Hybrid normal metal-superconductor devices

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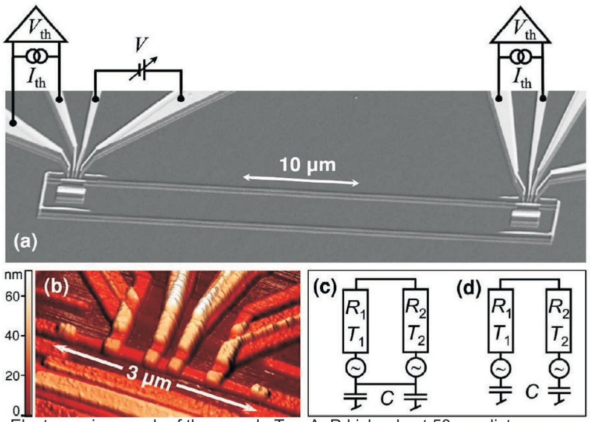
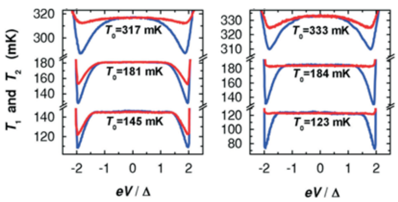
The quantum of thermal conductance

M. Meschke, W. Guichard, and J.P. Pekola, Single-mode heat conduction by photons, Nature **444** (2006) 187 .
A. V. Timofeev, M. Helle, M. Meschke, M. Möttönen, and J. P. Pekola, Phys. Rev. Lett. **102** (2009) 200801

Thermal conductance of a single channel is limited by its unique quantum value G_Q, as was shown theoretically by Pendry[1]. The single-mode heat conductance is particularly relevant in nano-structures. For the first time it was observed in heat transport through sub-micron dielectric wires by phonons[2], and it has been predicted to influence cooling of electrons in metals at very low temperatures due to electromagnetic radiation[3]. Here, we demonstrate quantum-limited electronic refrigeration of a metallic island in a low-temperature microcircuit. We show that matching the impedance of the circuit enables refrigeration at a distance, of about 50 μm in our case, through superconducting leads with a cooling power determined by the quantum of thermal conductance. In a reference sample with a mismatched circuit this effect is absent.



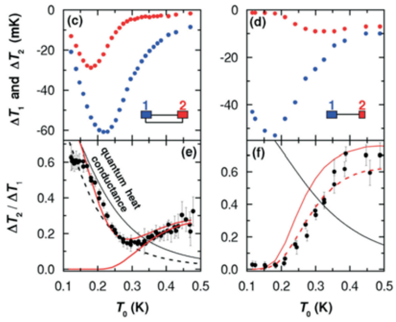
Electron micrograph of the sample.Two AuPd islands at 50 μm distance are connected with Al superconducting lines into a loop to match the impedance between them and enable remote refrigeration. (b) Colored atomic force microscopy image of the island. The four NIS junctions, contacting each island in the middle part, are used to perturb and to measure the island temperature. (c) Equivalent electrical circuit of the matched and (d) the mismatched structure.



Measured electronic island temperatures of the cooled (blue line) and the remotely connected (red line) island as a function of cooler voltage at three bath temperatures. The temperature of both islands is increasingly coupled in the matched sample towards lower temperatures.

$$G_Q \equiv \pi k_B^2 T / 6\hbar$$

The absolute temperature drops ΔT_1 and ΔT_2 of the two islands for the matched (left) and unmatched (right) sample. In both cases, the direct refrigeration (blue) is similar. In contrast, the refrigeration of the remote island (red) differs drastically: quasiparticle heat conduction freezes out in both cases towards low temperatures, but radiative heat conduction becomes the dominant effect only in the matched case. Red lines are the result of a numerical thermal model.

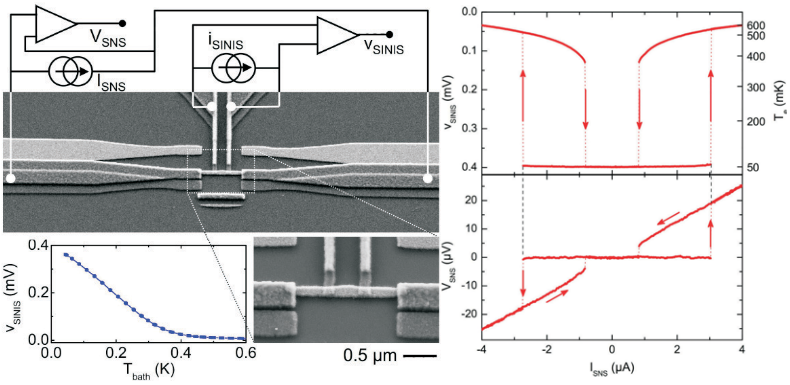


[1] Pendry, J.B. Quantum limits to flow of information and entropy, J. Phys. A 16, 2161-2171 (1983).
[2] Schwab, K., Henriksen, E.A., Worlock, J.M. & Roukes, M.L. Measurement of the quantum of thermal conductance, Nature 404, 974-977 (2000).
[3] Schmidt, D.R., Schoelkopf, R.J. & Cleland, A.N. Photon-mediated thermal relaxation of electrons in nanostructures, Phys. Rev. Lett. 93, 045901 (2004).

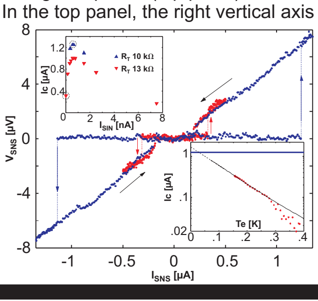
Proximity Josephson Junctions: Origin of Hysteresis and Thermometry

H. Courtois, M. Meschke, J.T. Peltonen, and J.P. Pekola, Phys. Rev. Lett. **101** (2008) 206801

We demonstrate by measuring directly the electron temperature in the normal metal that the hysteresis in the transport properties of SNS junctions at low temperatures results from an increase of the normal-metal electron temperature once the junction switches to the resistive state.



(left) Micrograph of the sample containing a SNS junction of 1.5 μm length with a sketch of the measurement circuit. Two tunnel probes (top of the image) are connected to the normal metal embedded between superconducting banks (on the left and right sides of the image). The overlap of the superconducting banks (dark gray) with the normal-metal layer (light gray) is visible. During the measurement, the SINIS junction is biased at a fixed current and the voltage drop is monitored. Bottom left panel: temperature dependence of the voltage of the SINIS probe with a current bias of 6 pA (no current is flowing through the S-N-S junction). Bottom right panel: A close-up of the sample image. (right) Current-voltage characteristic of the SNS (bottom panel) shown on the same current scale with the SINIS thermometer voltage response (top panel) measured simultaneously at a 50 mK cryostat temperature. In the top panel, the right vertical axis shows the corresponding electron temperature.

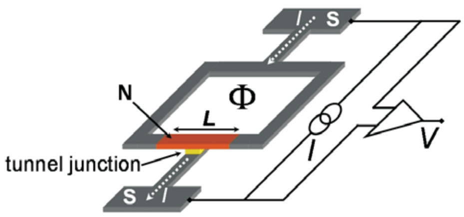


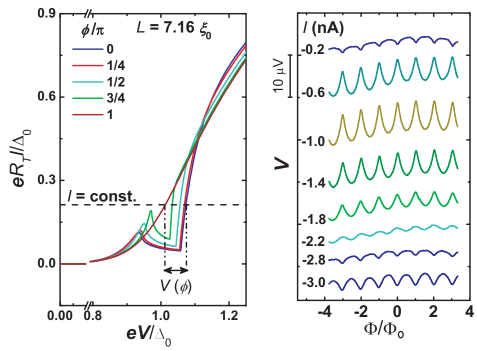
SNS structure for thermometry: the critical current (Ic) of the SNS junction depends exponentially on temperature, its magnitude can be tuned by the length of the junction. Calibration (right inset) yields the Thouless energy and enables extrapolation of the temperature reading towards lower temperatures. Cooling of the electronic system using the NIS probes (left inset) results in strong enhancement of Ic corresponding to a cooling from 150 mK (red) down to ~30 mK (blue).

Superconducting Quantum Interference Proximity Transistor

F. Giazotto, J.T. Peltonen, M. Meschke, and J.P. Pekola, arXiv:0909.3806

A novel-concept interferometer, whose operation is based on the modulation of the density of states of a proximized metallic wire embedded in a superconducting ring due to external flux. The device requires only a simple DC readout scheme similar to DC SQUIDS and operates at very low power dissipation levels.





(Top) schematic drawing of the SQUIPT: the superconducting tunnel probe (S) is placed in the middle of the normal metal (N) wire that forms the weak link in the superconducting loop. A constant current bias probes the magnetic field dependend modulation of the density of states in the proximized normal metal wire. (left) Calculation of the quasiparticle current-voltage characteristic as a function of magnetic flux through the loop.
(right) Experimental data obtained at different current bias levels.