

Cooper pair transistor in a high impedance environment

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We are conducting an experimental study on the effect of high impedance environment on a Cooper pair transistor (CPT). The CPT consists of two small-capacitance Josephson tunnel junctions in series with a gate electrode coupled through a capacitance C_g to a central island. In small-capacitance CPT the charging energy $E_{C\Sigma} = e^2 / 2C_\Sigma$, where $C_\Sigma \sim 2C_J + C_g$ is the total capacitance of the island, becomes relevant at low temperature, and charging effects influence the transport properties. In order to observe Coulomb blockade in a single Josephson junction and also in a CPT, care must be taken to isolate the junctions from their high frequency electromagnetic environment. The classical Josephson effect, realized in the low impedance environment ($\text{Re}[Z(\omega)] < R_Q = h/4e^2 \sim 6.45 \text{ k}\Omega$), is suppressed in the high impedance environment where there are large quantum fluctuations of the phase. In a high impedance environment, the current voltage (I-V) curve of the CPT does not present a supercurrent feature, but a Coulomb blockade feature, and a region of negative differential resistance which is the signature of coherent tunnelling of Cooper pairs [1]. In order to observe the Coulomb blockade of Cooper pair in a CPT, the main requirement on the environment is that its impedance ($\text{Re}[Z(\omega)]$) shunting the CPT must be much larger than the quantum resistance R_Q . In previous works [2], the impedance of the leads was increased by using small chromium resistors with a resistance of $50 \text{ k}\Omega$, located on the chip close to the junctions. In our experiments, as in those of Watanabe [3], the high impedance of the leads is obtained by biasing the CPT with four SQUID arrays. The SQUID geometry allows the tuning *in situ* of the leads impedance over several orders of magnitude ($10^4 \Omega < \text{Re}[Z(\omega=0)] < 10^8 \Omega$), providing different electromagnetic environments to the CPT. Note that the junctions defining the CPT do not have a SQUID geometry, and thus are unaffected by the relatively small magnetic fields (the flux $\Phi = \Phi_0/2$ at 5 mT , where $\Phi_0 = h/2e = 2 \times 10^{-15} \text{ Wb}$ is the flux quantum) needed to tune the SQUIDs.

Measurements were performed in a dilution refrigerator with a base temperature of 15 mK . No low temperature filtering is implemented in the cryostat. However, when the arrays are in the high impedance state, they act as good filters for electromagnetic fluctuations guided to the sample via the leads. The I-V characteristics of the CPT are measured in a four point configuration (Fig. 1). One pair of SQUID leads are used to apply a symmetric bias and measure the current, the other pair to measure the voltage across the CPT. Each array has 70 SQUIDs, with an area of $0.03 \mu\text{m}^2$ per junction. The CPT junctions are designed to have an area of $0.01 \mu\text{m}^2$ each. CPTs with different ratio $E_J/E_{C\Sigma}$ have been measured.

In several experiments performed in a low impedance environment [4,5], it has been shown how the $2e$ -periodicity of the supercurrent in the gate induced charge is suppressed by non-equilibrium quasiparticles. In order to study this effect in a high impedance environment, we fixed the bias voltage across the SQUID arrays at a value of $50 \mu\text{V}$ and measured the current and voltage of the transistor as function of V_g . The

tunneling of charges in and out the island results in an oscillating behaviour of both the current and voltage across the transistor (Fig 2). It is interesting to notice how the character of the oscillations changes as the impedance of the environment is increased. In fact, as the magnetic field reduces the coupling energy of the SQUID arrays (increasing their impedance), the V_g dependence changes from e -periodic to $2e$ -periodic. The change in periodicity is observed in both current and voltage oscillations. This suggests that non-equilibrium quasiparticles present in the system and responsible for the e -periodicity, can be suppressed by high impedance leads.

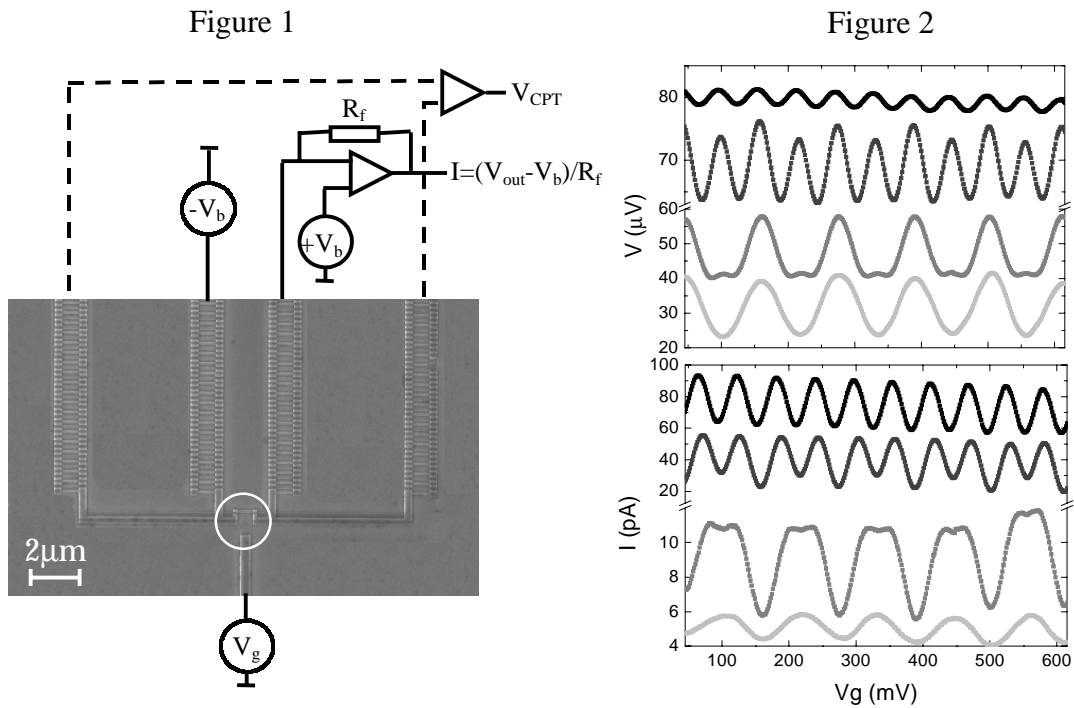


Fig 1: A SEM micrograph of the CPT biased by 4 SQUID arrays and measurement scheme.

Fig 2: Voltage and current modulation as function of V_g for different $\text{Re}[Z(\omega)]$. From top to bottom: $55 \text{ k}\Omega$, $450 \text{ k}\Omega$, $10 \text{ M}\Omega$, $20 \text{ M}\Omega$. For this CPT $E_J/E_{C\Sigma} = 0.62$.

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