PARITY-CONTROLLED CHARGE MODULATION OF THE SUPERCURRENT IN THE SINGLE ELECTRON TRANSISTOR

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Abstract

We have measured the parity-controlled charge modulation of the supercurrent in a superconducting single electron transistor, at different magnetic field and temperatures. We observed the characteristic features of the poisoning of the supercurrent enhancement.

Summary

The canonical conjugation between the phase difference and number-of-particle variables imposes an uncertainty relation for these two variables in a superconducting tunnel junction. However, in a circuit consisting of several tunnel junctions, it is possible to have both a phase difference and a Cooper pair number as good quantum variables. The superconducting single electron transistor (SET)[1] is an example of such a circuit. The SET consists of two small-capacitance tunnel junctions connected in series thus defining an island, and of a gate electrode capacitively coupled to the island. In the superconducting SET one can have at the same time phase coherence across the leads giving rise to a supercurrent and a well defined number of Cooper pair on the island, this number being imposed by the electrostatic energy cost of charging the island. The amplitude of the supercurrent can be dramatically enhanced by the gate charge if two island states differing by one Cooper pair become degenerate, thereby restoring partly number-of-particle quantum fluctuations [2]. This enhancement has been predicted to be suppressed when the odd-even free energy difference [3,4] becomes less than the charging energy of a single electron in the island [5]. In such a case a quasiparticle can enter the island, preventing the degeneracy to occur and thus poisoning the supercurrent enhancement.

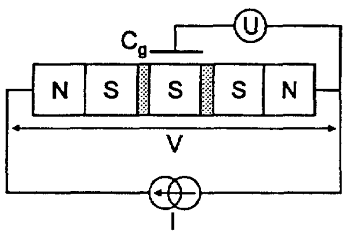

Fig. 1. Schematic of the experiment. The letters N and S refer to normal (Cu) and superconducting metal (Al), respectively. The tunnel barriers are represented by the shaded areas.

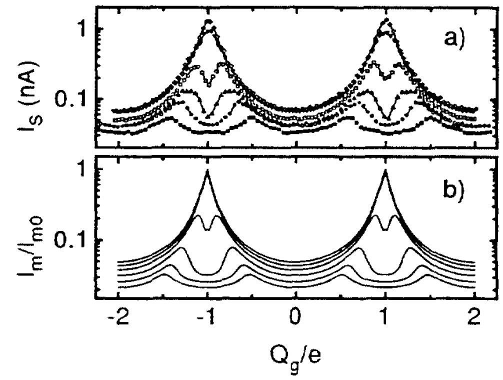

Fig. 2 a) Switching current as a function of the gate charge $Q_g=C_gU$, for several values of the magnetic field H, at T=65mK. Top to bottom: H=0, 0.075, 0.1075, 0.1375, 0.160, 0.175 T. b) Variations of the theoretical switching current as a function of gate charge, for the same field values as in a).

We have measured the supercurrent branch of a superconducting SET for different values of the gate charge, magnetic field and temperature. Our design of the sample included normal-metal filters in the leads, close to the island (see Fig. 1). Their purpose was to eliminate all possible out-of-equilibrium quasiparticles to prevent uncontrolled poisoning of the Josephson effect. Our measurements at low temperature and low field showed for the first time a gate charge-modulation of the supercurrent at least in qualitative agreement with theory (Fig. 2, top curves). When the magnetic field was raised we observed the characteristic features of the poisoning of the supercurrent enhancement (Fig. 2).

The theoretical predictions plotted in Fig. 2b are based on a minimal model involving four energy scales: thermal energy fluctuations k_BT, the charging energy E_C, the Josephson energy E_J and the odd-even free energy difference D [6]. The model reproduces the features of the measurements over all the temperature-field domain.

In conclusion, a clear description of the phase coherence across a superconducting single electron transistor has been obtained through the control of the quasiparticle population brought by the use of normal-metal filters, combined with new theoretical understanding. This contrasts with the previous experiments for which the interpretation of the supercurrent modulation could not be performed.

References

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