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Reentrance of conductance in mesoscopic normal-metal/superconductor junctions

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Abstract

Two different kinds of mesoscopic N–S–N junctions were fabricated by sandwiching Al or Pb film between two closely separated Au wires. dV/dI versus V curves for an Au–Pb–Au junction show a sharp zero-bias dip, while those for an Au–Al–Au show a reentrant zero-bias maximum. Interference between conjugate electrons and holes at an interface with different degree of transparency is responsible for the contrasting behavior. © 2000 Elsevier Science B.V. All rights reserved.

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Since the observation of the conductance enhancement in semiconductor–superconductor (Sm–S) junctions [1] even in the presence of a Schottky barrier at the interface, the proximity effect near a normal-metal–superconductor (N–S) interface has been studied intensively [2]. Interest has been focused on the interference phenomena between the disorder-scattered and the Andreev-reflected electron–hole pairs. In this study, we measured transport properties of diffusive mesoscopic N–S junctions with Al or Pb as superconducting electrodes. Junctions exhibited either a zero-bias enhancement or a reentrance of conductance [3] at low-enough temperatures, depending on the transparency of the interface.

We have fabricated two samples which consisted of N–S–N-junction structure as shown in the left inset of Fig. 1. S electrode sandwiched between the two N (Au) electrodes was made of Pb film (SA2) or Al film (SA3). As seen in the left inset of Fig. 1, potential difference across either the N–S–N or an N–S junction can be measured in a single sample. In the absence of quasiparticle tunneling probability through S the potential difference across an N–S–N junction is equivalent to that of the sum across the two serial N–S junctions. The typical resistivity of Au wires is $5.4\,\mu\Omega$ cm, which gives the diffusivity $D \approx 70$–80 cm^2/s.

Fig. 1 shows that resistances for both samples decrease abruptly as S becomes superconducting. The transition temperatures T_c of Pb and Al for SA2 and SA3 are 7.00 and 1.67 K, respectively. $R(T)$ curve of SA2 decreases monotonically, while that of SA3 reaches a minimum at T^*(≈ 720 mK) and then increases slightly as shown in the right inset of Fig. 1. dV/dI versus V characteristics for SA3 shown in Fig. 2 clearly exhibits non-monotonic behavior in the temperature range below T^*. We notice that the dV/dI curve at $T = 0.296$ K shows a resistance maximum at zero bias and a minimum at a bias voltage denoted as $2V^*$, which is far below the superconducting-gap voltage of Al, $2\Delta_{Al}/e$ (≈ 360 μeV).

The features for SA3 such as the resistance minimum at a temperature T^* and at a bias voltage $2V^*$, and the negative temperature coefficient below T^* are typical phenomena known as the reentrance of conductance. The fact that the magnitude of $k_B T^*$ ($\approx 720 k_B$ mK) and eV^* (≈ 23 μeV) is comparable to $5E_c$ (≈ 26 μeV $\approx 305 k_B$ mK) supports our reasoning. Here, we

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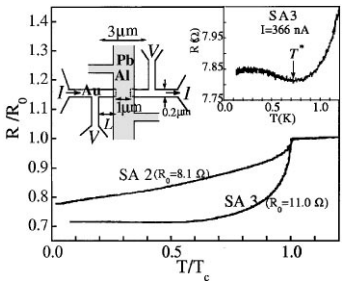

Fig. 1. Normalized resistance versus normalized temperature. R_0 is the sample resistance at T_c. Left inset: the schematic diagram of the sample geometry; the thickness of Au and Pb (or Al) were 20–30 and 80–95 nm, respectively. Right inset: R versus T for SA3.

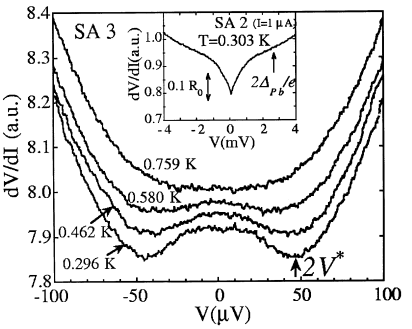

Fig. 2. dV/dI versus V around zero-bias voltage for various temperatures far below T_c. Each curve was shifted vertically for clarity. Inset: normalized dV/dI versus V for SA2.

estimated Thouless energy E_c to be 5.2 μeV or $61k_B$ mK assuming that the diffusivity D and L are 80 cm^2/s and 1 μm, respectively.

On the other hand, dV/dI for SA2 shows a resistance dip at zero bias at $T = 0.303$ K (see the inset of Fig. 2). The feature of sharp zero-bias dip far below twice that of the Pb superconducting-gap voltage $2\Delta_{Pb}/e$ is known as the zero-bias anomaly (ZBA). It is believed that ZBA originates from the interference of disorder-scattered and Andreev-reflected electron–hole pairs [2].

As pointed out in Ref. [4] we believe that the difference in the transparency at N–S interfaces of our samples resulted in the contrasting features of dV/dI for SA3 and SA2, respectively. Although Au-Al junction has larger mismatch of Fermi velocities than Au–Pb junction, the high material interdiffusion between Au and Pb atoms at the interface produced lower transparency of the N–S interface for SA2 than SA3. In fact, I–V characteristics exhibit higher excess current for SA3 than SA2 (not shown), which implies that SA3 has lower scattering barrier at the N–S interface than SA2.

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