Josephson Parametric Amplifiers Utilizing Aluminum Shadow Evaporation without a Suspended Bridge

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Low-noise amplification of microwave signals is a key requirement in numerous nanoelectronics experiments, including qubit readout, optomechanics and shot noise spectrometry. Lower system noise temperatures can be reached with superconductive parametric amplifiers which, however, have suffered from limited bandwidth and/or modest gain. Recently, a solution has been introduced, involving operating a Josephson LC resonator in an impedance-engineered environment [1].
We present our realization of these amplifiers, utilizing a bridgeless shadow evaporation technique [2] to achieve junctions with high critical currents, which is required by impedance engineering. The fabrication involves double-layer resist (PMMA/MAA) together with high/low dose e-beam lithography using high voltage (100 kV) to achieve low parasitic undercuts. We have found the process to be both reliable and high-yield, and parametric amplification using these junctions has also been successfully demonstrated.

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Coherent resonance electron transport in semiconductor quantum dots and functionalized biomolecular structures

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The fundamental research of coherent transport of single particle elementary excitations exploiting strong-light matter interactions in molecular nanostructures having practical technological relevance will be addressed. Confinement and coherent transport of elementary electron-hole excitations are directly monitored by high-spectral-resolution micro-Raman and photoluminescence spectroscopes in isolated semiconductor quantum dots in the temperature range 6-300 K. Crystalline nanostructures of nc-Si/SiO_2 quantum dots (QDs) and nitrogen-vacancy centers in nanodiamond and diamond as well as their functionalization by biomolecules will be considered.Developed approaches revealed an unprecedented resonance coherent energy transfer pathways of a photoexcited electron and hole in the complexes of the QDs dots functionalized by the DNAs. A selective resonant light scattering enhancement by a single molecule of the DNA giving evidence for coherent electron motion is discovered [1]. The functionalized structures with unique light-matter interaction properties have turn out to be one of a particularly important class of novel materials for molecular engineering used as a flexible quantum interface allowing to improve also bimolecular recognition. The new knowledge obtained on coherent resonance transport of elementary electron-hole excitations in the organic-inorganic interface can help tailor innovative capabilities of dynamic optical imaging in a broader perspective for vital applications.

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Non-universal transmission phase behaviour of a large quantum dot

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The electron wave function experiences a phase modification at coherent transmission through a quantum dot. This transmission phase undergoes a characteristic shift of π when scanning through a Coulomb-blockade resonance[1]. Between successive resonances either a transmission phase lapse of π or a phase plateau is theoretically expected to occur depending on the parity of the corresponding quantum dot states. Despite considerable experimental effort, this transmission phase behaviour has remained elusive for a large quantum dot. Here we report on transmission phase measurements across such a large quantum dot hosting hundreds of electrons. Using an original electron two-path interferometer[2] to scan the transmission phase along fourteen successive resonances, we observe both phase lapses and plateaus. Additionally, we demonstrate that quantum dot deformation alters the sequence of transmission phase lapses and plateaus via parity modifications of the involved quantum dot states. Our findings set a milestone towards a comprehensive understanding of the transmission phase of quantum dots

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Near Quantum Limited Amplification Based on a DC Voltage Biased Josephson Junction

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Usually, Cooper pair tunneling through a Josepshon junction is elastic: the dc voltage across the junction has to be zero. Nonetheless, tunneling can occur at non-zero bias if the difference of potential can be dissipated somewhere.

By coupling a Josphson junction with a resonator, we observe processes where the energy of a tunneling Cooper pair can be transformed into two photons. Our results show that these processes can provide amplification in analogy to Josephon parametric amplifiers.

In order to reach quantum-limited noise performance, the idler mode must be cold as in conventional amplifiers. However, the noise in the bias voltage can result in additional noise in our amplification scheme. We shown that by designing the linear part of the amplifier-circuit appropriately, we can eliminate this noise source and reach quantum-limited noise-performance. Our scheme can therefore provide quantum limited amplifiers powered by a simple DC voltage bias instead of a microwave pump tone.

Nanoscale Quantum Calorimetry with Electronic Temperature Fluctuations

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In small metallic islands, at low temperatures, electron-electron relaxation is typically much faster than the timescale on which energy is exchanged with the environment. Such systems have a well-defined effective temperature, whose fluctuations induced by energy absorption can be used for calorimetry. Here we consider a quantum calorimeter, with the aim of detecting single quanta of energy, by investigating temperature fluctuations induced by electrons tunneling between a superconducting lead and a normal metallic dot. In addition to the tunneling mechanism, we investigate the effect of electron-phonon relaxation on the temperature fluctuations. Using full counting statistics, we fully characterize the temperature fluctuations for both single event and long-time measurements. Our results constitute an important step towards detection of microwave photons in nanoscale systems.

Electrical autonomous Brownian gyrator

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Heat engines based on microscopic working substances with few degrees of freedom are of great interests for both demand of energy harvesting and development of stochastic thermodynamics. Here we report an experimental investigation of an electrical version of an autonomous Brownian ratchet truly relied on real heat baths. The ratchet is manifested via two resistor-capacitor circuits subject to two different thermal baths and coupled together through an additional capacitor. The collective dynamics of the fluctuating voltages across the two resistors exhibits an average gyrating motion owing to the lack of detailed balance caused by the unequal temperatures of the two baths. We look into the details of this stochastic gyrating dynamics, its dependences on the temperature difference and coupling strength, and the mechanism of heat transfer through this simple electronic circuit. Our experiment and analysis affirm the general principle and the possibility of a Brownian ratchet working near room temperature scale.

Magnetic Flux Sensor Based on a Superconducting Circuit

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Many important quantum algorithms, like Shor's factorization algorithm and Lloyd's algorithm for solving a system of linear equations, employ phase estimation algorithms. The latter allow for a fast extraction of information stored in a quantum state of a system. Besides its applicability in quantum computing and quantum information processing, phase estimation is at the core of quantum metrological measurements. Fast estimation of the phase can be realized in a coherent quantum system, where the phase precision is limited by the Heisenberg relation $\Delta E \geq 2\pi\hbar/\tau$, whereas in a standard classical measurement the precision is restricted by a shot noise limit $\sim 1/\sqrt{\tau}$. This opens a resource to make the phase estimation faster.
Here we show how to implement suitably modified Kitaev-[1] and Fourier phase estimation algorithms on a transmon type qubit in a superconducting quantum circuit architecture, and use it as a Heisenberg limited sensor of magnetic flux.

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Temperature Distributions for a Qubit-Calorimeter Model

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We aim to theoretically and numerically study the temperature distribution for the driven qubit-calorimeter model proposed by[1]. The dynamics of this system were modelled in the case of a weak or adiabatic drive [2]. We extend this approach to a general periodically driven qubit. The evolution of the qubit-calorimeter system can be expressed by a pair of coupled stochastic differential equations for the state of the qubit and the temperature of the calorimeter. The state of the qubit evolves by a stochastic Schrödinger equation with jumps between so-called Floquet states. These jumps go together with jumps of the temperature. Additionally, the calorimeter is modelled to be in contact with a super bath of phonons, causing an additional drift and noise term for the temperature process. Numerical methods show us that for physically relevant parameters the short term behaviour of the temperature, on the order of a period of the drive, is dominated by the jumps. For much larger time scales the drift term due to the interaction with the phonons and the jump process compensate each other and the temperature reaches a steady state.

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Phase measurement by quantum dot interferometer in Kondo regime

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We examine a general model for a mesoscopic ring with an embedded quantum dot to identify the phase shift measured using such a quantum dot interferometer in multi-terminal setup.[1] In our model, an arm of the ring includes a quantum dot (represented by tunnel couplings $V_{L,k}$ to state k in lead L and $V_{R,k'}$ to state k' in lead R) and the other arm is described by the direct tunnel coupling $W_{k',k}e^{i\phi}$ between the leads. A magnetic flux is taken into account by the Aharonov-Bohm phase ϕ. In the previous work,[2] the tunnel couplings are independent of states k, k', which is justified in the case of single conduction channel in the leads only. In general, overlap integral S between the conduction mode coupled to the dot and that coupled to the other arm of the ring is less than unity ($S = 1$ in Ref. [2]). Our model is applicable to the multi-terminal setup in which the leads consist of two parts. The Kondo effect is calculated by the Bethe ansatz exact solution. An asymmetric Fano-Kondo resonance is observed as a function of energy level in the quantum dot when $S \sim 1$, whereas a conventional Kondo plateau appears for small S in accordance with the experimental result.[1] The measured phase is defined as ϕ at the maximum of conductance. It is locked to $\pi/2$ in the Kondo valley though it is different from the phase shift through the quantum dot.

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Noise of a superconducting magnetic flux sensor based on a proximity Josephson junction

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A hybrid superconducting magnetometer based on the proximity effect (superconducting quantum interference proximity transistor, SQUIPT) has demonstrated in experiments high responsivity to magnetic flux [1], and theoretically the noise is predicted to be very low [2], comparable or below obtained with state-of-the-art nanoSQUIDs. Yet the intrinsic limits to flux noise performance of such a device have not been experimentally investigated in detail up to now. Here, we demonstrate simultaneous measurements of DC transport properties and flux noise of a SQUIPT using a cryogenic amplifier operating in the frequency range of a few MHz [3]. In the present non-optimized device, the flux noise was found to be $\sim 4\ \mu\Phi_0/\ \mathrm{Hz}^{1/2}$, set by the shot noise of the probe tunnel junction. The flux noise can be improved by further optimization of the SQUIPT parameters, primarily minimization of the proximity junction length and cross section. Furthermore, the experiment demonstrates that the setup can be used to investigate shot noise in other nonlinear devices with high impedance. Similar to high-bandwidth tunnel junction thermometry, the noise measurement technique opens the opportunity to fast readout of sensitive magnetometers including SQUIPT devices with very low dissipation.

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Superfluidity nature of a rotating Bose-Einstein condensation in a 2D shallow optical lattice

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The super-fluid nature can be studied using rotating Bose-Einstein condensate (BEC). However, for BEC that rotating at a frequency close to the trap frequency, the centrifugal force balances the trapping force. To overcome this centrifugal barrier, we can add a shallow optical potential to the redial harmonic potential. In this case the effect of optical potential is to act as a stirring mechanism. Consequently the effect of centrifugal force can be controlled. As will as the interaction effect can be consider. In this work, we employed the semi classical approximation, to calculate the moment of inertia in terms of the effective in situ radius for this system. Our approach includes the finite size effect. The calculated results show that: in the presence of the optical lattice, the effect of the fast rotation (centrifugal suppression) is extinguished.

Charge pumping through a polaron quantum dot

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Electron-vibron coupling in quantum dots can lead to a strong suppression of the average current in the sequential tunneling regime. This effect is known as Franck-Condon blockade and can be traced back to an overlap integral between composite electromechanical states, called polarons, which becomes exponentially small for large electron-vibron coupling strength.
Using a non-equilibrium Green's function approach, we show that the application of a time-dependent gate voltage lifts this blockade exponentially. Furthermore, we introduce a second time-dependence to the system, which enables us to model more involved driving schemes and pumping, thus turning the polaron quantum dot into a highly flexible and tunable piece of nanocircuitry.

Ballistic electron wave interference in carbon nanotube ring

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The magneto-conductance measurements are performed on a small ring conductor fabricated with an individual single-walled carbon nanotube. The Aharonov-Bohm oscillations with the amplitude up to 90 % of the conductance are observed at 5 K. The amplitude decays slowly at temperatures up to 8 K and quickly damps at higher temperatures. The constructive electron wave interference is always realized at zero magnetic field due to the ballistic transport in one-dimensional channels. The temperature dependence of the amplitude shows that the main decoherence factor is thermal broadening of the electron energy in the low temperature region and the phase breaking scatterings at higher temperatures. [1]

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Conduction Mechanisms of Charge Transport Through Individual Chemisorbed Benzene Molecules

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It is very important that one understands the fundamental processes of transport properties of one-dimensional assembles of molecules connected between two resrvoirs of charge carriers, usually metallic leads. Selzer et al.[1] have measured temperature effects on conduction through individual chemisorbed 1-nitro-2, 5-di(phenylethyny1-4 mercapto) benzene molecules spanning a gold electrode gap. They observed a clear transition between temperature independent and thermally activated transport regimes. The present author [2,3] has discussed the conductivity in three-dimensional and quasi–one-dimensional system of diluted magnetic semiconductors, using effective electron-coupling formula similar to one in the molecular system. In this study, extending the previous theoretical formula [2,3], we will disccuss the localization effect of transport properties in low temperature region and the polaronic conduction above 100 K on individual chemisorbed benzen molecules, through interaction between carriers and the rotational fluctuation of molecular rings. [1] Y. Selzer et al, Nanotechnology 15,S483(2004) [2] I. Kanazawa.,Phys. Lett.A355,460(2006) [3] T. Sasaki and I. Kanazawa, Physics Procedia 75,1172(2015)

Heat transport through a transmon qubit

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We investigate heat transport in a circuit consisting of a transmon qubit coupled to two LC resonators terminated by resistors serving as heat baths. Our analysis is based on two complementary approaches. In the first one, the classical model, we assume that the resonator and the resistor form a dissipative environment for the plain qubit. In the second, quantum model, the qubit and the two resonators form a coupled system of three harmonic oscillators influenced by the bare resistive baths. The two models are applicable in different parameter regimes and demonstrate filtering of heat current upon tuning the level spacing of the qubit.

Traceable Coulomb blockade thermometry

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We present a measurement and analysis scheme for determining traceable thermodynamic temperature at cryogenic temperatures using Coulomb blockade thermometry. The electrical measurement is improved by utilizing two sampling digital voltmeters as virtual lock-in amplifiers instead of conventional lock-in amplifiers. This technique minimizes noise that could increase the electron temperature, and decreases the uncertainty of the electrical measurement. The remaining uncertainty is dominated by that of the numerical analysis of the measurement data. Two analysis methods are demonstrated: numerical fitting of the full conductance curve and measuring the height of the conductance dip. The complete uncertainty analysis shows that using either analysis method the relative combined standard uncertainty in determining the thermodynamic temperature in the temperature range from 20 mK to 200 mK is below 0.5%. In this temperature range, both analysis methods produced temperature estimates that deviated from 0.39% to 0.67% from the reference temperatures provided by a superconducting reference point device calibrated against the Provisional Low Temperature Scale of 2000.

Mechanical resonance measurements with suspended graphene Corbino disk in fractional quantum Hall regime

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We have fabricated suspended graphene devices in Corbino disk geometry for study of interplay between quantum Hall effect and the mechanical motion. In these devices, a ring shaped graphene is contacted with gold electrodes at the inner and outer edge while the gold leads themselves are supported by LOR. By using a mechanical resonance detection based on down-mixing of an FM signal fed to the source of the graphene device, we find a rich set of resonances. Our Comsol simulations with the graphene-gold resonator system indicate that many of the observed resonances are either gold resonances detected via graphene or combined resonances of the whole structure. Good agreement is found between the experiment and the simulation. At high magnetic fields, up to 9 T in our experiments, the electrons in graphene display quantum Hall effect (QHE) and fractional quantum Hall effect (FQHE). We found that the QH and FQH states present themselves as dips in the measured mixing signal. In particular, we observe multiples of the FQH state $\nu = 1/3$ up to $\nu = 8/3$, at charge carrier density $n = 6.7{\times}10^{-10}$ cm$-^2$. This makes it in fact a more sensitive method for detection of FQH states in our samples than conductance measurements. We attribute this sensitivity to the fact that the incompressibility of QH/FQH states is probed directly in our measurements via the charge carrier density modulation by the mechanical motion.

Superconducting silicide nanowires for quantum phase slip applications

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Recently it has been demonstrated that in sufficiently narrow nanowires zero resistivity is not reached even at temperatures well below the critical point[1]. On the contrary, in high-impedance environment, such nanowires exhibit insulating transition[2]. This phenomenon is the magnetic counterpart for charge tunneling in a Josephson junction: instead of charge tunneling through electrically insulating layer, magnetic vortices tunnel through narrow superconducting nanowire (magnetic insulator). From the application point-of-view, nanowires may have major benefits: less fabrication process steps, robustness to larger electric currents, wide parameter range, and the lack of undesired two-level fluctuators present in the insulating contacts of Josephson junctions.
We have developed a fabrication process for high resistivity ultra-narrow superconducting silicide nanowires and have measured transport properties of these nanowires as a function of cross section. The larger wires exhibit sharp superconducting transition but in the smaller wires QPS broadens the transition. In case of very high sheet resistance wires we observe insulating transition.

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A SQUIPT Magnetometer based on Graphene and MoS_2

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The superconducting quantum-interference proximity transistor (SQUIPT) is a two-terminal device based on a NIS junction between a superconducting "probe" electrode and a normal-metal wire inserted in a superconducting loop geometry [1]. The SQUIPT takes advantage of the tunability of the density of states by phase bias over the SNS junction. It promises to achieve a high-sensitivity flux sensor with very low power dissipation and a simple readout scheme [2]. In this work, we have implemented a novel SQUIPT magnetometer (G-SQUIPT) with a NIS junction using exfoliated graphene and molybdenum disulphide (MoS_2) [3][4]. Graphene is encapsulated by thin MoS_2 (3∼6 layers) on the substrate. The MoS_2 flake is prepared on a polydimethylsiloxane (PDMS) stamp and released by using a micromanipulator and heated microscope stage. The whole stack is patterned by RIE process to expose one-dimensional graphene edges, which make good electrical contacts to the sputtered Molybdenum Rhenium (MoRe) loop. Our fabricated devices show tunnel resistances at the range of a few kΩ to MΩ at room temperature. Parallel to this work, we have demonstrated that a supercurrent can pass through a similar graphene channel with edge-contacted MoRe. In our preliminary low temperature measurements, we have observed a mini-gap in graphene induced by MoRe. Tunability of the sample conductance by magnetic flux was also observed.

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Controlling the Coupling to the Thermal Bath in Junction Refrigerators

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The single particle density of states of superconductor provides an energy filtering effect that can be utilized in tunnel junction refrigerators and thermal detectors[1] and cooling of macroscopic loads.[2] The tunnel junction can be either normal metal-insulator-superconductor (NIS) or semiconductor-superconductor (Sm-S) junction, where insulating layer (I) is replaced by a Schottky barrier. It has been shown recently that by careful engineering of the junction fabrication the performance of Sm-S devices can reach that of NIS at sub-1 K.[3] Here, we will discuss higher temperature operation (e.g. with Si-Nb junctions) and fundamental limits of superconductor based refrigerators. Concerning the latter we demonstrate a new method, not relying on bulk or thin film electron-phonon coupling, for engineering the coupling to the thermal phonon bath. This is one of our main results and it provides new insights on how to control electron and phonon heat/energy flux in solid-state quantum devices. Furthermore, this enables cooling of macroscopic loads and, here, by utilizing our thermal coupling engineering we demonstrate cooling of a Si chip for the first time.

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Squeezing and amplification with superconducting-insulator-superconducting junctions

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It has recently been demonstrated experimentally and theoretically that a dc- and an ac-biased tunnel junction generate squeezed microwave photons. As the tunnel junction is a linear element, squeezing is generated via dissipation. In the presence of an electromagnetic environment, the junction becomes nonlinear giving rise to squeezing produced via parametric interaction. Thus, we investigate the radiation emitted by a dc- and ac-voltage biased superconducting-insulator-superconducting (SIS) junction coupled to a transmission line. Applying a dc-voltage of the order of twice the superconducting gap Δ the quasiparticles current presents an extremely sharp behavior. Exploring this non-linear behavior, we show that the SIS junction is a source of broadband squeezing, and it also works as a phase-sensitive or phase-insensitive amplifier. Considering an aluminum junction, we demonstrate that squeezing and amplification are of the order of 26 dB and 34 dB, respectively. Moreover, we show that by varying the dc-voltage the squeezing and amplification bandwidth are easily controlled.

Strong coupling of microwave photons to antiferromagnetic fluctuations in an organic magnet

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Coupling between a crystal of di(phenyl)-(2,4,6-trinitrophenyl)iminoazanium (DPPH) radicals and a superconducting microwave resonator is investigated in a circuit quantum electrodynamics (cQED) architecture. The crystal exhibits paramagnetic behavior above 4 K, with antiferromagnetic correlations appearing below this temperature, and we demonstrate strong coupling at base temperature. The magnetic resonance acquires a field angle dependence as the crystal is cooled down, indicating anisotropy of the exchange interactions. These results show that multi-spin modes in organic crystals are suitable for cQED, offering a platform for their coherent manipulation. They also utilize the cQED architecture as a way to probe spin correlations at low temperature.

Anomalous Hall effect and magnetic properties of GaMnSb thin films grown by DC Magnetron co-Sputtering for spintronics applications

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Abstract. This work presents a study of the magnetic properties and Hall effect measurements on diluted magnetic semiconductors (GaMn)Sb obtained by DC magnetron co-sputtering method. Synthesis parameters, like substrate temperature (T_s), and deposition time (t_d) were varied while the magnetron power deposition applied to both targets, and the work pressure (WP) were kept constant. The values for t_d were 10 and 15 min; for T_s, these values were 423 and 523 K. The Mn_2Sb_2 and Mn_2Sb phases were identified through the X-ray diffraction measurements. The influence of synthesis parameters on the magnetic properties and Hall effect are discussed. Magnetization (M) studies as function of the applied magnetic field (H) at different temperatures (50, 150, and 300 K) were also performed. The paramagnetic and diamagnetic behavior, accompanied by the ferrimagnetic and ferromagnetic phases in two samples was evidenced through hysteresis curves. The Hall effect was used to establish carrier density (n_p) values between 3.19 x 10^{-15} cm^{-3} and 2.86 x 10^{20} cm^{-3}, consequently, the anomalous Hall effect was observed.

Keywords: spintronics, GaSbMn, thin films, anomalous Hall effect

Simple model of a quantum heat engine: Can noise-induced coherence enhance output power and/or efficiency?

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Recently, it was shown on a simple model [1, 2] that noise-induced coherence can lead to an enhanced output power of heat engines. We revisit this model and investigate whether the obtained interesting results are not only artefacts of an oversimplified optical-master-equation description. First, we study the model in the basis where the steady state density matrix is di-agonal and determine whether the non-zero steady state coherence are not just a product of wrong choice of the basis. Next, we consider also the situation where the model contains close, but non-degenerate energy levels and study whether the description using standard quantum optical master equation is appropriate in this situation.

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Properties of Single-Wall Carbon Nanotube as a Topological Insulator

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The single-wall carbon nanotube (SWNT) is a unique one-dimensional (1D) system made by rolling up a graphene sheet. It can be regarded as a 1D topological insulator owing to the sublattice symmetry for A and B lattice sites[1]. The electronic states are characterized by a Z topological invariant, winding number, in both the absence (class BDI) and presence (AIII) of magnetic field. We show that almost SWNTs are topologically non-trivial except armchair nanotubes. Next, we study the topological phase transition in a metallic SWNT, in which a small energy gap is opened by the mixing between σ and π orbitals due to a finite curvature of the tube surface and closed by applying a magnetic field $B = B^* \sim 1$ T parallel to the tube axis[2]. We demonstrate discontinuous changes in the winding number at B^*, which can be observed as a change in the number of edge states owing to the bulk-edge correspondence. This topological phase transition is generally observed except for armchair SWNTs, which is confirmed by numerical calculations for finite SWNTs of length ~ 1 μm, using a 1D lattice model to effectively describe the mixing between σ and π orbitals and spin-orbit interaction[3].

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On-chip Error Counting and Improved Quasiparticle Thermalization for Hybrid Single-electron Turnstiles

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I present our ongoing experiments on in-situ detection of individual electrons pumped through a hybrid metallic single-electron turnstile based on ultrasmall normal metal - insulator - superconductor tunnel junctions. In our setup, limited by the detector bandwidth, at low repetition rates we observe error-less sequential transfer of up to several hundred electrons through the system. At faster pumping speeds up to 100 kHz, we show relative error rates down to 10^{-3}, comparable to typical values obtained from measurements of average pumped current in non-optimized individual turnstiles. We compare the deviation from the expected current $I = ef$, observed both by direct counting at low duty cycle, and by measuring the average current under continuous drive at frequency f. I further show results from measurements of turnstiles with thick, low-resistive superconducting aluminium electrodes towards improved quasiparticle thermalization under driven operation.

Electron waiting times of a periodically driven single-electron turnstile

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The distribution of waiting times between tunneling events is a useful statistical tool to characterize quantum transport. Waiting time distributions (WTD) complement zero-frequency observables such as the mean current and the shot noise, for example by revealing the regularity of single electrons emitted from dynamically driven devices. In recent years, WTDs have been investigated for a variety of quantum transport setups, including quantun dots,[1] dynamic single-electron emitters,[2] mesoscopic conductors[3] as well as superconducting devices. In this contribution, we present a general theory for calculating the WTD of a periodically driven single-electron device.[4] Our approach is applicable for any periodic driving protocol and leads to analytic expressions for the WTDs. Our results can be compared with future measurements of WTDs in a single-electron devices based on a capacitively coupled charge detector.

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Parametrically Driven Hybrid Qubit-Photon Systems: Quantum Effects Amplification due to the Energy Dissipation

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We consider a dissipative evolution of parametrically driven qubit–cavity system under the periodical modulation of qubit–photon coupling energy, which leads to the amplification of counter-rotating wave processes[1]. We reveal a very rich dynamical behavior of this hybrid system. In particular, energy dissipation in one of the subsystems can enhance quantum effects in another subsystem. For instance, cavity decay assists to stabilize entanglement and quantum correlations between qubits even in the steady state and to compensate finite qubit relaxation. On the contrary, energy dissipation in qubit subsystem results in the enhanced photon production from vacuum for strong modulation, but destroys both quantum concurrence and quantum mutual information between qubits. Our results provide deeper insights to non-stationary cavity quantum electrodynamics in context of quantum information science and might be of importance for dissipative quantum state engineering.

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Partition-free theory of time-dependent current noise in molecular junctions

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Working within the Nonequilibrium Green's Function (NEGF) formalism, a formula for the two-time current correlation function is derived for the case of transport through a nanojunction in response to an arbitrary time-dependent bias. The one-particle Hamiltonian and the Wide Band Limit Approximation (WBLA) are assumed, enabling us to extract all necessary Green's functions and self energies for the system, extending the analytic work previously done for calculations on the current and particle number in nanojunctions driven by a bias with arbitrary time-dependence. We show that our new expression for the two-time correlation function generalizes the Landauer-Büttiker (LB) theory of shot and thermal noise on the current through a nanojunction to the time-dependent bias case including the transient regime following the switch-on. In addition, we present a technique which for the first time facilitates fast calculations of the transient quantum noise, valid for arbitrary temperature, time and voltage scales in extended molecules. We then perform calculations on a molecular wire system for both DC and AC biases. Frequency analysis reveals the signature of photon-assisted tunneling in the transient noise spectra, and we also find a novel signature of the traversal time for electrons crossing the wire in the time-dependent cross-lead current correlations.

Proposal for superfluid optomechanics within the nanofluidic environment

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Important progress in optomechanics has enabled the development of extremely sensitive nano-electromechanical systems, which have recently reached the ultimate limits imposed by quantum mechanics theory. These quantum-limited sensors offer new opportunities for many fields of research and application. The aim of this proposal is to exploit the unique properties of superfluid 4He at low mK temperature and the recent advances in quantum nanofluidics[1,2], to undertake a versatile programme of quantum optomechanics experiments. We will couple high quality factor superfluid acoustic resonators to high finesse superconducting microwave cavity within the nanofluidic environment. This platform offers a great flexibility in design over a wide range of parameters. Unlike classical materials, superfluid 4He is an exotic state of quantum matter showing exceptionally low dissipation at mK temperature. We expect optomechanical systems to show extremely high sensitivity and long phonon lifetime. We will investigate the effects of an electrostrictive optomechanical coupling and the acoustic nonlinearities in superfluid 4He to explore phonon-photon interactions in a new regime. Furthermore, the proposed architecture may allowed the study of many-body quantum effects with superfluid acoustic resonators arrays.

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Chiral Maxwell demon in a quantum Hall system with a localized impurity

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We investigate the role of chirality on the performance of a Maxwell demon implemented in a quantum Hall bar with a localized impurity. Within a stochastic thermodynamics description we investigate the ability of such a demon to drive a current against a bias. We show that the ability of the demon to perform is directly related to its ability to extract information from the system. The key features of the proposed Maxwell demon are the topological properties of the quantum Hall system. The asymmetry of the electronic interactions felt at the localized state when the magnetic field is reversed joined to the fact that we consider energy dependent (and asymmetric) tunneling barriers that connect such state with the Hall edge modes allow the demon to properly work.

Thermoelectricity without absorbing energy from the heat sources

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A thermocouple generates finite electrical power by coupling a part of an electrical conductor to an external heat source. Macroscopically, this part of the system equlibrates to an increased temperature that governs the thermoelectric performance. The generated power then depends on the heat current absorbed from the source. In a mesoscopic system, this is not necessarily the case. The coupling of a nanoscale system (e.g. a quantum dot) to a hot and a cold bath can be used to generate a finite power in the electrical conductor even in situations when it absorbed no heat. We show that this effect is possible in the presence of non-thermalized states [1]. We propose a configuration based on capacitively coupled quantum dots recently realized experimentally [2, 3], and show that the effect does not rely on the presence of interactions.

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Theory of Normal-Metal Quasiparticle Traps

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Superconducting qubits are thought to store the information needed for quantum information processing. However, it is a big challenge to store the information: unwanted interactions with the qubit's environment lead to decoherence of the qubit and thus information loss. In addition to these *extrinsic* sources for decoherence, there is also (at least) an *intrinsic* one: the coupling between the qubit and the non-equilibrium quasiparticles in the superconductor the qubit is made of. Decoherence is due to quasiparticle tunneling through a Josephson junction. This mechanism is highly depending on the location of the quasiparticles: Those far away from junctions have much less contribution to decoherence than the ones close to it. While it is difficult to prevent the generation of quasiparticles, trapping them in less active regions of the device seems to provide a practicable way to improve the device performance. We are aiming to establish a quantitative theory of normal-metal traps simply consisting of an island of normal metal which is in contact with the superconductor. To do so, we are applying a Green's function formalism - the Keldysh technique in the dirty limit with a quasiclassical approximation - to investigate the properties of non-equilibrium quasiparticles in mesoscopic devices. In the limit of weak electron tunneling, the proximity effect can be neglected. Thus, once the quasiparticles tunneled into the normal metal and lost energy due to phonon emission or inelastic electron-electron interaction, they are trapped in the island.

Superconducting proximity effect and spontaneous currents in hybrid systems with spin filters and strong ferromagnets

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The interplay of superconducting and magnetic orderings in hybrid ferromagnet/superconductor (F/S) structures results in the long-range spin-triplet proximity effect which can be used in superconducting spintronics applications. So far, proximity and transport calculations in F/S hybrids have mostly concentrated on the limit of weakly polarized systems where the exchange field is much smaller than the Fermi energy. This approximation leads to the additional symmetry constraint that prohibits the existence of many phenomena resulting from the broken time inversion in the presence of magnetic moment. Going beyond this limitation we demonstrate that F/S systems with spin-filtering elements can feature anomalous Josephson effect, spontaneous superconducting currents and phase-shifted thermal interference currents which can be controlled by the magnetic configuration.

In systems with strong ferromagnets where the exchange splitting is of the order of Fermi energy we develop the generalized quasiclassical theory of the long-range superconducting proximity effect. We derive the Usadel equations and boundary conditions for equal-spin Cooper pairs coupled to the spin-dependent Abelian gauge field and consider several generic examples of the Josephson systems supporting spontaneous superconducting currents.

Noiseless quantum measurement and squeezing of microwave fields utilizing mechanical vibrations

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A process which strongly amplifies both quadrature amplitudes of an oscillatory signal necessarily adds noise. Alternatively, if the information in one quadrature is lost in phase-sensitive amplification, it is possible to completely reconstruct the other quadrature. Here we demonstrate such a nearly perfect phase-sensitive measurement using a cavity optomechanical scheme, characterized by an extremely small noise less than 0.2 quanta. The device also strongly squeezes microwave radiation by 8 dB below vacuum. A source of bright squeezed microwaves opens up applications in manipulations of quantum systems, and noiseless amplification can be used even at modest cryogenic temperatures.

Thermopower in graphene quantum dots coupled by a superconductor

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Thermopower in hybrid nanodevices with energy-dependent transmission is an intriguing topic. We have studied thermal transport in two graphene quantum dots (QDs) tunnel-coupled via an Al superconductor. In our setup, we have separate control of the voltage bias and measurement of the two QDs. While having bias on QD2, we are able to detect temperature increase in the Al conductor by measuring the conductance of QD1, since the conductance of QD1 is quite sensitive to the temperature. And a voltage on QD1 has been observed, when Al is heated up by bias on QD2. This voltage shows a sawtooth-like oscillation as a function of the gate voltage with the same period as the Coulomb blockade oscillation, which is a sign of the thermopower of a quantum dot. [1] When applying a magnetic field on the device, the amplitude of the sawtooth-like voltage oscillation decreases. This is because the magnetic field suppresses the superconductivity of Al, whereby the thermal conductivity of Al will increase dramatically, leading to a smaller temperature difference and a reduced thermopower. Experiments with controlled temperature difference are presently underway.

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Rectifying full-counting statistics in a spin Seebeck engine

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We investigate the rectification effect of a spin Seebeck engine in which the quantum dot (QD) is coupled to both the electronic reservoir and magnetic insulator. The scaled cumulant generating function (SCGF) of the system is expressed in the framework of nonequilibrium Green's function. We present the rectification and negative differential effect of spin current and its higher order cumulants. The heat engine performances, such as the maximum output power and efficiency are also shown to exhibit rectification and negative differential effect. The strongly fluctuated interfacial electron density of states induced by QD is responsible for these intriguing properties. It can broaden our views of the nonequilibrium thermodynamics by studying the nontrivial phenomena occurred in the two terminal hybrid system involving both electronic and bosonic reservoir.

The Effect of Spin Orbit interaction on $LaTSi_3$(T = Ir, Pd and Rh) Materials with Density Functional Theory

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We have presented the structural, elastic, electronic, vibrational and electron-phonon interaction properties of the La-based noncentrosymmetric superconductors $LaIrSi_3$, $LaRhSi_3$ and $LaPdSi_3$ by using the generalized gradient approximation. The calculated elastic constants reveal the mechanical stability of all the studied compounds in their noncentrosymmetric structure. The calculated Eliashberg spectral function shows that all phonon branches of these materials couple considerably with electrons and thus, all of them make contribution to the average electron-phonon coupling parameter λ. Using the calculated values of λ and the logarithmically averaged phonon frequency ω_{ln}, the superconducting critical temperature T_c values for $LaIrSi_3$, $LaRhSi_3$ and $LaPdSi_3$ are estimated to be 0.89, 2.56 and 2.40 K, respectively, which coincide with their corresponding experimental values of 0.77, 2.16 and 2.60 K.

Josephson Parametric Amplifier at 600 MHz for Nano-calorimeter Readout

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We design a sub-gigahertz, lumped-element Josephson parametric amplifier (JPA) for the readout of nanoscale calorimeters which consist of normal-metal–superconductor heterostructures.[1] We fabricate the JPAs with a new wafer-scale process featuring cross-layer Nb-Al/AlO_x-Nb junctions. In order to meet the dynamic range requirement of the calorimeter readout at 600 MHz, we use an array of 200 SQUIDs as a non-linear inductance. An on-chip flux bias line allows continuous tuning of the JPA center frequency in a range between 550 MHz and 650 MHz, and robust operation with pumping at twice the signal frequency. The gain-bandwidth product is approximately $2\pi \times 3$ MHz, and the input saturation power is higher than -125 dBm. We present a performance comparison between the new devices and sub-GHz JPAs fabricated with an established niobium trilayer process.[2]

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Calorimetry with hysteretic superconductor-normal metal-superconductor Josephson junctions

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Calorimetry is an important tool in investigating thermodynamics. Especially for a small mesoscopic system, it would be of great benefit to have a fast and sensitive calorimeters which are able to measure a packet of energy transferred within the system. Recently it has been proposed that one could also couple the calorimeter to a quantum system, for instance, to a superconducting qubit. The calorimeter can then be used to observe the exchange of microwave photons. Works have been done before on fast and sensitive calorimeters [2-4]. In order to enhance the energy resolution of calorimeter, heat conductance and heat capacity of the absorber of calorimeter need to be low. Here, we will present measurements of the heat conductance and heat capacities of evaporated normal metal thin films. We find an anomalously high heat capacity for Au, Ag and Cu films at low temperatures, values measured for the three metals are about one order of magnitude higher than those calculated from the standard free electron model.

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Quantum heat transport in a spin-boson nanojunction

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Quantum heat transport in a spin-boson system under nonequilibrium steady state (NESS) is investigated by the nonequilibrium Green's function (NEGF) method. Spin-spin correlators are calculated via the Majorana fermion representation of spin operators, which allows us to make use of Wick's theorem through standard diagrammatic techniques. An analytic formula of heat current is obtained, and numerical results are presented in comparison with those obtained by other methods. Two types of transport mechanisms are identified in high- and low-temperature regions, respectively, which shows a transition from incoherent to coherent transport process with the baths' temperatures decreased.[1] Furthermore, by combining the polaron transformation, we are able to treat the system-bath coupling nonperturbatively,[2] that allows us to deal with not only the system from weak to strong coupling, but also the role of bias. For a unbiased spin system, we find the energy current result smoothly bridges predictions of two benchmarks, namely, the quantum master equation and the nonequilibrium non-interacting blip approximation, a considerable improvement over existing theories. In case of a biased spin system, we find a bias-induced nonmomotonic behavior of the energy conductance in the intermediate coupling regime.[3]

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Real space transmission properties of Graphene-Superconductor Lateral heterojunction

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Transport properties of 2D materials especially close to their boundaries have received much attention after the successful fabrication of graphene and other fascinating materials. While most previous work is devoted to the conventional lead-device-lead setup with a finite size scattering center, this project investigates real space transport properties of infinite and semi-infinite 2D system under the framework of Non-equilibrium Green function. The broadly used method of calculating the Green function by inverting a matrix in the real space directly can be unstable in dealing with large systems as sometimes it gives non-converging result. Not to mention that the calculation error and time increase drastically with size of the system. By transforming from the real space to momentum space, we managed to replace the matrix inverting process by Brillouin Zone integral process which can be greatly simplified by the application of contour integral. Combining this methodology with Dyson equations, we are able to calculate transport properties of semi-infinite graphene close to its zigzag boundary and its combination with other material including s-wave superconductor. Interference pattern of transmitted and reflected electrons, graphene lensing effects and difference between Specular Andreev reflection and normal Andreev reflection are verified through our calculation. We also generalize how to apply this method to a broad range of 2D materials.

Circuit Quantum Electrodynamics with Spin Qubits

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Electron spins in gate-defined Si/SiGe quantum dots are promising quantum bits (qubits) for future quantum information processors. Several desirable properties include long spin coherence times, great tunability of energy scales and compatibility with current manufacturing technologies. Many qubits are needed to collectively form a practical quantum computing system. Numerous proposals exist for increasing the number of qubits[1]. A promising way of scaling up entails a network of spin qubits in which on-chip superconducting microwave cavities are utilized as coherent links between distant qubits. In this approach a strong coupling between an electron spin and a cavity photon is essential. We make use of high-impedance resonators[2] to enhance the capacitive coupling between the microwave cavity and the qubit. Our devices are fabricated on Si/SiGe heterostructures grown both in-house and at Intel. We show double quantum dots in the few-electron regimes and we demonstrate dispersive gate readout with the cavity.

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On-chip mechanical thermometry at mK temperatures

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With the aim of measuring on-chip the phonon temperature of a mechanical nano-oscillator, we have set up an optomechanical system where a long mechanical beam is coupled to a microwave cavity. The experiment is mounted on the Grenoble nuclear demagnetization cryostat able to reach temperatures below 1 mK. We report on the first measurements of this set-up at dilution temperatures, and discuss future possibilities for ultra-cold nanomechanics where cooling relies only on cryogenic technologies. No active cooling techniques are used in our experiments, in which we plan to explore the limits of "brute force" cooling for these systems.