Super High Conductivity Effect in Metal - Polymer - Metal Structures

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Abstract

We have observed that films of a polyimide precursor of poly[4,4'-bis(4"-N-phenoxy)diphenyl-sulfone] amid acid of 1,3-bis(3',4-dicarboxyphenoxy)benzene which is called type (1) polymer, or a co-poly[4,4'-bis(4"-N-phenoxy)diphenyl-sulfone-α,ω-bis(γ-amino propyl)oligodimethylsiloxane]imide of 1,3-bis(3',4-dicarboxyphenoxy) benzene type (2) polymer, placed between two metallic electrodes become highly conducting in a relatively small electric field ($E < 1$ V/cm). If the metallic electrodes (Sn, Nb) in sandwich structures were in the superconducting state an effective resistance of zero was recorded. The current-voltage characteristic of an S-P-S structure is of Josephson type arrising from point contacts between the superconductor and the polymer film acting as weak links.

Key words: Josephson effect; electrification of polymers; conducting polymers; weak links;

1. Introduction and Preparation

In recent years there were reports on the super high conductivity effect in different polymers, such as polyimide and polydiphenylenphtalide [1],[2] at a thickness of the polymer of up to 1.5 μm, which are placed between metallic electrodes in a small electrical field. If the electrodes undergo transition to the superconducting state in a small magnetic field also Josephson oscillations have been obtained. The effect was observed in sandwich structures M-P-M (here M is a metallic or superconducting electrode and P - polymer of type (1) or (2)) with a thickness of polyimide film up to 2.5 μm as well as in planar geometry with a gap between two gold electrodes up to 2.8 μm. The polyimide films were prepared by deposition of a drop of solution of type (1) or (2) in N-methyl-2-pyrrolidone on a polished metallic bulk electrode with sandwich structure or on planar gold electrodes on semiinsulating GaAs substrates with a varying gap of 0.8, 1.4, 1.8, 2.8 μm. The films were heated in air for 2 h at a constant temperature of 370 - 400 K to remove the polymer solvent resulting in partially imidized polyimide precursors.

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2. Results and Discussion

We observed a correspondence between the contact area and the total value of the resistance. The smaller the contact area, the higher the resistance of the structure. We have also observed that the effect of high conductivity vanishes non-reversibly at $T > 500$ K. It was found that if the metallic electrodes (Sn, Nb) in sandwich structures were in the superconducting state, i.e. at $T < T_c$, where T_c is the bulk value of the superconducting transition temperature, in the Superconductor-Polymer-Superconductor (S-P-S) an effective resistance of zero was recorded (Fig. 1).

Two - terminal resistance measurements with constant current showed that as the temperature decreased, slow fluctuations of the resistance were ob-

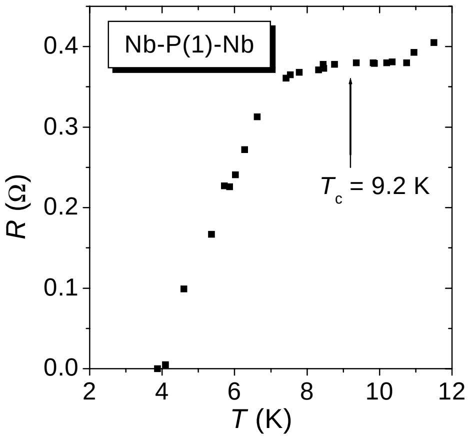

Fig. 1. Typical temperature dependence of the resistance in a 1 μm Nb-P(1)-Nb sandwich structure.

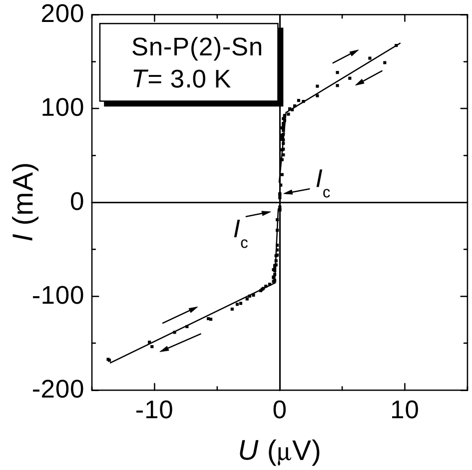

Fig. 2. Typical current-voltage characteristic of Sn-P(2)-Sn.

served down to the temperature $T \geq T_c$. At $T < T_c$ the resistance fluctuations disappear sharply. The sharp drop in the resistance below T_c shown in Fig. 1 is similar to a superconducting transition of the S-P-S structure with reduced T_c. A typical current-voltage characteristic (CVC) of an S-P(2)-S structure is shown in Fig. 2. It looks like a Josephson CVC. The reversible behavior of the CVC excludes the existence of insulator barriers between the two superconductors. We have experimentally shown that for a superconducting S-P-S structure, a point contact between the superconductor and polymer films plays the role of a weak link [2]. In the sandwich structures with polymer film thickness of about one micron, the estimated relation of total area of point contacts to the overall area of the electrodes covered by the polymer film is 10^{-6}, while the total area of all conductive channels is about $10^{-7}\,\mathrm{cm}^2$. The nanoscale dimension of individual conductive channels is independently estimated by the Josephson-effect behavior at a low magnetic field, which is observed in S-P-S structures due to the weak links [1],[2] connected by point contacts. We measured the voltage drop over the S-P-S sandwich structure at constant electrical current just above I_c by sweeping a small transverse magnetic field ($H \perp I$). The shape of the amplitude and period of the voltage oscillations shows that:

i) there are many conductive channels through the polymer film;
ii) the areas of all point contacts are nearly the same; and
iii) the distance between Josephson contacts is no more than 30 μm.

It should be emphasized that we did not observe Josephson oscillations if one of the electrodes was in the normal state. Therefore, at first sight this seems to show that the superconducting state in the polymer channel itself could not be connected with classical pairs of the BCS - theory; instead, it could possibly be explained by ballistic transport of charge carriers in polymer channels or by an unconventionally superconductivity. The reason for the last two conclusions regarding M-P-M structures is connected with the temperature dependence of the resistance which obeys Wexler's law for point contact resistance up to room temperature [3]. The highly conducting state in polymers presupposes that there is a high concentration of charge carriers with high mobility. Electrification of polymers in contact with metals, i.e. charge transport across the interface, is a well-known phenomenon [4]. The charge acquired by a polymer from a metal that touches it depends on the type of polymer, on the type of the metal and on the contact area. At the moment there is no satisfactory explanation for the supercurrent in superconductor-polymer-superconductor sandwich structures through relatively thick polymer films.

Acknowledgements

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