HL 3: Quantum Dots and Wires: Transport

Time: Monday 9:30–12:45 Location: EW 202

Invited Talk HL 3.1 Mon 9:30 EW 202

Unraveling spin dynamics from charge fluctuations — Eric Kleinherbers[1,2] and •Jürgen König[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]Department of Physics and Astronomy, University of California, Los Angeles, USA

The use of single electron spins in quantum dots as qubits requires detailed knowledge about the processes involved in their initialization and operation as well as their relaxation and decoherence. In optical schemes for such spin qubits, spin-flip Raman as well as Auger processes play an important role, in addition to environment-induced spin relaxation. In [1], we demonstrate how to quantitatively extract all these rates in one go from analyzing charge fluctuations of the quantum dot measured with resonance fluorescence [2]. For this, we employ the tools of waiting-time distributions and full counting statistics characterized by factorial cumulants and discuss the role of detector imperfections [3].

[1] E. Kleinherbers et al., Phys. Rev. Res. **5**, 043102 (2023).
[2] A. Kurzmann et al., Phys. Rev. Lett. **122**, 247403 (2019).
[3] E. Kleinherbers et al., Phys. Rev. Lett. **128**, 087701 (2022).

HL 3.2 Mon 10:00 EW 202

Coupling a single spin to high-frequency motion — Federico Fedele[1], •Federico Cerisola[1,2], L. Bresque[3], F. Vigneau[1], J. Monsel[4], A. Palyi[5], J. Anders[2,6], and Natalia Ares[1] — [1]Univ. of Oxford, Oxford, UK — [2]Univ. of Exeter, Exeter, UK — [3]Univ. Grenoble Alpes, CNRS, Grenoble, France — [4]Chalmers Univ. of Technology, Göteborg, Sweden — [5]Budapest Univ. of Technology, Budapest, Hungary — [6]Univ. of Potsdam, Potsdam, Germany

Coupling a single spin to mechanical motion is exciting from a fundamental perspective and is also at the heart of applications such as quantum sensing, long-distance spin-spin coupling, and classical and quantum information processing. Previous experiments have observed such coupling in low-frequency mechanical resonators that are mostly confined to the classical regime, such as diamond cantilevers. Here we report the first experimental demonstration of spin-mechanical coupling with a high-frequency resonator. We achieve this all-electrically on a fully suspended carbon nanotube device. A new mechanism gives rise to this coupling, which stems from spin-orbit coupling, and it is not mediated by strain. We observe both resonant and off-resonant coupling as a shift and broadening of the electron dipole spin resonance, respectively. We develop a complete theoretical model taking into account the tensor form of the coupling and non-linearity in the motion. Our results advance spin-mechanical platforms to an uncharted regime, with promising applications ranging from the operation of fully quantum engines to the demonstration of macroscopic superpositions, to quantum simulators.

HL 3.3 Mon 10:15 EW 202

Spin-flip rates of single electrons in coupled quantum dots — •Olfa Dani[1], Robert Hussein[2], Johannes C. Bayer[1], Klaus Pierz[3], Sigmund Kohler[4], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Hanover, Germany — [2]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Jena, Germany — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [4]Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain

Spin-flips are one of the limiting factors for spin-based information processing. We study electron transport through asymmetrically coupled InAs double quantum dots, demonstrating an approach for determining the spin-flip rates in such devices. Due to the different Landé-factors of the two quantum dots, the Zeeman splitting becomes inhomogeneous so that two spin channels are never resonant simultaneously. This leads to a spin-dependent blockade mechanism for single electrons at low temperatures. An electron may be trapped in the off-resonant channel and block transport until a spin flip occurs. We analyzed this blockade in terms of spin flips for different temperatures and magnetic fields and we were able to directly extract the spin-flip rates for single spins in coupled quantum dots from the measured resonant tunnel currents [1].

[1] Dani, O., Hussein, R., Bayer, J. C., Pierz, K., Kohler, S., Haug, R. J., Direct measurement of spin-flip rates in single-electron tunneling, arXiv:2310.11259 (2023)

HL 3.4 Mon 10:30 EW 202

Impact of competing energy scales on the shell-filling sequence in elliptic bilayer graphene quantum dots — •Lucca Valerius[1], Samuel Möller[1,2], Luca Banszerus[1,2], Angelika Knothe[3], Katrin Hecker[1,2], Eike Icking[1,2], Kenji Watanabe[4], Takashi Taniguchi[5], Christian Volk[1,2], and Christoph Stampfer[1,2] — [1]JARA-FIT and 2nd Institute of Physics, RWTH Aachen, Germany — [2]Peter Grünberg Institute, FZ Jülich, Germany — [3]Institut für Theoretische Physik, Universität Regensburg, Germany — [4]Research Center for Functional Materials, NIMS, Tsukuba, Japan — [5]International Center for Materials Nanoarchitectonics, NIMS, Tsukuba, Japan

We investigate the shell-filling sequence of gate-defined elliptic bilayer graphene quantum dots (QDs) with low charge carrier occupation ($N \leq 12$), using magnetotransport spectroscopy and numerical calculations. Considering short-range electron-electron interactions and wave-function-dependent valley g-factors, we deepen our understanding of the fourfold shell-filling sequence, emphasizing the need to include these factors. They introduce an additional energy splitting at half filling of each orbital state, and different energy shifts in out-of-plane magnetic fields. Our analysis of 31 bilayer graphene QDs shows that the valley g-factor and energy splitting increase as QD size decreases, aligning with theoretical predictions. The charging energy of these QDs does not consistently correlate with size, revealing complex electrostatics and offering insights for future BLG QD devices.

HL 3.5 Mon 10:45 EW 202

Electron dynamics of the inter Coulombic decay in higher excited states — •Sara Marando[1,3] and Annika Bande[1,2] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Hahn-Meitner-Platz 1, 10409 Berlin, Germany — [2]Institute of Inorganic Chemistry, Leibniz University Hannover, Callinstr. 9, 30167 Hannover, Germany — [3]Institute of Chemistry and Biochemistry, Freie Universität Berlin, Arnimallee 22, 14195 Berlin, Germany

Quantum dots (QDs) are semiconducting nanoparticles important due to their size-tunable excitation energy and optical properties: in their self-assembled form they can host electronic or spin qubit states with a decent lifetime . To model electronic processes like the interatomic Coulombic decay (ICD) , in QDs, we apply the Multiconfiguration Time-Dependent Hartree (MCTDH) algorithm in an antisymmetrized version. ICD is described as a decay process between two or more atomic species facilitated by the long-range Coulomb interaction between electrons at different spatial locations: on the one hand, an electron in a high energy state relaxes to a lower energy state while the energy is transferred to an electron neighbour, which is simultaneously ionised. The system studied in this work consists of a one-dimensional double-well GaAs potential. It is modeled to accommodate different electronic levels (s to d energy levels) and allows ICD to occur among higher excited states.

15 min. break

HL 3.6 Mon 11:15 EW 202

Study of non-linear dynamics of a nanomechanical resonator with single-electron tunneling — •Sofia Sevitz[1], Kushagra Aggarwal[2], Janet Anders[1,3], and Natalia Ares[4] — [1]University of Potsdam, Institute of Physics and Astronomy, 14476 Potsdam, Germany — [2]Department of Materials, University of Oxford, Oxford OX1 3PH, United Kingdom — [3]Physics and Astronomy, University of Exeter, Exeter EX4 4QL, United Kingdom — [4]Department of Engineering Science, University of Oxford, Oxford OX1 3PJ, United Kingdom

Devices that present non-linear behaviour are of much interest for their broad applications ranging from thermodynamics, chaos to metrology. A promising platform is a suspended Carbon Nanotube (CNT) containing an electrostatically defined quantum dot. The electronic transport couples to the mechanical degrees of freedom of the CNT. When the coupling is in the ultrastrong regime, the CNT experiences a pronounced back-action that leads to non-linear dynamics. When the CNT is driven weakly, this non-linearity is presented as a softening of the resonance frequency of the CNT. However, when the CNT is subjected to a strong driving, intrinsic non-linearities of the mechanics take over. The main feature is the emergence of arch-like resonances in the

electronic transport. In this talk, we describe our physical model that captures the combined interplay between the intrinsic non-linearities of the mechanics (modeled as a Duffing oscillator) and the electromechanical coupling under different driving regimes. Finally, we show that our model is in good agreement with our experimental electron transport measurements.

HL 3.7 Mon 11:30 EW 202

Size distribution determines the charge transport in ZnO quantum dot (QD) materials — •Morteza Shokrani, Dorothea Scheunemann, Clemens Göhler, and Martijn Kemerink — Institute for Molecular Systems Engineering and Advanced Materials Heidelberg University, 69120 Heidelberg, Germany

QD solids, often referred to as artificial atoms, offer the potential to create new materials with tunable macroscopic properties. Indeed, the investigation of the electronic properties of such QD assemblies has attracted attention due to the increasing applications of QD arrays in both electronics and optoelectronics. In literature, charge transport in QD assemblies has been explained by a variety of mutually exclusive theories, with the Mott and Efros-Shklovskii variable range hopping models being the most common. However, these theories fall short in explaining the anomalous exponents of the temperature-dependent conductivity $\propto \exp\left(-\left(\frac{T_0}{T}\right)^{\gamma}\right)$ observed in various QD materials. Here, we measure the temperature dependent conductivity of ZnO QDs under different UV illumination intensity. Regulating the UV intensity allows us to systematically change the effective diameter of the ZnO QDs without having to rely on cumbersome size control by synthesis. Instead, the UV level controls the width of the QD depletion shell and therefore the size distribution in the overall material. We observe exponents that systematically increase from $\gamma = 0.25$ to $\gamma = 0.75$ with increasing illumination intensity, which we interpret in terms of a charge transport being limited by the (size-dependent) charging energy of the QDs.

HL 3.8 Mon 11:45 EW 202

Coherent Charge Oscillations in a Bilayer Graphene Double Quantum Dot — •Katrin Hecker[1,2], Luca Banszerus[1,2], Aaron Schäpers[1], Samuel Möller[1,2], Anton Peters[1], Eike Icking[1,2], Kenji Watanabe[3], Takashi Taniguchi[4], Christian Volk[1,2], and Christian Stampfer[1,2] — [1]2nd Institute of Physics, RWTH Aachen University, Germany — [2]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Germany — [3]Research Center For Functional Materials, NIMS Tsukuba, Japan — [4]International Center for Matertial Nanoarchitronics, NIMS Tsukuba, Japan

The coherent dynamics of a quantum mechanical two-level system passing through an anti-crossing of two energy levels can give rise to Landau-Zener-Stückelberg-Majorana (LZSM) interference. LZSM interference spectroscopy has proven to be a fruitful tool to investigate charge noise and charge decoherence in semiconductor quantum dots (QDs). Recently, bilayer graphene has emerged as a promising platform for highly tunable QDs potentially useful for hosting spin and valley qubits. So far, coherent oscillations have not been observed in this system and little is known about charge noise in this material. Here, we report coherent charge oscillations and T2* charge decoherence times in a bilayer graphene double QD. The charge decoherence times are independently measured using LZSM interference and photon assisted tunneling. Both techniques yield T2* average values ranging from 400 to 500 ps. The observation of charge coherence allows to study the origin and spectral distribution of charge noise in future experiments.

HL 3.9 Mon 12:00 EW 202

Dynamics of hot carriers in core-shell InGaAs/InAlAs nanowires — •Nabi Isaev[1], Hamidreza Esmaielpour[1], Jayesh Solomon Dayal[1], Imam Makhfudz[2], Markus Döblinger[3], Jonathan J. Finley[1], and Gregor Koblmüller[1] — [1]Walter Schottky Institut, TUM School of Natural Sciences, Technical University of Munich, 85748 Garching, Germany. — [2]IM2NP, UMR CNRS 7334, Aix-Marseille Université, Marseille 13013, France. — [3]Department of Chemistry, Ludwig-Maximilians-University Munich, Munich, 81377, Germany.

The study of hot carrier dynamics in nanowires is of significant importance for advanced concept photovoltaic solar cells, such as hot carrier solar cells, which aim to improve the efficiency of this technology beyond the upper theoretical limit for single junction devices. The one-dimensional geometry of nanowires can improve the effects of hot carriers by confining them spatially, and increase photo-absorption by increasing internal reflection. Here we present our results on hot carrier dynamics in core-shell InGaAs/InAlAs nanowires grown by molecular beam epitaxy using a catalyst-free growth method. Microphotoluminescence spectroscopy has shown evidence of hot carrier effects in these nanowires. Furthermore, strong structural and dimensional dependencies in hot carrier properties were observed for these nanowires with diameters ranging from 110 nm to 200 nm. The origin of this effect is attributed to the influence of phonon bottleneck effects, Auger recombination and structural properties of the nanowires on hot carriers.

HL 3.10 Mon 12:15 EW 202

Silicon Nanowire Transistors: Device Characteristics to Sensing Applications — •Sayantan Ghosh[1,2], Ahmad Echresh[1], Ulrich Kentsch[1], Slawomir Prucnal[1], Vaishali Vardhan[3], Subhajit Biswas[3], Justin Holmes[3], Artur Erbe[1,2], and Yordan M. Georgiev[1,4] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]TU Dresden, Dresden, Germany — [3]School of Chemistry, University College Cork, Cork, Ireland — [4]Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria

Field-effect transistors based on silicon nanowires have been extensively used for sensing applications since the compact nanoscale structures allow excellent regulation of electrostatic potential across the nanowire channel. Sensors based on Junctionless Nanowire Transistors (JNT) have shown excellent sensitivity in liquid phases but they have not yet been operated in the gas phase.

In this work, we report the fabrication and characterisation of silicon-based JNT devices and their initial tests as gas sensors. Silicon-on-insulator wafers are doped by ion implantation and flash lamp annealing. Device patterning is based on electron beam lithography, inductively-coupled reactive ion etching, metal deposition and lift-off.

JNT sensor tests exhibited characteristic shifts in the transfer curve and a systematic increase and decrease of p- and n-type current, respectively, under the influence of different gases like NO2 and NH3 confirming potential suitability as gas sensors for detecting atmospheric radicals.

HL 3.11 Mon 12:30 EW 202

frequency effect on channel blockade in a two- path gate-defined quantum dot — •hatef ghannadi maragheh[1], johannes c. bayer[1], nikolai spitzer[2], arne ludwig[2], and rolf j. haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, D-30167 Hanover, Germany — [2]Ruhr-Universität Bochum, Lehrstuhl für angewandte Festkörperphysik, Universitätsstraße 150, 44801 Bochum, Germany

Knowing how any quantum device, like semiconductor-based qubit, is functioning under any condition is of vital importance to characterizing nano devices. This would be more difficult in case the structure of the device gets complicated. The device under the investigation consists of split-gate quantum dots in a GaAs/AlGaAs heterostructure where one side has a quantum dot while the other side is free. The frequency of the measurement ranged from 280 Hz to 1980 Hz.

Electron transport through the quantum dot system has been investigated for different conditions [1] including frequency [2,3] and two path cases [4,5]. For two path case, while one side has higher probability for electron transport compare to the other side, as the frequency changes, the transport behavior of the free side also changes due to the fact that the conductivity of the quantum dot is influenced by the frequency. But, these changes become less explicit as the number of electrons in the quantum dot is reduced. Furthermore, the correspondence between differential conductance for a fixed value for the plunger gate for both sides, has been investigated.