Effect of anisotropy of epitaxial $YBa_2Cu_3O_x$ films on tunneling properties of $YBa_2Cu_3O_x$-metal junctions

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"Planar" and "edge" tunnel junctions based on epitaxial $YBa_2Cu_3O_x$ films have been studied. The differences in the current-voltage characteristics of the contacts and the structural features on these characteristics are linked with an anisotropy of the state density $N(\epsilon)$ and the existence of a narrow peak in $N(\epsilon)$ near the Fermi level in the Cu–O plane. A change in the $YB_2Cu_3O_x$ state density has been observed at $T \sim 30$ K.

Despite the anisotropy seen in the electrical and magnetic properties of the high-temperature superconductors, the anisotropy of the energy gap and of the spectrum of quasiparticle excitations in metal-oxide compounds remains an open question. In research on high-temperature superconductors by tunneling and point-contact methods, the short coherence lengths and the presence of a nonsuperconducting layer on the surface complicate the interpretation of the resulting current-voltage characteristics. Most of the research on tunneling in high-temperature superconductors has used point contacts between a needle of the metal and crystallites of the high-temperature superconductor. When the needle makes an indentation, however, the structure of the barrier region of the crystals is disrupted. It is thus difficult to determine the anisotropy of the properties of high-temperature superconductors by this method.[1] An anisotropy in the properties would presumably be manifested in film contacts, which would be free of this difficulty.

In the present letter we report a study of $YBa_2Cu_3O_x$-metal (Pb, Pt, In) tunnel junctions formed on epitaxial $YBa_2CU_3O_x$ films. The films were synthesized by a one-step rf sputtering in oxygen on cleaved {100} MgO surfaces without additional heat treatment.[2] The resulting films had $T_c = 83$ K and $\Delta T_c = 5$–7 K. The unit-cell parameter c of the films was 1.17–1.175 nm; the vertical disorientation of the grains did not exceed 1–2°. The upper electrode was deposited by vacuum deposition through a mask. Planar contacts, in which the current flowed in the direction perpendicular to the Cu–O layers, and also edge contacts, in which the current flowed along the Cu–O planes, were formed. The current-voltage characteristics of the contacts of both types were asymmetric and corresponded to p-type charge carriers in the high-temperature superconductor, according to the sign of the rectifying effect of the contact.[3]

Figure 1 shows $R_d = dV/dI$ versus the bias voltage at various temperatures for a planar $YBa_2Cu_3O_x$-Pb junction. The apparent reason for the low-voltage minimum is a gap maximum of the state density of Pb, since this minimum is not resolved at temperatures above T_c(Pb). The minimum at $V \sim 20$ mV depends weakly on the temperature at $T < 20$ K and reflects a peak in the $YBa_2Cu_3O_x$ state density. The increase in the resistance at a zero bias, $R_d(0)$, with decreasing temperature (see the inset in Fig. 1) is evidence of a tunneling mechanism for the current flow in the planar contact. The contacts with resistances from $R_d \sim 100\ \Omega$ to 10 kΩ at $V \sim 30$ mV and with Pt and In upper electrodes had characteristics of similar shape.

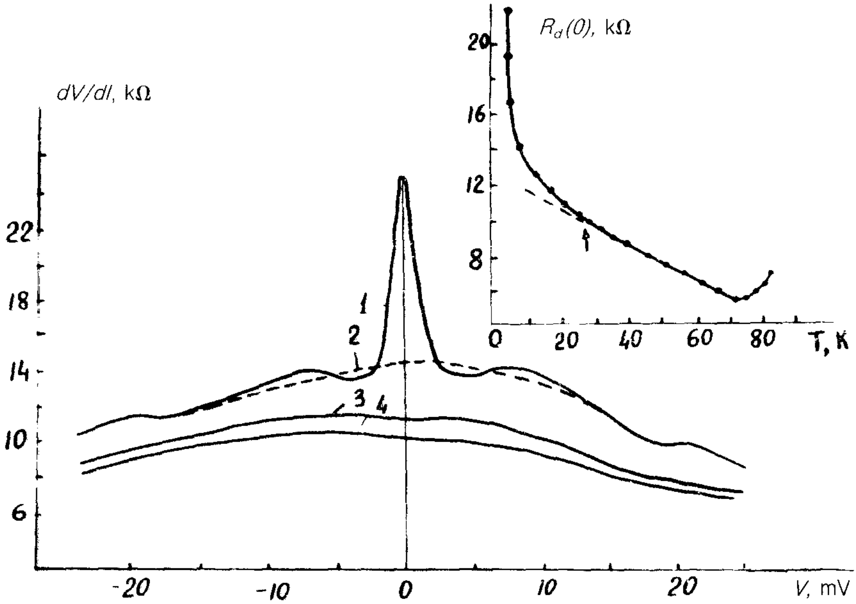

FIG. 1 dV/dI versus the bias voltage for a "planar" $YBa_2Cu_3O_x$-Pb junction at several temperatures: 1–4.2 K; 2–8 K; 3–10 K; 4–45 K. The inset shows $R_d(0) = dV/dI\ (V=0)$ versus the temperature for a "planar" junction.

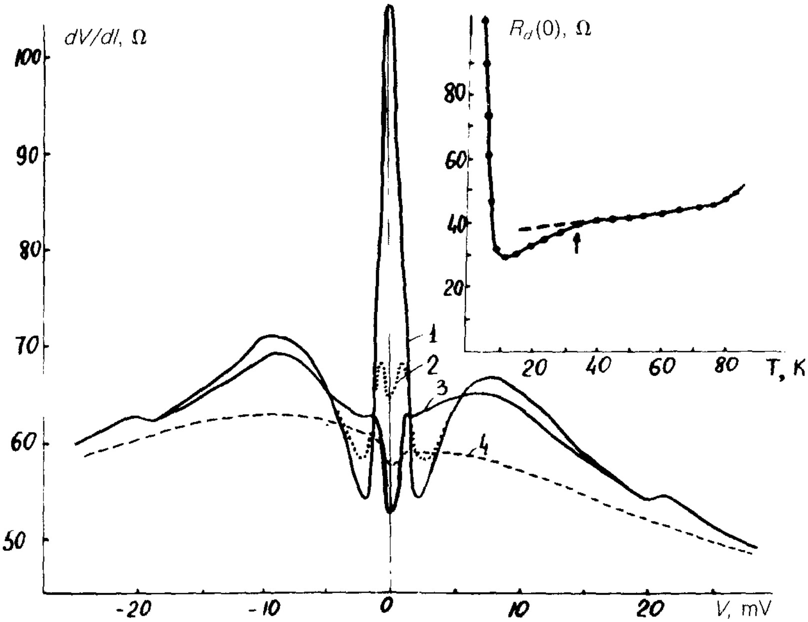

FIG. 2. dV/dI versus the bias voltage for an "edge" $YBa_2Cu_3O_x$-Pb junction at several temperatures: 1–4.2 K; 2–6 K; 3–10 K; 4–45 K. The inset shows the temperature dependence of $R_d(0)$ for an "edge" contact.

A distinctive feature of $R_d(V)$ of the edge $YBa_2Cu_3O_x$-Pb junctions (Fig. 2) is a minimum as $V \to 0$, which is usually linked with a microscopic short circuit. In the case at hand, we observe a sharp increase in $R_d(0)$ as the temperature is lowered below T_c(Pb) (see the inset in Fig. 2), and at $T \ll T_c$(Pb) the characteristic acquires the customary shape for an S–I–S_2 contact. There is accordingly no microscopic short circuit in these contacts, and the current flows through a tunnel barrier.

At $T < T_c$(Pb) the dip in $R_d(V)$ at low voltages gradually disappears with decreasing temperature (curves 3–2–1 in Fig. 2). The reason is an increase in the energy gap $\Delta(T)$ of Pb. This behavior of the $R_d(V)$ dip observed on the tunneling characteristics indicates that there is a narrow maximum in the state density of the high-temperature superconductor near the Fermi level ($V = 0$). The difference between the curves of $R_d(V)$ for the edge and planar junctions can be attributed to an anisotropy of the state density with respect to the Cu–O planes.

A study of the temperature dependence of $R_d(0)$ reveals the nature of the changes in the energy parameters of the superconductor. For the planar junctions, $R_d(0) = R_0$ increases with decreasing temperature, while for the edge junctions $R_d(0)$ characteristically decreases. At $T < 30$ K the sharp decrease in $R_0(T)$ for the edge junction correlates with the rapid increase in $R_0(T)$ for the planar junction. We have also observed a nonmonotonic change in $R_0(T)$ in ceramic samples of $YBa_2Cu_3O_x$ (Ref. 3). Changes of this sort in $R_0(T)$ for the planar and edge contacts are evidence of a restructuring of the electron spectrum at $T \sim 30$ K and of the existence of correlations in the temperature dependence of the state density along the Cu–O planes and in the direction perpendicular to them.

These features of the state-density spectrum suggest that new superconducting-ordering mechanisms are operating in the high-temperature superconductors.

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