Thermodynamics of nanostructures at low temperatures

How to measure temperature by flipping a coin?

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MOTIVATION

Studies of magnetoelectrical properties at nanoscale have been much more popular than thermal investigations. To big extent this apparent dichotomy could have been attributed to lack of fast thermometers that could be easily integrated with nanostructures operating at low temperatures. Yet, a proper understanding of thermal processes at nanoscale is essential for failure-free functioning of low temperature quantum circuits, involving design of nanoscale calorimeters – devices measuring absorbed or dissipated heat, and related to them bolometers – thermal detectors of incident radiation for health, security and astronomy applications. Superconducting bolometers operating at infrared or terahertz frequencies are already available commercially and used for example in airports for non-invasive scanning of people. Reliable microwave bolometers are yet to be developed. Application of a fast and robust thermometer that could be easily integrated with a nanostructure is also essential for studies in emerging fields of quantum thermodynamics and phase-coherent caloritronics. First discipline investigates heat flows arising from difference in temperature between two bodies at quantum level. Second one involves generation and manipulation of heat currents to demonstrate novel-concept devices.

INNOVATION

I have proposed and demonstrated experimentally switching thermometry as a novel tool for testing temperature of nanostructures in thermal transients with resolution approaching a single nanosecond. In our pioneering studies, we used superconducting aluminum nanobridge probed with short (≥1ns) pulses to measure its switching probability i.e. transition from superconducting to normal state. The probability depends on temperature just providing feature necessary for a temperature sensor. The bridge is probed with N pulses (typically N=10000). In response to each pulse the bridge may switch or remain in the superconducting state. The number of switchings weighted by N gives switching probability. The protocol remains in the full analogy with a flipping coin experiment. The switching can be associated with the head and lack of switching with the tail. Unlike a fair coin, our bridge exhibits probability of obtaining the head that is dependent on temperature. We can monitor rapidly changing temperature with temporal resolution approaching a single nanosecond. Nobody has been able to measure temperature of nanostructures so fast.

GOAL

I would like to demonstrate operation of novel-concept calorimeters and microwave bolometers based on the switching thermometry that has been developed by me over recent years. We will create a versatile platform for measuring heat capacity of small metallic islands and thin films at cryogenic temperatures. We want to focus on heat transfer across a nanostructure provided by microwave photons. More precisely, we will demonstrate detection of such photons, either produced by external source and guided to bolometer, or emitted by resistive components of nanostructure (i.e. black-body radiation which is characteristic to each body at non-zero temperature). We will also measure propagation of phonons between two different nanodevices defined at the top of silicon chip.