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Supercurrent through a polyamidine film

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Abstract

We have investigated the temperature dependence of the conductivity of polyamidine films with different contact area between electrode and polymer surface at low temperatures. At low temperatures we observed a decreasing conductivity as well as a supercurrent flow through the polyamidine film in superconductor–polyamidine–superconductor sandwich structures with film thickness about 1 μm.
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1. Introduction

The effect of high conductivity with an estimated limiting value of at least 10^{12} S/cm at liquid helium temperatures was observed in many undoped and non-conjugated polymers [1, and references therein]. The effect is observed in sandwich structures metal–polymer–metal with electrodes of diameters of some mm at $E < E_c$ (here E_c is the breakdown field). A superconducting current is observed in a superconductor–polymer–superconductor sandwich with a polymer film thickness of up to 2 μm. Another characteristic was that the conductivity effect was not observed if the contact area was too small, area less about 100 nm^2 [2]. In accordance with model [3] the electrification effect plays the crucial role in switching to the high conductive state [4]. Inside the forbidden gap of the polymers, energy states with energy close to the Fermi level of metals are formed as a result of atomic and electronic relaxation processes due to electrification [3].

In [1] the surface topography of the polyamidine films and the current distribution was simultaneously investigated using the atomic force microscope with a spreading resistance mode at room temperature. The contact area between the tip and polymer was about 100 nm^2. A correlation between surface topography and current distribution was observed, namely: the highest current is observed at the thickest points of the surface. It was shown that the conductivity depends on the electronic work function of the metallic substrates used. Furthermore, there is a critical charge density, which must be accepted by the polymer film from the metallic electrodes in order to produce a high conductive state in the polymer.

In the following, we focused our investigations on the temperature dependence of conductivity for polyamidine films with different contact areas between electrode and polymer surface at low temperatures.

2. Results and discussion

The chemically pure polyamidine was prepared as described in [5]. X-ray investigation showed that in our case the polyamidine was in an amorphous state at temperatures of up to 150 °C. A droplet of 5% mass solution of polyamidine in pure alcohol was deposited onto a polished tin electrode. After heat treatment at 90–100 °C for 30–60 min, the major part of the solvent was removed and polymer films with a thickness of 0.8–1.8 μm were obtained.

Fig. 1 shows the current–voltage characteristics (CVC) at different points on the polyamidine surface which we obtained by an atomic force microscope in the spreading resistance mode at room temperature. The experiments showed that in places of low conductivity the polymer

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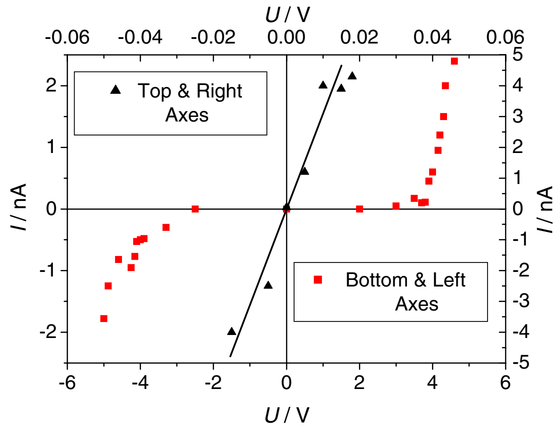

Fig. 1. Reversible on/off current switching and Ohm's law behavior at different points of the polymer surface. In both cases the CVC scanning time was about 1 s.

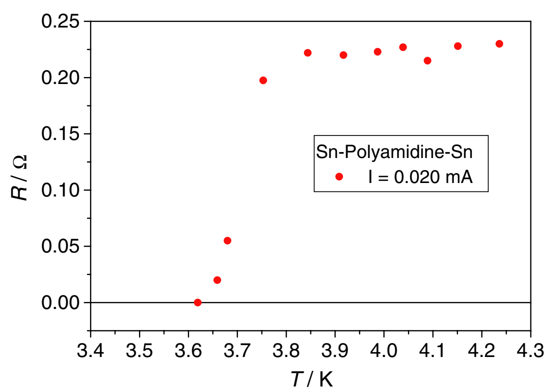

Fig. 2. Temperature dependence of the resistance of a Sn–polymer–Sn sandwich of thickness 2 μm (placed inside a dielectric spacer ring of inner diameter of about 360 μm).

exhibited a reversible off/on switching effect at $U \sim 4$ V with an electrical field strength less than the breakdown field (10^6 V/cm). There were also places with high conductivity where we found Ohm's law behavior.

Fig. 2 presents the $R(T)$ dependence of a polyamidine film placed between Sn electrodes. The sandwich arrangement consisted of a ring spacer with an inner diameter of about 360 μm and a thickness of 2 μm made from a dielectric polyetherquinoline film, which fixed the given thickness of the polyamidine film. As seen from the figure there is transition to $R = 0$ at $T < 3.6$ K (T_c for Sn = 3.72 K).

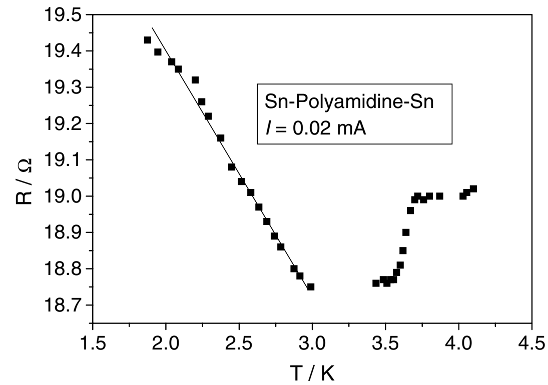

Fig. 3. Temperature dependence of the resistance of a Sn–polymer–Sn sandwich of thickness 2 μm (placed inside a dielectric spacer ring of inner diameter of about 3–4 μm).

Fig. 3 shows the $R(T)$ dependence of the polyamidine film placed in a smaller ring spacer with an inner diameter of about 3–4 μm and with the same thickness as before. As is seen from Fig. 3:

(i) the absolute value of the resistance is larger than that in Fig. 2 by a factor of 10^2;
(ii) the transition to the superconductor state for tin electrodes is observed at $T < 3.7$ K;
(iii) the resistance starts to increase at $T < 3.0$ K.

From our experiments we suggest that the high conductive state of this particular polymer is a collective phenomenon of some critical number of polymer chains.

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