HL 19: Quantum dots and wires: Transport properties

Time: Tuesday 9:30–13:15 Location: A 151

HL 19.1 Tue 9:30 A 151

Tunnelling dynamics and hole storage of quantum dots measured by conductance spectroscopy — •Carsten Ebler, Arne Ludwig, and Andreas D. Wieck — Ruhr-Universität Bochum, Bochum, Deutschland

Approaching the goal of a memory, storing single charge quanta, especially in quantum dots are interesting. Therefore, we use epitaxially grown self-assembled InAs QDs (SAQD) as crystalline hosts compatible with coupling to photons. This is envisaged as a progress compared to amorphous indirect semiconductors used in today's flash memories.

We establish the SAQDs in tunnel contact with an inverted GaAs/$Al_{0.3}Ga_{0.7}$As HEMT structure containing a 2-dimensional electron gas (2DEG), manipulate the system with electronical and optical pulses and perform time resolved conductivity measurements of the 2DEG to readout the charge occupation of the QDs.

The structure is appropriately biased, that the Fermi level is in electronical resonance with the X^0state in the QD to store one single hole. This metastable hole state is read out over conductivity changes in the channel of the HEMT. Thereby it is possible to resolve electron tunnelling dynamics in and out of the quantum dots and furthermore the interaction with the holes trapped inside the QDs. It was possible to store the metastable hole for at least 4 s and to read it out during this time laps. Further experimentation with different voltage pulses provide information about tunnelling processes of the electron states and dynamics of non-equilibrium states.

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Illumination-induced non-equilibrium charge states in self-assembled quantum dots — Sascha R. Valentin[1], Jonathan Schwinger[1], Pia Eickelmann[1,2], Patrick A. Labud[1], Andreas D. Wieck[1], Björn Sothmann[2], and •Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]Fakultät für Physik und CENIDE, Universität Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany

We report on capacitance-voltage spectroscopy of self-assembled InAs quantum dots under constant illumination [1]. Besides the electronic and excitonic charging peaks in the spectrum reported earlier [2], we find additional resonances associated with non-equilibrium state tunneling unseen in C(V) measurements before. We derive a master-equation based model to assign the corresponding quantum state tunneling to the observed peaks. C(V) spectroscopy in a magnetic field is used to verify the model-assigned non-equilibrium peaks. The model is able to quantitatively address various experimental findings in C(V) spectroscopy of quantum dots such as the frequency and illumination dependent peak height, a thermal shift of the tunneling resonances [3] and the occurrence of the additional non-equilibrium peaks.

[1] S. R. Valentin, et al., arXiv:1710.07545.

[2] P. Labud, A. Ludwig, A. Wieck, G. Bester, and D. Reuter, Phys. Rev. Lett. 112, 046803 (2014).

[3] F. Brinks, A. D. Wieck, and A. Ludwig, New J. Phys. 18, 123019 (2016).

HL 19.3 Tue 10:00 A 151

Magnetotransport measurements of single MnAs/InAs hybrid nanowires — •Patrick Uredat[1], Ryutaro Kodaira[2], Ryoma Horiguchi[2], Shinjiro Hara[2], Peter J. Klar[3], and Matthias T. Elm[1] — [1]Center for Materials Research, Justus Liebig University, 35392 Giessen, Germany — [2]Research Center for Integrated Quantum Electronics, Hokkaido University, Sapporo 060-8628, Japan — [3]Institute for Experimental Physics I, Justus Liebig University, 35392 Giessen, Germany

III-V semiconducting nanowires are seen as building blocks for future nano-scaled optical or electrical devices. To be suitable for spintronic applications nanowires have to exhibit adjustable ferromagnetic properties. As the growth of diluted magnetic semiconductors is still challenging, MnAs/InAs hybrid nanowires may represent an alternative. MnAs/InAs hybrid nanowires are grown using selective-area MOVPE followed by endotaxial growth of MnAs nanoclusters. By varying temperature and time of this endotaxial growth process one can tune the shape as well as the number of nanoclusters. Structural analysis confirms high crystal quality of the hybrid nanowires, while magnetic force microscopy reveals the ferromagnetic properties of the MnAs nanoclusters. Magnetotransport measurements of pure InAs nanowires show quantum interference effects and a large positive magntoresistance effect. In contrast, MnAs/InAs hybrid nanowires exhibit a linear negative magnetoresistance effect. Furthermore, angle-dependent transport measurements indicate additional boundary scattering at intermediate temperatures due to the confined transport pathway.

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Random-walk topological transition revealed via electron counting — Georg Engelhardt[1], •Mónica Benito[2,3], Gloria Platero[3], Gernot Schaller[1], and Tobias Brandes[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [3]nstituto de Ciencia de Material de Madrid, CSIC, 28049 Madrid, Spain

The appearance of topological effects in systems exhibiting non-trivial topological band structures strongly relies on the coherent wave nature of the equations of motion. Here, we reveal topological dynamics in a classical stochastic random walk version of the Su-Schrieffer-Heeger model with no relation to coherent wave dynamics. We explain that the commonly used topological invariant in the momentum space translates into an invariant in a counting field space. This quantization gives rise to clear signatures of the topological phase in an associated waiting time distribution.

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Laplace DLTS on InAs-SAQDs — •Laurin Schnorr[1], Thomas Heinzel[1], Arne Ludwig[2], and Andreas Wieck[2] — [1]Solid State Physics Laboratory, Heinrich-Heine-Universität, Düsseldorf, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Self-assembled InAs quantum dots in a GaAs matrix are studied by Laplace deep level transient spectroscopy (LDLTS). It is shown that in the tunneling regime, the superior resolution in comparison to conventional DLTS weighting functions allows for the separation of the two s-states and a meaningful analysis of the electric field dependence of their life times. It can also be used to check the validity of the widely used tunneling corrections of conventional DLTS results in the thermal emission regime. Furthermore, we use Laplace DLTS to determine the effective height of the self-assembled quantum dots via the Poole-Frenkel effect.

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Nanoscale Tipping Bucket Effect In A Quantum Dot Transistor-Based Counter — •Fabian Hartmann[1], Patrick Maier[1], Mariama Rebello Sousa Dias[2], Sebastian Göpfert[2], Leonardo Castelano[2], Monika Emmerling[1], Christian Schneider[1], Martin Kamp[1], Yuriy Pershin[3], Gilmar Marques[2], Victor Lopez-Richard[2], Sven Höfling[1,4], and Lukas Worschech[1] — [1]Technische Physik, Universität Würzburg — [2]Departamento de Fisica, Universidade Federal de Sao Carlos — [3]Department of Physics and Astronomy, University of South Carolina — [4]SUPA, University of St Andrews

Electronic circuits composed of one or more elements with inherent memory, memristors, memcapacitors, and meminductors, offer lower circuit complexity and enhanced functionality for certain computational tasks. Networks of these elements are proposed for novel computational paradigms that rely on information processing and storage on the same physical platform. We show a nanoscaled memdevice able to act as an electronic analogue of tipping buckets that allows reducing the dimensionality and complexity of a sensing problem by transforming it into a counting problem. The device offers a well adjustable, tunable and reliable periodic reset that is controlled by the amounts of transferred quantum dot charges per gate voltage sweep. When subjected to periodic voltage sweeps the quantum dot (bucket) may require up to several sweeps before a rapid full discharge occurs thus displaying period doubling, period tripling and so on between self-governing reset operations.

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Scaling of the Fermi-Edge-Singularity in Asymmetric Quantum Dots — •Jan K. Kühne and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany

We study the transport properties of a self-assembled InAs quantum dot at low temperatures. Transport properties depend on a variety of parameters, such as temperature, size of the dots, magnetic field and thickness of the two tunneling barriers. We focus on the influence of the dimensionality of the connected leads on the tunneling in and out of the quantum dot.

In dependence on the direction of current we encounter different transport behavior, especially under the influence of a magnetic field. This can be explained by a different density of states in the two leads. Further information is gained via shot noise measurements, which are known to reveal more about the correlation between electrons than current measurements alone; e.g. interaction effects have been shown to suppress or enhance shot noise [1]. The Fermi-edge-singularity (FES) is one example, where interaction between the dot and the emitter electrons can lead to a Fano-factor larger than one [2]. To study the FES in more detail we use a scaling function approach introduced by H. Frahm [3] to analyze the temperature-dependent current resonance.

[1] H. C. Liu, et al., Phys. Rev. B 51, 5116 (1995).
[2] N. Ubbelohde, et al., Scientific Reports 2, 374 (2012).
[3] H. Frahm, et al., Phys. Rev. B 74, 35329 (2006).

15 min. break.

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Charge Reconfiguration in Quantum Dot Arrays — •Johannes C. Bayer, Timo Wagner, Eddy P. Rugeramigabo, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany

The quantum dot device is based on a two-dimensional electron gas formed in a GaAs/AlGaAs heterostructure. Metallic Schottky gates are used to laterally define arrays of up to four quantum dots in series. Two quantum point contacts (QPCs) in the vicinity act as sensitive charge detectors, allowing the real-time detection of electrons tunneling through the system [1].

Isolating a double quantum dot from the electron reservoirs has been shown to significantly simplify the stability diagram and at the same time increase the tunability of the system [2]. While transport vanishes for isolated quantum dots, charge reconfigurations inside the array are still observable in the detector signal. Our experimental studies on isolated double, triple and quadruple quantum dot arrays are complemented by model simulations which enable us to identify the different transitions occurring in our systems, including higher order tunneling in triple and quadruple quantum dots.

References

[1] T. Wagner, P. Strasberg, J. C. Bayer, et. al., Nat. Nanotech. **12**, 218-222 (2017).
[2] B. Bertrand, H. Flentje, S. Takada, et. al., Phys. Rev. Lett. **115**, 096801 (2015).

HL 19.9 Tue 11:45 A 151

Excess noise in $Al_xGa_{1-x}As$/GaAs based quantum rings — •Christian Riha[1], Sven S. Buchholz[1], Olivio Chiatti[1], Dirk Reuter[2], Andreas D. Wieck[3], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, D-12489 Berlin — [2]Optoelektronische Materialien und Bauelemente, Universität Paderborn, D-33098 Paderborn — [3]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum

The characteristics of electrical noise provide various information about an electronic system. In ballistic 1D quantum devices excess noise was already found to be related to an electron's transmission probability [1]. In this work, cross-correlated noise measurements are performed in etched $Al_xGa_{1-x}As$/GaAs based ballistic quasi 1D quantum rings at a bath temperature of $T_{\mathrm{bath}} = 4.2$ K in equilibrium. The measured white noise exceeds the thermal noise expected from the measured electron temperature T_{e} and the electrical resistance R of the devices. This excess noise decreases as T_{bath} increases and is not observable anymore at $T_{\mathrm{bath}} \geq 12$ K. Furthermore, a reduction of the excess noise is observed when one arm of a quantum ring becomes electrically non-conducting. This excess noise is not observed in 1D-constrictions that share a comparable length and width with the quantum rings. The results suggest that the excess noise is a result of electron interference in the quantum ring. [1] Y. M. Blanter *et al.*, Phys. Rep. **336**, 1 (2000).

HL 19.10 Tue 12:00 A 151

Quantum stochastic resonance in driven single-electron tunneling — •Timo Wagner[1], Johannes C. Bayer[1], Eddy P. Rugeramigiabo[1], Peter Hänggi[2], and Rolf. J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Institut für Physik, Universität Augsburg, Germany

Ambient noise is generically considered to be harmful for an error-free signal detection. However, a certain level of noise can actually have a constructive influence and boost an otherwise subthreshold signal, known as stochastic resonance (SR) [1]. All reported SR systems thus far exhibit either thermal noise or need an additional external noise generator. For quantum systems, theory predicted that intrinsic quantum randomness may give rise to stochastic resonance as well [2,3]. Here, we experimentally evidence quantum stochatic resonance (QSR) in the periodically driven charging of single-electrons in a quantum dot. By extracting the counting statistics [4,5], we demonstrate that the synchronization of the tunneling events with the periodic driving runs across an optimum, no matter whether the external frequency or the internal shot-noise level are tuned. The tunneling events were temporally resolved, using single-electron charge detection [5,6].

[1] L. Gammaitoni, et al. Rev. of Mod. Phys. 7, 223-288 (1998)
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[3] M. Grifoni & P. Hänggi, Phys. Rev. Lett. 76, 1611-1614 (1996).
[4] P. Talkner, et al. New J. Phys. 7, 14 (2005).
[5] S. Gustavsson, et al. Phys. Rev. Lett. 96, 076605 (2006).
[6] T. Wagner, et al. Nature Nanotech. 12, 218-222 (2017).

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High-speed error counting in silicon quantum dot charge pumps — •Máté Jenei[1], Ruichen Zhao[2], Alessandro Rossi[3], Kaun Yen Tan[1], Yuxin Sun[2], Andrew Dzurak[2], and Mikko Möttönen[1] — [1]QCD Labs, Department of Applied Physics, Aalto University, Espoo, Finland — [2]School of Electrical Engineering and Telecommunications, University of New South Wales, Sidney, Australia — [3]Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom

Single-charge pumps have demonstrated to produce a highly accurate quantized current of 160 pA with a relative uncertainty below 0.27 ppm, specifically for applications in quantum metrology[1]. The reported uncertainty mostly dominated by the experimental apparatus, resulting inconveniently long averaging times. To overcome this and systematic errors, in-situ charge sensing is a promising solution. We present our most recent progress on a novel twin aluminium single-electron-transistor charge sensor capacitively coupled to a silicon quantum dot pump. The sensor constitutes an improvement in the detection sensitivity that was the limiting factor of our first generation of designs [2]. The new hybrid device potentially allows us to carry out error counting by combining bidirectional pumping and charge sensing.

[1] R. Zhao et al., Phys. Rev. Applied 8, 044021 (2017)
[2] T. Tanttu et al., New J. Phys 17, 10, 103030 (2015)

HL 19.12 Tue 12:30 A 151

Coulomb staircase in CMOS-compatible large-area junctions of self-assembled quantum dots using graphene — Hippolyte P.A.G. Astier[1], Joel M. Fruhman[1], Lissa Eyre[1], Bruno Ehrler[4], Marcus Boehm[1], Piran R. Kidambi[2], Ugo Sassi[2], Domenico De Fazio[2], Jonathan P. Griffiths[1], Alexander Robson[3], Benjamin J. Robinson[3], Stephan Hofmann[2], Andrea C. Ferrari[2], and •Christopher J.B. Ford[1] — [1]Cavendish Laboratory, JJ Thomson Av. CB3 0HE, Cambridge, UK — [2]Cambridge Graphene Centre, 9 JJ Thomson Av. CB3 0FA, Cambridge, UK — [3]Department of Physics, University of Lancaster, Lancaster LA1 4YB, UK — [4]Center for Nanophotonics, AMOLF, Science Park 104, 1098 XG, Amsterdam, The Netherlands

Nanomaterial and molecular electronics suffers from unscalable and complex fabrication. Here, we use graphene to make arrays of $\sim 1\mu m^2$ junctions contacting self-assembled monolayers of PbS quantum dots (QDs) to obtain films with zero-dimensional transport characteristics. Our junctions exhibit Coulomb blockade and staircases with a yield above 40% before optimisation, thus demonstrating single-electron effects in a robust and scalable architecture. Electron-beam lithography can reduce contact areas to nanometre sizes, enabling a statistical comparison between junctions with a range of QD numbers. Topographical imaging combining atomic force microscopy (AFM) and ultrasonic force microscopy (UFM) allows us to investigate the conduction parameters in these complex films in relation to their mechanical aspect.

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Electrical characterization of semiconductor nanowires with axial pn-junction — •Cornelia Timm[1], Andreas Nägelein[1], Matthias Steidl[1], Klaus Schwarzburg[2], Peter Kleinschmidt[1], and Thomas Hannappel[1] — [1]Institute of Physics, TU Ilmenau, Germany — [2]Helmholtz Zentrum Berlin, Germany

Semiconductor nanowires are of great interest for applications in future nanoscale optoelectronic devices. For optimal performance it is crucial to understand the precise electrical characteristics of the nanowires, in particular their electrical transport properties.

Here we present resistance profiling along the axial pn-junction of GaAs nanowires. This was probed directly using a 4-tip STM, an advanced technique resulting in a high spatial resolution of the nanowire resistance. Applying a transport model allows for the determination of the doping profiles. As expected we detected a voltage drop at the pn-junction, correlated to the forward bias of the diode. The nonlinear I-V characteristic revealed a reduced differential conductivity at the pn-junction.

Additionally, spatially resolved photoluminescence and cathodoluminescence measurements were conducted to further examine the pn-junction of the GaAs nanowire. The p and n-segment of the nanowire exhibited a different photoluminescence spectrum. Due to the electric field gradient, the photoluminescence intensity at the pn-junction was strongly quenched. Cathodoluminescence measurements confirmed the findings of the photoluminescence measurements.

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Orbital contributions to the electron g-factor in semiconductor nanowires — Georg Winkler[2], Daniel Varjas[1], •Rafal Skolasinski[1], Alexey Soluyanov[2], Matthias Troyer[2,3], and Michael Wimmer[1] — [1]QuTech, Delft University of Technology, Delft, Netherlands — [2]Theoretical Physics and Station Q, ETH Zurich, Zurich, Switzerland — [3]Quantum Architectures and Computation Group, Microsoft Research, Redmond, WA, United States

Recent experiments on Majorana fermions in semiconductor nanowires [Albrecht et al., Nat. 531, 206 (2016)] revealed a surprisingly large electronic Landé g-factor, several times larger than the bulk value - contrary to the expectation that confinement reduces the g-factor. Here we assess the role of orbital contributions to the electron g-factor in nanowires and quantum dots. We show that an LS coupling in higher subbands leads to an enhancement of the g-factor of an order of magnitude or more for small effective mass semiconductors. We validate our theoretical finding with simulations of InAs and InSb, showing that the effect persists even if cylindrical symmetry is broken. A huge anisotropy of the enhanced g-factors under magnetic field rotation allows for a straightforward experimental test of this theory.