TT 21: Quantum Dots and Wires: Transport (joint session HL/TT)

Time: Tuesday 11:15–13:00 Location: H13

TT 21.1 Tue 11:15 H13

Transport properties of quantum dots for single-electron pumps — •Johannes C. Bayer, Thomas Gerster, Dario Maradan, Frank Hohls, and Hans W. Schumacher — Physikalisch-Technische Bundesanstalt, 31668 Braunschweig, Germany

A single-electron pump (SEP) is a device emitting a well-defined number of n electrons per cycle of an external drive. With driving frequency f and elementary charge e, this results in a current of $I = nef$. Since the revision of the SI system, the elementary charge e hereby is an exact value, so that SEPs provide a suitable basis for a quantum current standard. The accuracy of this current is directly related to erroneous cycles, where the emitted number of electrons deviates from n. Our SEP devices are based on electrostatically defined quantum dots in GaAs/AlGaAs two-dimensional electron gases. In such devices, the tunnel barriers as well as the energy levels are controllable via gate voltages. Based on multiple quantum dot devices we here investigate relations between transport properties and SEP operation characteristics.

TT 21.2 Tue 11:30 H13

Non-Markovian higher-order electron pump: improvement of efficiency — •Lukas Litzba, Jürgen König, and Nikodem Szpak — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, Duisburg 47057, Germany

We consider an electron pump that consists of a non–interacting quantum dot and electron baths. Our pumping setup utilizes only higher–order tunneling processes, which are purely quantum mechanical and have no classical analog. In order to study higher order tunneling–mechanism and non–Markovian effects, we extend the exact Heisenberg equation and the Laplace transform technique to time–dependent Hamiltonians and apply this technique to our model. Thereby, we identify parameter ranges which lead to a significant increase of the current flowing through the quantum dot and an improvement of the energetic efficiency of these processes.

TT 21.3 Tue 11:45 H13

Fast Machine-Learning assisted characterisation of current quantisation — •Wang Ngai Wong[1], Yannic Rath[1], Nikolaos Schoinas[1], Shota Norimoto[1], Masaya Kataoka[1], Alessandro Rossi[1,2], and Ivan Runnger[1,3] — [1]National Physical Laboratory, Teddington, TW11 0LW, UK — [2]Department of Physics, SUPA, University of Strathclyde, Glasgow G4 0NG, UK — [3]Department of Computer Science, Royal Holloway, University of London, Egham, TW20 0EX, UK

Characterisation of single-electron pumps (SEPs) has long been bottlenecked by the process of fine-tuning measurement parameters to study their novel properties. This limits potential experimental parameters to those that can remain static throughout the fine-tuning process. We demonstrate a novel method assisted by machine learning which has led to an eightfold speedup in the measurement process (see Appl. Phys. Lett. 125, 124001 (2024)), and in so doing opens the door to further characterisation experiments which are impossible using conventional methods. Our method is based around an active learning cycle to navigate the information landscape of the gate voltage parameter space, while also significantly reducing the number of measurement points required. This is paired with a post-processing approach which allows us to accurately predict and characterise the small operational regimes significantly more efficiently than conventional sweeps across the parameter space. We exploit the framework to characterise the behaviour of multiplexed GaAs multi-pump devices across a range of magnetic fields.

TT 21.4 Tue 12:00 H13

Novel Mixed-Dimensional Reconfigurable Field Effect Transistors — •Sayantan Ghosh[1,2], Muhammad Bilal Khan[1], Phanish Chava[1], Kenji Watanabe[3], Takashi Taniguchi[3], Slawomir Prucnal[1], René Hübner[1], Thomas Mikolajick[2], 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]Technische Universität Dresden, Dresden, Germany — [3]National institute for Material Science, Tsukuba, Japan — [4]Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria

The limitations of CMOS downscaling drive the exploration of alternative device concepts like reconfigurable FETs (RFETs), which can dynamically switch between n- and p-polarity through electrostatic gating. This work introduces a novel mixed-dimensional RFET utilizing 1D silicon (Si) nanowires combined with 2D hexagonal boron nitride (hBN) as a dielectric and encapsulating layer. hBN*s insulating properties, chemical stability, and absence of dangling bonds make it ideal for its use as a dielectric in 1D electronics. The RFET fabrication employs electron beam lithography, reactive ion etching, and flash lamp annealing for precise silicide formation. Mechanically exfoliated hBN flakes (5-10 nm) were integrated using dry stamping transfer, with thickness characterized by microscopy techniques. Device characterization reveals improved subthreshold swing, on-current, and ION/IOFF ratio due to hBN*s 2D passivation, highlighting its potential for advanced nanowire-based RFET architectures.

TT 21.5 Tue 12:15 H13

Kondo effect for half-filling of the third shell of a quantum dot — •Olfa Dani[1], Johannes C. Bayer[1], Timo Wagner[1], Gertrud Zwicknagl[2], and Rolf J. Haug[1] — [1]1Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany — [2]2Institut für Mathematische Physik, Technische Universität Braunschweig, Braunschweig, Germany

In this work, we investigate the electrical transport in the third shell [1] of a gate-defined GaAs quantum dot. The exact number of electrons in the quantum dot (N_e) is determined using a quantum point contact as a sensitive charge detector, detecting single-electrons tunneling through the system [2]. N_e is varied by changing the applied gate voltage.

The addition energy E_c for N_e = 7 - 11 shows a triangular behavior with a maximum at half-filling of the shell. This observed behavior is described analytically with Hund's rule exchange interaction. Besides, for successive numbers of electrons occupying the quantum dot N_e = 7 to 11, a Zero-bias anomaly (ZBA) characteristic for the Kondo effect is observed [3]. The width of the ZBA exhibits a triangular behavior, with a maximum at $N_e = 9$, similar to E_c. The broadening of the ZBA is attributed to the contribution of the Kondo resonance as well as Hund's satellite peaks, originating from the degenerate orbitals observed in the spectral function.

[1] L. P. Kouwenhoven, et. al., Rep. Prog. Phys. 64, 701-736 (2001).
[2] T. Wagner, et. al., Nat. Phys.15, 330-334 (2019).
[3] J. Schmid, et. al., Phys. Rev. Lett. 84, 5824 (2000).

TT 21.6 Tue 12:30 H13

Beyond full counting statistics and Langevin theory: The quantum polyspectra approach to multi-detector measurements — •Armin Ghorbanietemad, Markus Sifft, and Daniel Hägele — Ruhr University Bochum, Faculty of Physics and Astronomy, Experimental Physics VI, Germany

The quantum polyspectra approach to quantum measurements has recently been shown to cover the full range between weak and strong quantum measurements [1 - 3]. It provides thus a more general approach to quantum measurements than the full counting statistics used in nano-electronics or the Langevin-approach used in spin noise spectroscopy. This approach draws its strength from comparing higher order spectra of the measurement record with model spectra calculated from quantum expressions that are calculated on the level of a Lindblad master equation. Here, we generalize the polyspectra approach to include the case of the simultaneous measurements of more than one quantity of a quantum system. The approach regards measurement induced damping, measurement backaction, and the quantum Zeno effect. We give a few examples of multi-detector polyspectra that were calculated by a multi-detector extension of our SignalSnap and QuantumCatch library [4, 5].

[1] Hägele et al., PRB 98, 205143 (2018)
[2] Sifft et al., PRR 3, 033123 (2021)
[3] Sifft et al., PRA 109, 062210 (2024)
[4] https://github.com/MarkusSifft/SignalSnap
[5] https://github.com/MarkusSifft/QuantumCatch

TT 21.7 Tue 12:45 H13

Revealing Hidden States in Quantum Dot Array Dynamics: Quantum Polyspectra Versus Waiting Time Analysis

— •Markus Sifft[1], Johannes C. Bayer[2], Daniel Hägele[1], and Rolf J. Haug[2] — [1]Faculty of Physics and Astronomy, Ruhr University Bochum, GER — [2]Institute of Solid State Physics, Leibniz Universität Hannover, GER

We show how by virtue of the recently introduced quantum polyspectral analysis of transport measurements [1,2], the complex transport measurements of multi-electron QD systems can be analyzed. This method directly relates higher-order temporal correlations of a raw quantum point contact (QPC) current measurement to the Liouvillian of the measured quantum system. By applying this method to a two-electron double QD system, we uncover dynamics between singlet and triplet states, indistinguishable in the QPC current, without requiring the identification of quantum jumps or prior assumptions about the number of quantum states involved. Our findings demonstrate that system models in such cases of hidden dynamics are inherently non-unique. Furthermore, we compare our method to a traditional analysis via the waiting-time distribution. Our method achieves parameter estimates with up to 50% lower errors, while also being applicable in scenarios with low signal-to-noise, where traditional counting methods falter. Our approach challenges previous assumptions and models, offering a more nuanced understanding of QD dynamics and paving the way for the optimization of quantum devices. [1] Hägele et al., PRB 98, 205143 (2018), [2] Sifft et al., PRR 3, 033123 (2021)