Josephson effect between a $Eu_1Ba_2Cu_3O_y$ single crystal and Nb

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(Submitted 22 December 1987)
Pis'ma Zh. Eksp. Teor. Fiz. **47**, No. 3, 159–161 (10 February 1988)

The Josephson properties of superconducting contacts between a niobium needle and a $Eu_1Ba_2Cu_3O_y$ single crystal have been studied. The current-voltage characteristics and curves of the microwave-induced current steps on the I-V characteristics versus the microwave power seem to indicate the ordinary mechanism for the pairing of the superconducting electrons in these new superconductors.

Several recent papers (e.g., Refs. 1–3) have reported observations of Josephson effects in the new high-temperature superconductors: metal oxide ceramics (MOC). The results have shown unambiguously that the superconducting current in these superconductors is due to electron pairs. Polycrystalline samples of La and Y ceramics with a fine-grain structure and a Josephson tunneling between individual internal granules of the ceramic were studied in Refs. 1–3. Even in those cases in which the

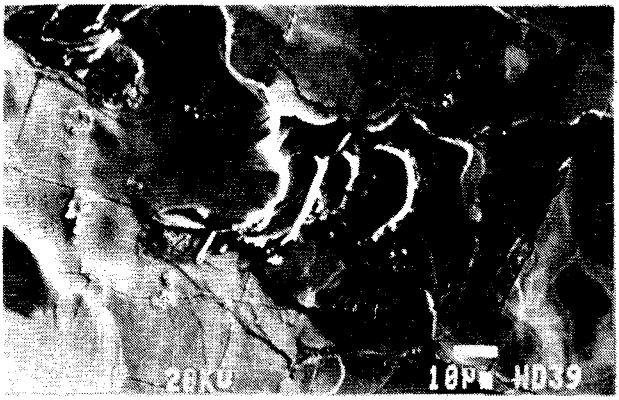

FIG. 1. Electron micrograph of the surface of the single crystal studied.

second electrode of the contact was niobium[1] or lead,[3] a tunneling very probably also occurred between the individual grains of the metal oxide ceramic, separated by a layer of a superconductor or a normal metal. (This conclusion is indicated by the particular temperature dependence of the critical current I_c.) It seemed worthwhile to study Josephson effects in metal oxide ceramics of a composition different from those in Refs. 1–3 and to observe the tunneling of superconducting pairs out of an ordinary superconductor, with a phonon mechanism for electron pairing, into a metal oxide ceramic, where the superconductivity may occur by some other mechanism.

In the present experiments we studied point-contact junctions between a sharpened niobium needle and a $Eu_1Ba_2Cu_3O_y$ single crystal. The use of a single crystal made it possible to obtain unambiguous results, and it also essentially eliminated the effect of interior regions of the sample of the metal oxide ceramic. The dimensions of the single crystals were several tenths of a millimeter. The crystals differed in external appearance, but shapes with a clearly expressed habit in the form of rectangular prisms and wafers were predominant. The single-crystal structure of the samples was determined by x-ray measurements and electron microscopy. The superconducting transition temperatures of the samples were 83–90 K. The results presented below were obtained with a sample with dimensions of 0.6×0.6 mm and a thickness of 0.1 mm. The C axis ran perpendicular to the plane of the sample.

Figure 1 is an electron micrograph of the surface of the sample. Along with the growth figures we can see a network of microcracks with a predominant orientation along the A and B crystallographic directions. The formation of the microcracks may have resulted from either a size effect in the course of a polymorphic conversion or strong thermal stresses in the course of the growth and cooling of the single crystal.

The electrodes of the adjustable point contact were mounted in a waveguide. The contact was adjusted and studied in liquid helium ($T = 4.2$ K). In the course of the study of the transient effect, the sample was subjected to radiation at a frequency $\nu_m = 9.1$ GHz. We know that as the pressure between the electrodes of a contact is increased, the resistance of the contact will decrease, and the current-voltage characteristics will change from the shape typical of single-particle tunneling to a Josephson shape. In these particular experiments, in which the resistance of the contacts reached

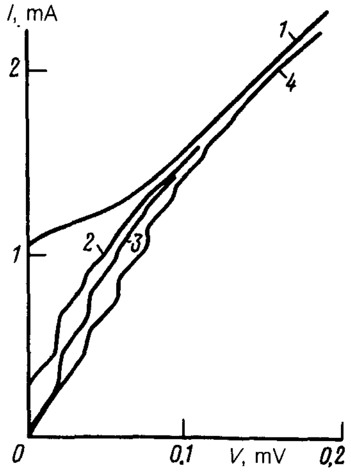

FIG. 2. Current-voltage characteristics of the $Eu_1Ba_2Cu_3O_y$-Nb superconducting point contact (1) at a zero microwave power and (2–4) at increasing microwave power levels.

$\sim 1\ \Omega$, the I-V characteristics over the voltage interval 0–10 mV had the shape typical of *N-I-S* tunnel junctions, with a clearly expressed gap feature at 1–2 mV. This feature yielded a value of 1.4–1.5 meV for the energy gap of niobium. At voltages $V > 10$ mV the conductance of the contacts decreased with increasing current, indicating a low quality of the tunnel barrier. As a result, we were not able to unambiguously interpret the structural features seen on the I-V characteristics at $V > 10$ mV.

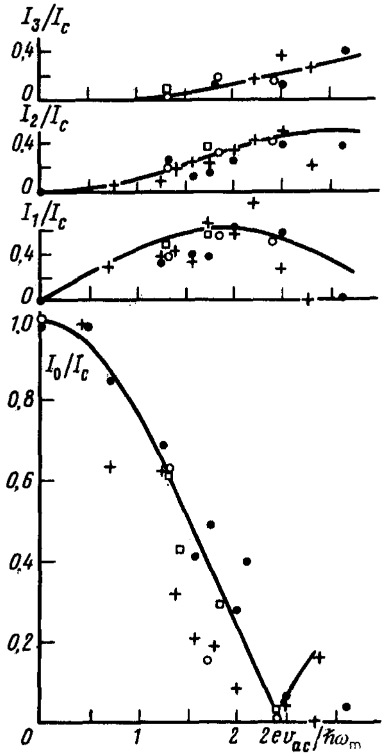

FIG. 3. Height of the induced current steps versus the normalized alternating voltage across the contact.

Figure 2 shows characteristics of one of the superconducting Josephson junctions at various microwave power levels (curve 1 corresponds to a zero microwave power). Figure 3 shows the critical current I_c ($n = 0$) and the heights of the induced current steps with $n = 1$, 2, and 3 as functions of the alternating voltage across the contact, v_{ac}. The different symbols correspond to different Nb-MOC contacts. The solid lines are Bessel functions of zeroth, first, second, and third order; these functions should correspond to the curves of $I_n(v_{ac})$ for Josephson superconducting junctions.[4]

It follows from Figs. 2 and 3 that the characteristics and properties of the point-contact Josephson junctions studied do not differ from ordinary Nb-Nb Josephson junctions with electrodes made of a substance with a very short electron mean free path. We know quite well that in a Josephson structure consisting of two superconductors there will be an exchange of electron pairs (the long-range order is "transmitted" through the tunnel barrier and across the weak link), and the entire system behaves to some extent as a single superconductor. The interaction between two superconductors is treated theoretically with the help of a tunnel Hamiltonian which includes the product of creation and annihilation operators for electrons with identical spins on the two sides of the barrier.[4] One might say that an interference of the two wave functions of the superconductors forming the contact occurs near the Josephson junction. It would be difficult to expect that junctions with electrodes, in which the pairing mechanisms were substantially different, would exhibit typical Josephson characteristics. In all probability, the pairing mechanism for the superconducting electrons in the $Eu_1Ba_2Cu_3O_y$ single crystal studied in these experiments is approximately the ordinary mechanism.

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Translated by Dave Parsons