TT 47: Fluctuations, Noise and Other Transport Topics (joint session TT/DY)

Time: Thursday 15:00–18:30 Location: H31

TT 47.1 Thu 15:00 H31

Noise and reliability characterization of ferroelectric field-effect transistors under cryogenic conditions — •Yannick Raffel[1], Shouzhuo Yang[1], Oliver Ostien[1], Maik Simon[1], Thomas Kämpfe[1], Konrad Seidel[1], Maximilian Lederer[1], and Johannes Heitmann[2] — [1]Fraunhofer Institute IPMS-CNT, Dresden, Germany — [2]TU Bergakademie Freiberg, Freiberg, Germany

This study explores the impact of defects in the ferroelectric (FE) hafnium oxide (HfO_2) layer on the low-frequency noise (LFN) characteristics of HfO_2-based ferroelectric field-effect transistors (FeFETs), which show great potential as memory devices for quantum computing applications under cryogenic conditions. The investigation focuses on device degradation and material-dependent changes under various temperature conditions, including cryogenic temperatures as low as 2 K. A clear link between device reliability and flicker noise was identified. Initially, the endurance of the devices was evaluated across a range of temperatures, including cryogenic conditions. Subsequently, their data retention behavior was characterized, revealing a notably prolonged electron detrapping time at 2 K. In addition, flicker noise trends were analyzed and discussed, shedding light on key factors influencing device optimization and reliability.

TT 47.2 Thu 15:15 H31

Charge dissipation in Josephson systems and its impact on phase diffusion — •Johannes Hauff, Joachim Ankerhold, and Dominik Maile — Institut für komplexe Quantensysteme, Universität Ulm

We theoretically investigate the dynamics of the Josephson phase for different quantum circuits in the presence of dissipative couplings. Thereby, we study the environmental assisted quantum tunneling of the superconducting phase in a current-biased Josephson junction and consider Ohmic resistors inducing dissipation both in the phase and in the charge of the quantum circuit. We find that the charge dissipation leads to an enhancement of the quantum escape rate, which is strongly dependent on the shape of the potential. This effect appears already in the low Ohmic regime and also occurs in the presence of phase dissipation that favors localization [1]. Inserting realistic circuit parameters, we address the question of its experimental observability, the impact of temperature and discuss suitable parameter spaces for the observation of the enhanced rate. Furthermore, we show how the interplay of thermal and quantum fluctuations in such nonlinear systems can lead to an interesting stochastic cooling process. In this context, we also discuss the relevance of dissipative couplings for quantum annealing procedures.

[1] D. Maile et al., Phys. Rev. B 106, 045408 (2022)

TT 47.3 Thu 15:30 H31

Thermodynamic and energetic constraints on out-of-equilibrium tunneling rates — Ludovico Tesser[1], •Matteo Acciai[2,1], Christian Spånslätt[3,1], Inès Safi[4], and Janine Splettstoesser[1] — [1]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Göteborg, Sweden — [2]Scuola Internazionale Superiore di Studi Avanzati, Trieste, Italy — [3]Department of Engineering and Physics, Karlstad University, Karlstad, Sweden — [4]Laboratoire de Physique des Solides, CNRS-Université Paris-Sud and Paris-Saclay, Orsay, France

We consider a bipartite quantum system, where the two parts are kept at different temperatures and are connected by a tunnel coupling. In this setup, we show that the out-of-equilibrium tunneling rates between the two subsystems (depending on the applied temperature bias) are bounded by two constraints. The derived bounds are related to the dissipated heat and the absorbed energy neede to establish and deplete the temperature bias, thus providing a thermodynamic and energetic constraint on the tunneling rates.

Except for the restriction to the tunneling regime, our results are valid for arbitrary Hamiltonians of the two subsystems, that can include generic many-body interactions. The derived bounds thus apply to a large class of systems, such as molecular junctions and coupled cavities, and can be tested by measuring the out-of-equilibrium tunneling current and its fluctuations.

Based on: arXiv:2409.00981

TT 47.4 Thu 15:45 H31

Colored noise Langevin equation for photon counting — •Steven Kim and Fabian Hassler — Institute for Quantum Information, RWTH Aachen, Germany

For open quantum systems, obtaining the photon counting statistics of the emitted radiation is central to obtain insights into phenomena such as entanglement and correlations, in particular super- and anti-bunching. Typically, these systems are described by a Lindblad master equation, which allows the counting statistics to be derived from normal-ordered number operators. However, the Lindblad equation relies on the rotating wave approximation (RWA), which assumes that the dissipation rate is much smaller than the characteristic photon frequency. While this requirement is always fulfilled at optical frequencies, microwave cavities can have broader linewidths, making the RWA inaccurate. Alternatively, such systems can be effectively described by an equivalent Langevin equation with correlated (colored) noise, which bypasses the need for the RWA. In this work, we derive the photon counting statistics directly from the Langevin equation, providing a broader framework for understanding photon emission in open quantum systems.

TT 47.5 Thu 16:00 H31

Quantum stochastic resonance in a periodically-driven quantum dot — •Johann Zöllner[1], Hendrik Mannel[1], Eric Kleinherbers[2], Marcel Zöllner[1], Nico Schwarz[1], Fabio Rimek[1], Andreas Wieck[3], Arne Ludwig[3], Axel Lorke[1], Martin Geller[1], and Jürgen König[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen — [2]Department of Physics and Astronomy, University of California, Los Angeles — [3]Faculty of Physics and Astronomy, Ruhr University Bochum

The combination of periodic driving and fluctuations in a system with an inherent noise source leads to stochastic resonance, where the synchronization of the system dynamics with the external drive leads to an enhanced signal-to-noise ratio. This phenomenon has been found in many different noisy systems in palaeoclimatology, biology, medicine and physics. The classical stochastic resonance with thermal noise has recently been experimentally extended to the quantum regime, where the fundamental randomness of individual quantum events is the noise source [1]. Here we demonstrate quantum stochastic resonance in the single-electron tunneling dynamics of a periodically driven single self-assembled quantum dot, tunnel-coupled to an electron reservoir [2]. We extend the statistical evaluation to factorial cumulants to gain a deeper understanding of the transition between stochastic and deterministic transport through the quantum dot.

[1] T. Wagner et al., Nat. Phys. 15, 330 (2019).
[2] A. Kurzmann et. al., Phys. Rev. Lett. 122, 247403 (2019).

TT 47.6 Thu 16:15 H31

Curvature-assisted high harmonic generation in strongly-driven superconductors — •Björn Niedzielski and Jamal Berakdar — Institut für Physik, Martin-Luther Universität Halle-Wittenberg, Halle/Saale 06099, Germany

Superconductors (SCs) under strong driving fields show inherently nonlinear dynamics, offering potential for nonlinear optics and high harmonic generation. However, the weak coupling of SCs to homogeneous transverse fields limits their efficiency. Here, we show that introducing curvature to mesoscopic type-II SC structures enables enhanced coupling to strong THz fields. Applied transport currents further allow for controlled emission of even and odd-order harmonic light modes.

The enhanced coupling of SCs and light arises from geometric and finite-size effects steering supercurrents while preserving the coherence of the SC state. Using the time-dependent Ginzburg-Landau framework, we simulate the dynamics of the superconducting order parameter in nanostructures with large coherence lengths under near-gap driving frequencies. Our simulations reveal the time-dependent supercurrents and their contributions to dipole radiation and high harmonic generation.

Our results highlight the role of the SC geometry and finite-size effects for amplifying nonlinear optical responses, offering a new method to use SCs for nonlinear THz optics.

15 min. break

TT 47.7 Thu 16:45 H31

Quantum oscillations in magneto-thermoelectrical conductivities of 2DEG: The Keldysh field-theoretical approach — •Kitinan Pongsangangan — Mahidol University, Bangkok, Thailand

The purpose of this work is to formulate a kinetic theory describing transport properties of interacting electrons in a uniform magnetic field of arbitrary magnitude. Exposing an electronic system to a constant magnetic field quenches its energy bands into a series of discrete energy levels, known as Landau levels. Following Keldysh formalism, we derive the quantum kinetic equation with the Landau-level basis. The Landau-level states, exact solutions of the Schroedinger equation in a constant background magnetic field, are natural and suitable basis to use, especially, for the investigation of strong-magnetic-field phenomena. In the weak-field limit, the lowest order approximation of the quantum kinetic equation reduces to a Boltzmann equation into which the magnetic field enters as the Lorentz force. As an application of our quantum transport equation, we calculate magneto-thermoelectric coefficients of a disordered two-dimensional electron gas (2DEG) in the quantum hall regime interacting with acoustic phonons.

TT 47.8 Thu 17:00 H31

Typical medium theory for disordered electronic systems on simple lattices with Cauchy distribution of on-site potentials — Andreas Ostlin[1], Hanna Terletska[2], Dylan Jones[1], and •Liviu Chioncel[1,3] — [1]Institute of Physics, University of Augsburg, Augsburg, Germany — [2]Middle Tennessee State University, Murfreesboro, Tennessee, USA — [3]ACIT, University of Augsburg, Augsburg, Germany

Effective medium approaches using single-site averaging procedures of various kinds contributed substantially in understanding the density of states of electronically disordered systems in models and materials. The nature and the conditions for appearance of single-particle (Anderson) localization seems to be qualitatively understood, yet discussions concerning special applied methods and quantitative results for the critical conditions are still ongoing. Here we present results using the typical medium theory for the one-particle and two-particle Green's function (conductivities) for the special case of Cauchy-distribution.

TT 47.9 Thu 17:15 H31

Dynamical current as tool to distinghuish degenerate spin states in open-shell graphene nanoribbons — •Nico Leumer, Thomas Frederiksen, and Geza Giedke — Donostia International Physics Center

The recent advances of surface synthesis unlocked the potential of open-shell physics in graphene nanoribbons (GNRs) which ever since have gained significant attention. Normally chemically unstable, these structures feature unpaired, localized p_z-electrons pinned at zero energy, giving rise to the unique phenomenon of π-magnetism. Intrinsically low spin-orbit/hyperfine interactions suppress spin relaxation, making GNRs ideal for tunable spin physics and spintronics applications. Although scanning probe techniques provide the necessary access to electron's spins and their interactions, state preparation, manipulation and detection remains an open challenge. Our ambition addresses the latter.

At half-filling certain GNRs host quasi degenerate spin singlets/triplets states with a vanishing energy gap for long ribbons. Without significantly increasing the gap, e.g., via magnetic fields, conventional current-based measurements hardly distinguish these spin textures. However, and even for absent gap, we demonstrate that in our setup $I(t)$ discriminates between the responsible states by exploiting the states's distinct spatial profiles. To probe the spatial information, we apply a constant bias between two STM tips. The scheme is suitable for single shot measurements and a quantum master equation (Hubbard model) accounts for the time evolution (GNR).

TT 47.10 Thu 17:30 H31

Josephson force in a vibrating carbon nanotube Josephson junction — •Andreas K. Hüttel[1,2], Jukka-Pekka Kaikkonen[2], Keijo Korhonen[2], and Pertti Hakonen[2] — [1]Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany — [2]Low Temperature Laboratory, Dept. of Applied Physics, Aalto University, Espoo, Finland

A single carbon nanotube suspended between superconducting electrodes acts simultaneously as nanomechanical resonator and as Josephson junction. Its energy-dependent density of states and thus displacement-dependent Josephson energy couple electronics and mechanics. Measurements on such a system display complex behaviour of the vibrational resonance with respect to junction biasing; strikingly, the resonance frequency decreases in a distinct parameter region where the bias is similar in size to the junction switching current.

We numerically solve the coupled differential equation system of the driven (via an ac gate voltage and an ac bias) system for realistic device parameters, using highly parallelized Julia code, and characterize the evolving steady state. Specific attention is given to the effect of the Josephson junction behaviour on the mechanical resonance frequency and the vibration amplitude. In the numerical results, we observe a clear impact of superconductivity on the mechanical response, with a rather counterintuitive dependence on externally tunable parameters.

TT 47.11 Thu 17:45 H31

Tunable nonlinear Duffing response of a driven carbon nanotube nanomechanical resonator — •Akong Loh, Furkan Özyigit, Fabian Stadler, Katrin Burkert, Niklas Hüttner, and Andreas K. Hüttel — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

Extremely lightweight and with very high quality factors, Carbon nanotube nanomechanical resonators have been used as ultrasensitive force, mass, and charge sensors [1-5]. When suspended on source and drain leads and gated, a CNT nanomechanical resonator can also be operated as a quantum dot. The motion of the nanotube is strongly coupled to single electron tunneling, dominating the nonlinear response [1-5]. Control of the strong nonlinear dynamics of a CNT will be useful for engineering mechanical qubits with information stored in the vibrations and mechanical Schrödinger's cat states [3]. Here, we analyze the nonlinear vibrational response of a driven CNT quantum dot, at ∼10mK in a dilution refrigerator and with opaque tunnel barriers to minimize dissipation. We demonstrate how the nonlinearity parameters of the coupled system can be controlled via Coulomb blockade and the associated gate voltage, leading to a rich interplay of frequency, damping, and Duffing behavior.

[1] A. K. Hüttel *et al.*, Nano Lett. 9, 2547 (2009).
[2] G. A. Steele *et al.*, Science 325, 1103 (2009).
[3] C. Samanta *et al*, Nat. Phys. 19, 1340 (2023).
[4] S. Blien *et al.*, Nat. Commun. 11, 1636 (2020).
[5] N. Hüttner *et al.*, Phys. Rev. Appl. 20, 064019 (2023).

TT 47.12 Thu 18:00 H31

Vibrational instabilities in molecular nanojunctions: A mixed quantum-classical analysis — •Martin Mäck, Samuel Rudge, Riley Preston, and Michael Thoss — Institute of Physics, University of Freiburg

Understanding the current-induced vibrational dynamics in molecular nanojunctions is critical for gaining insight into the stability of such systems. While it is well known that Joule at higher bias voltages plays an important role for the stability of the nanojunction, a different mechanism caused by current-induced nonconservative forces has been reported to cause vibrational instabilities already at much lower voltages [1].

In this contribution, we apply a mixed quantum-classical approach based on electronic friction and Langevin dynamics [2,3] to a model system for which vibrational instabilities have previously been reported. Such a mixed quantum-classical description has the benefit of giving valuable insight into the electronic forces acting on the molecular vibrations. We analyze the possible occurrence of vibrational instabilities and compare our results to previous approaches, which were limited to small amplitude motion of the vibrational degrees of freedom [1].

[1] J.-T.Lü, M.Brandbyge, P.Hedegård, Nano Lett. **10**, 1657 (2010).
[2] S.L.Rudge, C.Kaspar, R.L.Grether, S.Wolf, G.Stock, M.Thoss, J.Chem. Phys.**160**, 184106 (2024).
[3] R.J.Preston, D.S.Kosov, J.Chem.Phys.**158**, 224106 (2023).

TT 47.13 Thu 18:15 H31

Vortex shedding in superfluid He-4 and in a Bose-Einstein condensate — •Wilfried Schoepe — Fakultät für Physik, Universität Regensburg, D-93040 Regensburg, Germany

Our experiments on vortex shedding from a microsphere oscillating in superfluid He-4 at mK temperatures is compared with experiments on vortex shedding from a laser beam moving in a Bose-Einstein condensate as observed by other authors. In either case a linear dependence of the shedding frequency fv=a(v-vc) is observed a above some critical velocity vc for the onset of turbulence and the coefficient a is proportional to the oscillation frequency f above some characteristic value and assumes a finite value for steady state motion f=0. An analytical relation between the superfluid Reynolds number and the superfluid Strouhal number is presented.