Josephson and single-particle tunneling in superconducting bicrystals $BaPb_{1-x}Bi_xO_3$

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Tunneling has been observed at the barrier formed by the intergrowth surface of the superconducting bicrystals $BaPb_{1-x}Bi_xO_3$. It has been determined that this compound has a ratio $2\Delta(0)/kT_c = 3.6 \pm 0.1$ and that the differential-conductivity peak has a doublet structure.

We have studied the conductivity of $BaPb_{1-x}Bi_xO_3$ bicrystals, in which a current flows between single-crystal blocks in the direction perpendicular to the layers of the edge atoms which are formed by cutting the atomic planes by the intergrowth surface. We investigated bicrystals grown by spontaneous crystallization in a PbO-Bi_2O_3-$BaCO_3$ melt, whose intergrowth surface was determined from the angles of entry and constituted a plane. The dimensions of the single-crystal blocks were $0.7 \times 1 \times 1$ mm and their chemical composition corresponded to the formula $BaPb_{1-x}Bi_xO_3$, $x = 0.27 \pm 0.03$. The current and potential contacts for the four-point measurements were installed in each of the two single-crystal blocks by fusing in gold wires.

The conductivity of the prepared samples was studied as a function of temperature T and the magnetic field H. A resistive superconducting transition, which began at $T_{c1} = 11$ K and ended at $T_{c2} = 9.6$ K, was suppressed by increasing the density of the transport current to $j \sim 0.1$ A/cm^2 or by applying a magnetic field $H \sim 60$ Oe. In these cases, the resistance of the samples, which amounted to 0.1–0.2 Ω in the normal state, increased with decreasing temperature at $T < T_{c2}$, increasing by an order of magnitude at $T = 4.2$ K. The described behavior of the bicrystals differed from the behavior of $BaPb_{1-x}Bi_xO_3$ single crystals of identical composition, in which a superconducting transition was observed in fields up to 40 kOe at a current density $j = 0.5$ A/cm^2 (Ref. 1).

We determined that the current-voltage characteristic of the samples has a shape typical of a tunnel junction between superconductors. In the initial part of the I-V characteristic, shown in Fig. 1, we clearly see, in addition to a superconducting tunnel

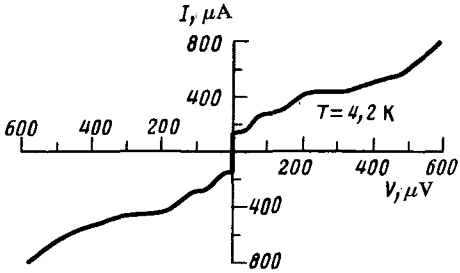

FIG. 1. The initial part of the I-V characteristic of the bicrystal.

current, several current resonances arising in the earth's magnetic field. The critical Josephson current I_c of the samples was measured after cancelling this field. In the part of the $I_c(H)$ curve where the field H was applied parallel to the intergrowth surface, we see oscillations of the critical current I_c with a period $\Delta H = 60 \pm 2$ mOe at $T = 4.2$ K; the amplitude of the superconducting tunneling current decreases with increasing H and vanishes in $\sim$60-Oe fields. The experimental data presented above support our viewpoint that the intergrowth surface of $BaPb_{1-x}Bi_xO_3$ bicrystals is a barrier at which tunneling occurs when a current is passed between single-crystal blocks.

The hypothesis of the local change in the chemical composition of a growing crystal near the intergrowth surface is a possible explanation of a tunneling barrier in $BaPb_{1-x}Bi_xO_3$ bicrystals. A $BaPb_{1-x}Bi_xO_3$ bicrystal is a superconductor when $x < 0.35$ and a semiconductor when x is large.[2] If we assume that the concentration of bismuth atoms, which replace the lead atoms in this solid solution, increases near the intergrowth surface where the lattice defects accumulate during growth, we can expect the appearance of a thin semiconducting layer, which divides the two superconducting single-crystal blocks and which serves as the tunneling barrier. The suggestion that there is a semiconducting barrier is qualitatively confirmed by the fact that the temperature dependence of the critical current $I_c(T)$ obtained by us is different from that predicted theoretically by Ambegaokar and Baratov for a dielectric barrier (Fig. 2).

The presence of an intergrowth surface in the tested samples enabled us to measure the I-V characteristic of single-particle tunneling (Fig. 3). The dependence of the

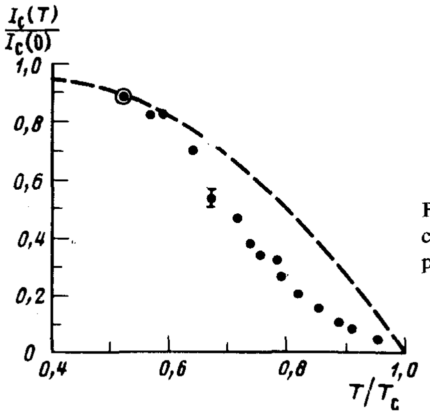

FIG. 2. Temperature dependence of the critical Josephson current of the samples, $I_c(T)$. Dashed curve—theoretical dependence of Ambegaokar and Baratov.

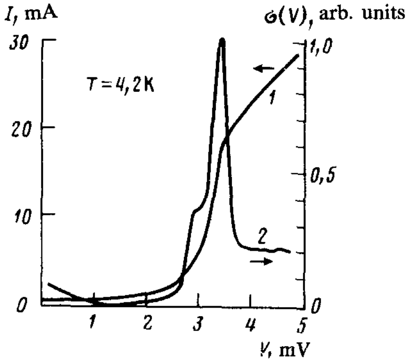

FIG. 3. The I-V characteristic (1) and the dependence of the differential conductivity on voltage $\sigma(V)$ (2) of a tunnel junction in a $BaPb_{1-x}Bi_xO_3$ bicrystal.

differential conductivity on voltage $\sigma(V)$, also shown in Fig. 3, with a characteristic peak, was determined from a numerical analysis of the I-V characteristic.

We see that the $\sigma(V)$ peak has a heretofore unexplained doublet structure, which is evident in all the measurements in the temperature range $T < T_c$. The temperature dependence of the energy-gap parameter Δ was determined from the position of the $\sigma(V)$ peak in the temperature range $2.1 \leqslant T \leqslant 4.2$ K. Working from this dependence, we determined the extrapolated value $2\Delta(0) = 3.42 \pm 0.05$ meV and calculated the value $2\Delta(0)/kT_c = 3.6 \pm 0.1$ for $BaPb_{1-x}Bi_xO_3$ (here $T_c = 10.9 \pm 0.3$ K was determined by an induction method from the time at which the transition began).

We note in conclusion that measurement of the energy gap for $BaPb_{1-x}Bi_xO_3$, which has become possible because of the presence of a tunneling barrier in the bicrystals of this compound, and the detection of the differential conductivity are of considerable interest, since there may be a superconductivity mechanism in this compound which is an alternative to the BCS theory.

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