Shot Noise in diffusive SNS and SIN junctions

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Abstract

We studied shot noise in metallic SNS and doped silicon based SIN junctions. In SNS structures, the shot noise is very much enhanced due to Incoherent Multiple Andreev Reflections (IMAR) which are truncated, at low voltage, by inelastic electron-electron interaction. These experimental results show good agreement with recent semiclassical theory. In SIN junctions, the zero voltage conductance is increased by disorder induced coherent MAR (reflectionless tunneling) and we found that the shot noise is double ($S_I = 4eI$) below the Thouless energy and equals the full shot noise ($S_I = 2eI$) above. We also present conductance measurements which show the same zero bias anomaly but in a double-barrier metallic SININ junction.

Key words: Proximity effect; Inelastic processes; Shot noise

1. SNS Junctions

In SNS junctions with a good electrical contact at the interfaces, electron-hole pairs penetrate from the superconductor (S) into the normal metal (N) over a distance $L_c = min(l_\Phi, \sqrt{\hbar D/\epsilon})$ with $\epsilon = max(eV, k_BT)$. If the sample length L is smaller than the correlation length L_c (coherent case), the phase coherence covers the entire normal metal and the shot noise is enhanced compared to normal junctions due to the coherent transfer of large quanta. Here, we consider the opposite case (incoherent case) where electron-hole coherence is not preserved along the sample. This particular situation have been recently studied theoretically by Nagaev [1] and Bezuglyi et al. [2]. Because of the two SN interfaces that prevent single particle current, the quasiparticles of the normal metal experience Incoherent Multiple Andreev Reflections (IMAR). The number of IMAR needed for the quasiparticles to reach the superconducting gap Δ is $N = 2\Delta/eV + 1$ and the shot noise is just that generated by normal electrons in a diffusive conductor times the number of Andreev reflections : $S = 2/3eI * (2\Delta/eV + 1) = 2/(3R) * (eV + 2\Delta)$. At low voltage, the number N diverges such that IMAR are interrupted by e-e interaction and a Fermi-Dirac like distribution with an effective temperature T_{eff} is restored. This situation refers then to the problem of heat transfer through SN interfaces by quasiparticles above the gap, but in the context of SNS junctions. When the sample is long enough, some power can also be evacuated towards the phonon bath by electron-phonon interaction. To discriminate between the different situations, we measured shot noise in three different planar SNS junctions (figure : 1) made of aluminum and copper [3]. The distances between the two superconducting aluminum electrodes are $L = 4$, 10 and 60 μm and the phase coherence length in the normal metal (estimated independently) is very short ($l_\Phi \simeq 0.3\mu m$). Figure 1 shows the current noise power of the three junctions times the resistance $R = V/I$ as a function of the applied voltage at a base temperature of $100mK$. We see that the shot noise increases very rapidly with the voltage and that except for the $60\mu m$ sample, one can barely see the thermal cross-over at $eV \approx k_BT$. Above $70\mu V$, the data obtained for the shortest sample, are compatible with the linear behavior predicted in the case of no inelastic collisions with $\Delta = 0.135mV$ (straight

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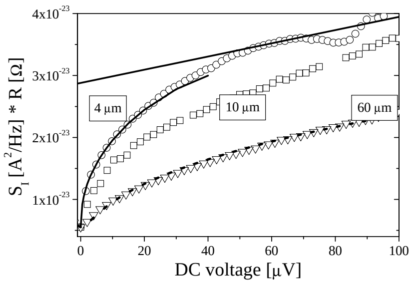

Fig. 1. Noise measurements in three different SNS junctions of various lengths : 4, 10 and 60 microns at $100mK$

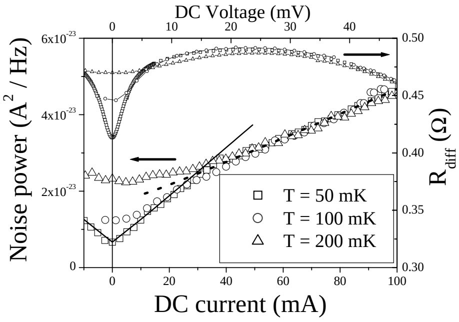

Fig. 2. Noise power (left) and conductance (right) of a SIN junction at various temperatures.

line). The superconducting gap is reduced in this junctions because the normal metal and the superconducting electrodes of equal thicknesses overlap. At low voltage, the results follow the theoretical description where e-e interactions are dominant and for which it is supposed that all the power can only be dissipated through the SN interfaces (solid curve). For the longest sample ($30\mu m$), the raise of the effective temperature of the quasiparticles is much weaker, and we considered that only electron-phonon interaction can evacuate the injected power. The dashed line is the corresponding fit with $T_{eff}\,\alpha\,(eV)^{2/5}$.

2. SIN junctions

Figure 2 shows both the differential resistance (right scale) and the shot noise (left scale) of a SIN junction where a strongly degenerate ($n_e = 2.10^{19}cm^{-3}$) silicon is in contact with a superconductor (TiN, $T_c = 4.6K$) separated by a Schottky barrier. The differential resistance shows a zero bias anomaly which is due to the disorder enhanced confinement of the electrons close to the SIN interface. In this situation, the low probability of Andreev reflection ($\Gamma \simeq 10^{-2}$) can be increased by the number of times the quasiparticles return coherently to the interface (reflectionless tunneling) [4].

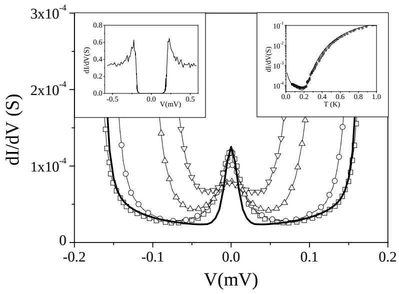

Fig. 3. Conductance of a SININ junction at various temperatures : from bottom to top : 60, 90, 150 and 180 mK.

Using the same experimental set-up, we measured the shot noise which is equal to twice the full shot noise at low energy ($S = 2 * 2eI$, solid line) and crosses over to the full shot noise ($S\alpha 2eI$, dashed line) above $20\mu V$ [5]. This result reveals a rather complete change in the mechanism of charge transfert from pairs to quasiparticles whereas only 20% of the conductance is affected.

This experimental situation is always obtained for Superconductor-Semiconductor junctions where the native Schottky barrier is soft and the “normal” metal disordered enough. With oxide barrier and normal metal this kind of sample is impossible to make because the barrier is too opaque and the square resistance of the normal metal is too low. To compensate the lack of disorder in the normal metal, we introduced a second barrier (NIN) 30 nm apart from a SIN junction and fabricated SININ structures [6]. The superconductor is aluminum, the barrier aluminum oxide and copper is the normal metal. Figure 3 shows the conductance of such a junction as a function of voltage and temperature. At $T < 250mK$ and $V < 50\mu V$ the conductance shows a zero bias anomaly of the same kind than that described in the case of the silicon based SIN junction. In this new sample, the role of the second barrier is to scatter back the quasiparticles towards the low transparent interface ($\Gamma \simeq 10^{-6}$). In figure 3, the solid line corresponds to the theoretical prediction by Volkov et al. [7].

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