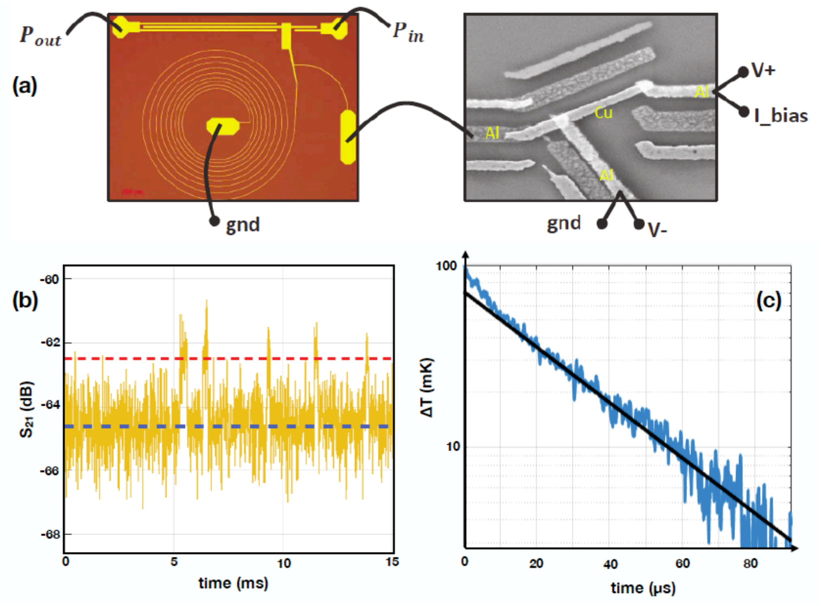
NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Detection of elementary dissipative processes in quantum devices

Recent years have seen rapid developments in coherent quantum electronics based on nanoscale devices at low temperatures, with promising applications in quantum information technology. Yet, little is known about dissipation in these systems, although proper heat management is key for preserving quantum coherence. This is mainly due to the slowness of most currently available thermometry techniques, together with the difficulties in obtaining *local* information on temperature, in particular in nanoscale semiconductors. Beyond applicative motivations, elementary dissipative processes pose fundamental physical questions in the growing field of quantum thermodynamics, related to the understanding of heat in the quantum world.



(a) *Radiofrequency thermometry scheme, involving a superconducting LC resonator (left), coupled to the device to be measured, here a 500 nm-long metallic Josephson junction (right).* ***(b)*** *Time-resolved resonator transmission S_{21}, revealing here five rapid switches of the current-biased Josephson junction to the dissipative (hot) state, seen as excursions of S_{21} above the red dashed line.* ***(c)*** *Real-time temperature relaxation in a silicon micro-bolometer at 80 mK after a heating pulse, demonstrating μs-scale thermometry (the black line is an exponential fit).*

Our group has recently set up a μs-resolution thermometry technique, suited to the study of quantum circuits. Local electron thermometers are provided by the temperature-dependent conductance properties of superconducting nano-junctions, which are coupled to a superconducting LC resonator (Fig. 1a). The tank circuit transmission S_{21} provides a direct probe of the instantaneous electron temperature. This was recently demonstrated in proof-of-principle experiments probing dissipative excursions in a current-biased Josephson junction (Fig. 1b) and temperature relaxation in a Si bolometer (Fig. 1c). Basing on this, the present PhD project will couple this technique to more complex driven quantum electronic devices. The aim of this project is to detect the heat released by two of the most elementary dissipative processes in quantum electronic devices.

The first of them is the tunneling of a single electron: we will detect the energy released by such individual tunneling events. On-demand single-electron tunneling will be achieved by ac-driving the chemical potential of a quantum dot tunnel coupled to a metallic absorber. We will investigate the crossover from adiabatic to quench tunneling dynamics and relate the measured dissipation to the basic quantum tunneling processes. Further, in superconducting devices, electron transport is in principle dissipation-free. Yet, above some current density threshold, the quantum phase of the superconducting condensate is strongly twisted. This can lead to individual 2π phase slips in a Josephson junction, which provide the elemental bricks of dissipation in superconducting electronics. We will induce such phase slips in a RF-SQUID via a fast flux coil, and demonstrate their calorimetric signature.

Precise calorimetry of both above dissipative effects will provide important insights into the quantum processes involved, and help understand how to protect quantum devices from thermal decoherence. The experiments will be performed at milliKelvin temperatures, using both ultra-low noise dc transport and radiofrequency measurements. All necessary instrumental tools are already available. The scientific work will involve the design, nanofabrication and measurements of nanoelectronic devices, along with analysis and interpretation of the results.

Possible collaboration and networking: The work bases on existing strong collaborations with experimental partner teams in Helsinki and Lund, as well as theoreticians in Grenoble. The Lund partner will provide heterostructured InAs/InP nanowires, which will be used as quantum dots. The Helsinki partner (J. Pekola) is strongly involved in the RF thermometry measurements. Theoretical aspects of the project will benefit from the guidance by D. Basko (LPMMC/Grenoble).

Required skills: MSc level in Physics or Applied Physics. Prior experience in low temperature physics, thermodynamics or nanoelectronics is a plus.

Starting date: 2022

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