamp[2], Uwe Wichmann[1], and Christoph Stampfer[1,2] — [1]JARA-FIT and II. Institute of Physics, RWTH Aachen University, 52074 Aachen, Germany — [2]Institute of Bio and Nanosystems, Forschungszentrum Jülich, 52425 Jülich, Germany

Graphene with its unique electronic properties is one of the most promising materials for future nanoelectronic applications. However, the missing band gap in graphene makes it difficult to transfer state-of-the-art electronic device concepts to a graphene-based technology. By tailoring graphene into narrow ribbons a transport and effective energy gap can be opened, which is crucial for semiconductor related applications. We show that these effective energy gaps scale inversely with the nanoribbon width and are roughly constant as function of length. The origin of these effective energy gaps and the local resonances are assumed to be related with the disorder potential arising from the substrate and the edge roughness. We present transport measurements on lithographically defined and etched graphene nanoribbons with focus on studying the influence of the disorder potential on the transport gaps. Treatments with hydrofluoric (HF) acid are used to change the disorder potential and result in different transport characteristics. With a short HF dip the disorder potential is significantly reduced and a complete HF release, which removes the underlying silicon oxide, leads to fully suspended graphene nanostructures with only edge roughness induced disorder and no substrate interaction.

HL 4.12 Mon 13:15 POT 251

Nonlinear elasticity of graphene and other hexagonal carbon allotropes — •Pasquale Pavone[1,2], Rostam Golesorkhtabar[1,2], Jürgen Spitaler[1,2], and Claudia Ambrosch-Draxl[1] — [1]Atomistic Modelling and Design of Materials, University of Leoben, Austria — [2]Materials Center Leoben, Forschung Gmbh, Leoben, Austria

In this work, we present a first-principles study of the linear and nonlinear elastic properties of diamond, graphene monolayers, as well as simple-hexagonal, hexagonal, and rhombohedral graphite. Calculations are performed using the pseudo-potential density-functional-theory code Quantum ESPRESSO (QE) and both the local-density and generalized-gradient approximations for the exchange-correlation energy. For each system, the Lagrangian stress tensor is calculated for distorted structures defined by given values of the Lagrangian strain. The investigation of the stress vs. strain curves allows the determination of second and higher-order elastic constants. The results we have obtained for elastic constants at different orders are discussed in comparison with experiment and previous calculations, and with results achieved using the full-potential LAPW codes WIEN2k and `exciting`. In particular, we consider the issue of numerical accuracy in the abinitio calculation of higher-order elastic constants. Furthermore, we investigate the role of van-der-Waals interlayer interactions by using the vdW-DF extension to the QE software package.