HL 3: Quantum Dots and Wires 1: Transport and Electronic Properties

Time: Monday 9:30–13:00 Location: H32

Invited Talk HL 3.1 Mon 9:30 H32

Pushing the limits in real-time meeasurements of quantum dynamics — •Eric Kleinherbers[1], Philipp Stegmann[2], Annika Kurzmann[3], Martin Geller[1], Axel Lorke[1], and Jürgen König[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, 47057 Duisburg, Germany — [2]Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA — [3]2nd Institute of Physics, RWTH Aachen University, 52074 Aachen, Germany

Time-resolved studies of quantum systems are the key to understand quantum dynamics at its core. The real-time measurement of individual quantum numbers as they switch between certain discrete values, well known as random telegraph signal, is expected to yield maximal physical insight. However, the signal suffers from both systematic errors, such as a limited time resolution and noise from the measurement apparatus, as well as statistical errors due to a limited amount of data. Here we demonstrate that an evaluation scheme based on factorial cumulants can reduce the influence of such errors by orders of magnitude [1]. The error resilience is supported by a general theory for the detection errors as well as experimental data of single-electron tunneling through a self-assembled quantum dot. Thus, factorial cumulants push the limits in the analysis of random telegraph data which represent a wide class of experiments in physics, chemistry, engineering and life sciences.

[1] E. Kleinherbers et al., Phys. Rev. Lett. 128, 087701 (2022)

HL 3.2 Mon 10:00 H32

Creating and detecting poor man's Majorana bound states in interacting quantum dots — •Athanasios Tsintzis[1], Rubén Seoane Souto[1,2], and Martin Leijnse[1,2] — [1]Division of Solid State Physics and NanoLund, Lund University, S-221 00 Lund, Sweden — [2]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark

We theoretically study a system of two quantum dots (QDs) coupled via a third (coupler) QD which is additionally proximitized by an s-wave superconductor. For a wide parameter range, the system can be tuned to sweet spots with a doubly-degenerate ground state, as switches between even- and odd-parity ground states are found to be ubiquitous. The necessary ingredients are a) a finite magnetic field to break the spin degeneracy and b) spin-orbit interaction to mix the spin species. The sweet spots harbor poor man's Majorana bound states (Phys. Rev. B 86, 134528, 2012) whose quality is quantified by calculating the Majorana polarizations of the degenerate ground states (Phys. Rev. B 101, 125431, 2020). The QDs' electrochemical potentials are the control knobs utilized to reach the sweet spots and local and non-local conductance calculations provide a useful map for experimentalists navigating the parameter space. The above system can be realized in a semiconductor 2D electron gas or nanowire with gate- or epitaxially defined QDs coupled to a grounded superconductor. This work provides a path towards near-future demonstration of nonabelian and non-local Majorana properties, with possible (more long-term) applications in topologically protected quantum computing.

HL 3.3 Mon 10:15 H32

Interference and parity blockade in transport through a Majorana box — •Maximilian Nitsch[1], Rubén Seoane Souto[1,2], and Martin Leijnse[1,2] — [1]Division of Solid State Physics and NanoLund, Lund University, S-22100 Lund, Sweden — [2]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark

A Majorana box - two topological superconducting nanowires coupled via a trivial superconductor - is a building block in devices aiming to demonstrate nonabelian physics, as well as for topological quantum computer architectures. We theoretically investigate charge transport through a Majorana box and show that current can be blocked when two Majoranas couple to the same lead, fixing their parity. In direct analogy to Pauli spin blockade in spin qubits, this parity blockade can be used for fast and high-fidelity qubit initialization and readout, as well as for current-based measurements of decoherence times. Furthermore, we demonstrate that transport can distinguish between a clean Majorana box and a disordered box with additional unwanted Majorana or Andreev bound states.

HL 3.4 Mon 10:30 H32

Wave-function mapping of excited quantum dot states — •Daniel Hecker[1], Jens Kerski[1], Nelson Creutzburg[1], Arne Ludwig[2], Andreas D. Wieck[2], Martin Geller[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Self-assembled quantum dots (QDs) are promising candidates for quantum information technologies, quantum sensing and various electro-optical applications. They are often approximated as two-dimensional harmonic oscillators. Although this approximation of electron states in a harmonic oscillator is very successful, the influence of the electron-electron interaction on the excited few-particle wave-functions and their dynamics into equilibrium has not been studied in detail.

We investigate an ensemble of InAs/GaAs QDs, embedded in a high-electron-mobility transistor with a two-dimensional electron gas (2DEG) as conductive channel. By applying a gate voltage to the transistor, the QDs can be selectively occupied with electrons tunneling from the 2DEG, and the time-resolved transconductance of the 2DEG can be measured. A rate equation based evaluation of the transconductance allows us to determine the tunneling rates of the QD states. In combination with a magnetic field that tunes the wave function-dependent tunneling probability, this enables us to investigate the shape and dynamics of the (excited) few-electron states.

HL 3.5 Mon 10:45 H32

Charge tuning of GaAs quantum dots using Schottky diode structure — •Nand Lal Sharma[1], Ghata Satish Bhayani[1], Oliver G. Schmidt[2], and Caspar Hopfmann[1] — [1]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Material Systems for Nanoelectronics, Technical University Chemnitz, 09107 Chemnitz, Germany

Semiconductor quantum dots (QDs) are promising candidates for high quality photon sources and the biexciton-exciton cascade in these structures is one of the most advanced techniques for generation of entangled photon pairs. In this work droplet etched GaAs/AlGaAs QDs [1] are embedded in Schottky diode structures within nanomembranes. The membranes are transferred to Au coated substrates via selective etching. The Au coated substrate facilitates the back while the Si-doped GaAs acts as the top contact. The QD photoluminescence from different charge states is controlled by application of an external bias. The effects of quantum dot charging, quantum confined Stark effect, exciton fine structure and photon coherence are investigated as a function of bias voltage.

[1] Keil et. al. Nat. comm. 8, 15501 (2017)

30 min. break

HL 3.6 Mon 11:30 H32

Modeling and simulation of the electric control of quantum dot photodiodes — •Dustin Siebert[1], Alex Widhalm[1,2], Sebastian Krehs[2], Nand Lal Sharma[2], Timo Langer[2], Björn Jonas[2], Dirk Reuter[2], Andreas Thiede[1], Artur Zrenner[2], and Jens Förstner[1] — [1]Paderborn University, Electrical Engineering Department, Warburger Straße 100, 33098 Paderborn, Germany — [2]Paderborn University, Physics Department, Warburger Straße 100, 33098 Paderborn, Germany

Optoelectronic devices like photodiodes based on single quantum dots are one of the new major fields of research for quantum computing, communication and sensing. In our work, we present our theoretical model and approaches using optoelectronic Bloch simulations to reproduce experimental results considering influences of a timing jitter between optical and electric pulses. Further, we use our model to validate quantum sensing methods and we show low frequency field simulations to estimate the electric properties of photodiodes, especially the RC-characteristics, to obtain a better understanding of the quantum dynamic and its electric control.

[1] Amlan Mukherjee, Alex Widhalm, Dustin Siebert, Sebastian Krehs, Nand Lal Sharma, Andreas Thiede, Jens Förstner, and Artur Zrenner, APL, Vol.116, 251103 (2020)

[2] Alex Widhalm, Sebastian Krehs, Dustin Siebert, Nand Lal Sharma, Timo Langer, Björn Jonas, Dirk Reuter, Andreas Thiede,

Jens Förstner, and Artur Zrenner, APL, Vol. 119, 181109 (2021)

HL 3.7 Mon 11:45 H32

Electrostatic coupling of double layer self-assembled quantum dots — •Lukas Berg[1], Laurin Schnorr[1], Thomas Heinzel[1], Arne Ludwig[2], and Andreas Dirk Wieck[2] — [1]Heinrich-Heine Universität, Düsseldorf, Germany — [2]Ruhr-Universität, Bochum, Germany

The electron capture- and emission dynamics of two layers of self-assembled quantum dots in large distance to each other as well as to their reservoirs is studied by time resolved capacitance spectroscopy. The occupation dynamics of the individual layers can be well separated at certain bias voltages. Additionally, an interaction of the electrostatic character is observed in terms of a shift of emission lifetimes and the extracted binding energies. To model this effect, the corresponding system of rate equations is solved.

HL 3.8 Mon 12:00 H32

Temperature-dependence of current peaks in InAs double quantum dots — •Olfa Dani[1], Robert Hussein[2], Johannes C. Bayer[1], Sigmund Kohler[3], 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]Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain

We investigate electron transport through asymmetrically coupled InAs double quantum dots. Measurements of the resonances of single-electron tunneling shows a quite strong temperature dependence of those coherent current peaks. Their width and background increase with temperature in the range of 1.5-21 K, which indicates an influence of the substrate phonons. The broadening of such peaks can be modeled with rather good precision and can be fully explained with quantum dissipation [1] modeled by two baths, the one coupling to the dot occupation, the other to the inter-dot current. Application of magnetic fields helps us to identify the different quantum dot states.
[1] Olfa Dani, Robert Hussein, Johannes C. Bayer, Sigmund Kohler, Rolf J. Haug, Temperature-dependent broadening of coherent current peaks in InAs double quantum dots, arXiv:2204.06333 (2022)

HL 3.9 Mon 12:15 H32

Heterogeneous III-V nanowire quantum emitters on silicon photonic circuits — •Hyowon Jeong[1], Akhil Ajay[1], Nitin Mukhundhan[1], Marcus Döblinger[2], Jonathan J. Finley[1], and Gregor Koblmüller[1] — [1]Walter Schottky Institute & Physics Department, Technische Universität München, Garching, Germany — [2]Department of Chemistry, Ludwig-Maximilians-Universität München, Munich, Germany

III-V quantum dots (QDs) act as naturally bright and highly efficient quantum emitters that can generate deterministic single or entangled photons pairs. QDs embedded in a nanowire (NW) serve as a scalable platform for site-selective and geometry-controlled in-situ heterogeneous integration onto photonic waveguides (WG) - a crucial milestone for the realization of a Quantum Photonic Integrated Circuit.

In the first part, we show by numerical modelling how geometrical parameters of a NW and Si-WG design influence the spontaneous emission enhancement of the QD emitter and the in-coupling efficiencies at the NW-WG interface [1]. Preliminary experiments towards the development of an integrated III-V NW-QD system are then presented. Here, we demonstrate a droplet-free site-selective epitaxy of NWs, where first data of GaAsSb/InGaAs axial heterostructures and their distinct luminescence features will be shown. Furthermore, we discuss control of Indium incorporation into the InGaAs axial segment, in order to tune the emission wavelength before optimizing the axial size, progressing towards an axial QD.

[1] N. Mukhundhan, et al., Opt. Express 29, 43068 (2021).

HL 3.10 Mon 12:30 H32

Optoelectronic properties of GaAs(Sb)-AlGaAs core-shell NW diodes on silicon — •Tobias Schreitmüller, Patrick Jong, Daniel Ruhstorfer, Akhil Ajay, Andreas Thurn, Jonathan Finley, and Gregor Koblmüller — Walter Schottky Institute, Technical University of Munich, 85748 Garching, Germany

The ability to integrate III-V semiconductor nanowires (NW) on the silicon (Si) platform opens many perspectives for advanced nanoelectronic and optoelectronic device applications on-chip. However, for energy-efficient device performance, the design of axial or radial heterostructures, the control of accurate doping properties and the formation of low-resistance ohmic contacts are crucial. In this contribution, we present ongoing developments of radial n-i-p core-multishell NW heterostructures monolithically integrated on the n-Si (111) platform. The NW structure is designed to host n-type doped GaAs(Sb) cores, while the shell is composed of either GaAs homojunctions or (In,Al)GaAs(Sb)-based heterojunctions that define intrinsic and p-type doped regions. We show that n-type conduction is feasible in the Si-doped core by pioneering a novel catalyst-free, vapor-solid growth process of Si-doped GaAs NWs using molecular beam epitaxy (MBE). The n-doped NW cores were then implemented into radial n-i-p NW homo-junction devices to establish electrical contact formation and perform first electroluminescence (EL) experiments. The EL measurements illustrate successful diode characteristics, with luminescence features that are typical for the underlying material properties.

HL 3.11 Mon 12:45 H32

Band structure and end states in InAs/GaSb core-shell-shell nanowires — •Florinda Viñas Boström[1,2], Athanasios Tsintzis[2], Michael Hell[2], and Martin Leijnse[2] — [1]Institute for Mathematical Physics, TU Braunschweig, Braunschweig, Germany — [2]Division of Solid State Physics and NanoLund, Lund University, Lund, Sweden

Heterostructures made from the III-V semiconductors InAs and GaSb have been studied mainly for their bulk broken band gap alignment, meaning that the valence band of GaSb is higher in energy than the conduction band in InAs, in bulk. In addition, the materials are nearly lattice matched, leading to structures with almost no strain. In two dimensions, the InAs/GaSb quantum well is a topological insulator, exhibiting a hybridization gap in the topologically non-trivial regime where quantum spin Hall edge states are present. We have calculated the non-trivial band structures and wave functions of InAs/GaSb core-shell-shell nanowires, using $\mathbf{k}\cdot\mathbf{p}$ theory. For hollow core-shell-shell InAs/GaSb nanowires, we also calculate the wave functions for a finite system with wire ends, using a BHZ model with parameters taken from the resulting $\mathbf{k}\cdot\mathbf{p}$ calculations. We establish that there are localized end-states, with energies inside the bulk gap. However, in contrast to the topological edge states in two dimensions, these end states are fourfold degenerate, and split into two Kramers pairs under potential disorder along the nanowire growth direction. Nevertheless, the end states are robust against potential disorder applied in the angular direction, as long as the bulk band gap is not closed.