The Merceau effect in Josephson point-contact junctions based on $YBa_2Cu_3O_{7-\delta}$ at nitrogen temperatures

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The current-voltage characteristics of Josephson point-contact junctions based on $YBa_2Cu_3O_{7-\delta}$ have been studied over a broad temperature interval. Contacts of various geometries were found to exhibit interference effects in a magnetic field at nitrogen temperatures. The Mercerau oscillation frequency of a double-contact interferometer with an effective circuit diameter of $\sim 8\ \mu m$ was found to increase upon approaching T_c because of the increase in the penetration depth of the magnetic field, $\lambda(T)$.

The discovery of high-temperature superconductors[1] set the stage for a vigorous research of these materials. The study of the Josephson effect in these compounds is one of the most important directions of research both from the scientific and applied points of view.

We have studied the current-voltage characteristics of the Josephson junctions based on metal-oxide compound $YBa_2Cu_3O_{7-\delta}$ over wide temperature range. The method used to synthesize the samples is described elsewhere.[2] The point contacts were fabricated according to a method described in Ref. 3. To analyze the I-V characteristics of the tunnel junctions, we used an automatic bridge whose design is described in Ref. 4.

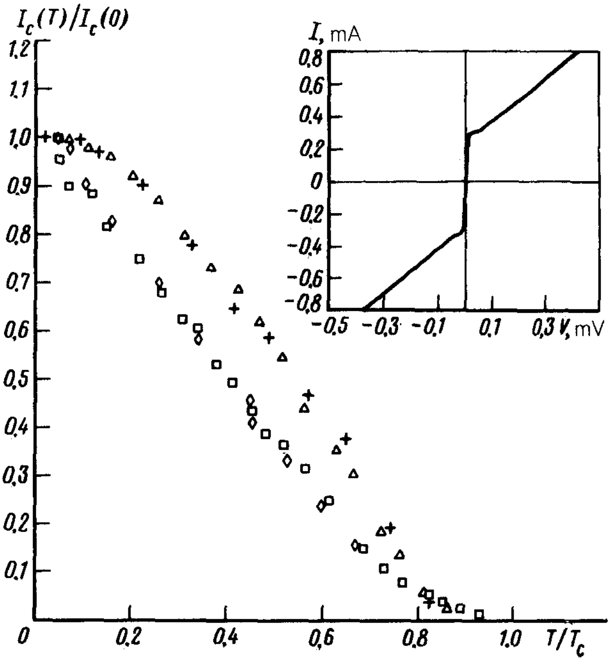

FIG. 1. Reduced critical current $I_c(T)/I_c(0)$ versus reduced temperature T/T_c for four Josephson junctions based on $YBa_2Cu_3O_{7-\delta}$ [$I_c = 120$ μA(+); 220 μA (◇); 670 μA (□); 2 mA (△) at $T = 4.2$ K]. Inset—The *I-V* characteristic for one of the Josephson junctions at $T = 77.3$ K.

A typical *I-V* curve for a Josephson point contact at $T = 77.3$ K is shown in the inset of Fig. 1. The plots of the reduced critical current $I_c(T)/I_c(0)$ versus the reduced temperature T/T_c for four Josephson point contacts are shown in Fig. 1. It is pertinent to note that the temperature dependences of the critical Josephson current of the test junctions cannot be described by the standard Ambegaokar-Baratoff relation.[5] The dependences obtained by us are characteristic for structures such as SNINS[6] or SNS junctions.[7] The presence of a Schottky-type dielectric barrier at the grain surface and of a metallic transition layer between the dielectric barrier and the bulk superconductor was discussed previously in the case of a metal-oxide compound[8] $BaPb_{1-x}Bi_xO_3$. Similar $I_c(T)$ curves for junctions based on high-T_c superconductors were obtained by several authors.[9–11]

At nitrogen temperatures the *I-V* characteristics of the test junctions become smeared by the thermal fluctuations. The phase coherence which accounts for the interference effects in the magnetic field remains in force to ~80 K.

In the case of a single point contact with a dI/dV characteristic at $H = 0$, shown in the insert of Fig. 2a, the dependence of the differential conductivity at zero bias voltage $dI/dV|_{V=0}$ on the magnetic field is described by oscillations whose amplitude decays as H is raised (Fig. 2a). This dependence is qualitatively analogous to the field dependence of the critical superconducting current of an "ideal" Josephson junction.

This functional dependence is given by[12]

$$I_c(H) = I_c(0)\left|\frac{\sin(\pi\Phi/\Phi_0)}{\pi\Phi/\Phi_0}\right|,$$

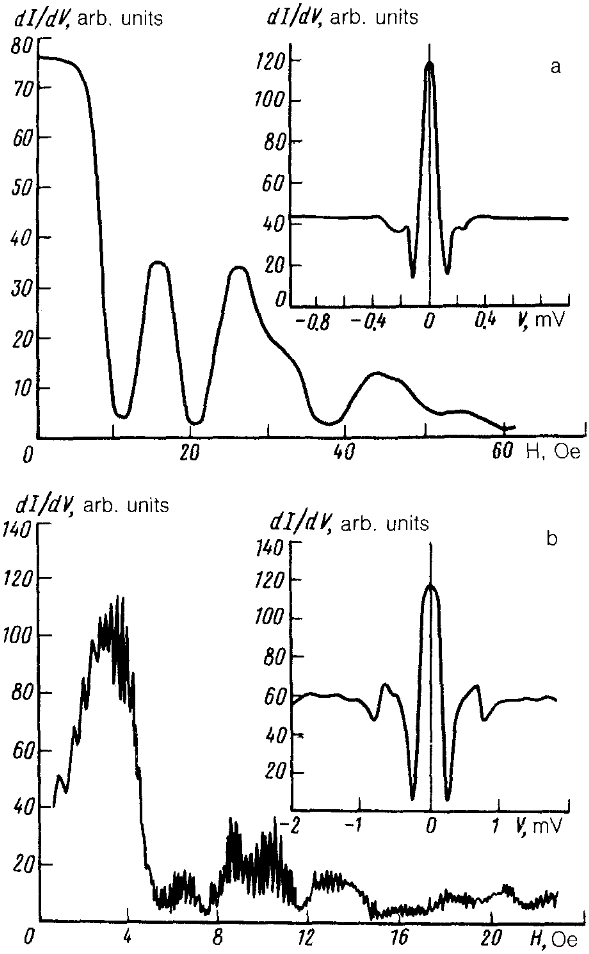

FIG. 2. The $dI/dV|_{V=0}$ (H) curve and $dI/dV_{H=0}$ (V) curve (inset) of one of the Josephson point-contact junctions at $T = 62.4$ K (a) and of a double-contact interferometer at $T = 66.5$ K (b).

where Φ is the total flux through the lateral section of the junction, and $\Phi_0 = 2.07 \times 10^{-7}$ G·cm^2 is a quantum of magnetic flux (fluxoid).

The beats on the $dI/dV|_{V=0}(H)$ Curve (Fig. 2a) are the results of a nonuniform distribution of the current in the plane of the junction.[12]

In the case of several Josephson point-contact junctions which we have studied the oscillatory dependence of the type $|\sin(x)/x|$ was modulated by a higher frequency (Fig. 2b). Such a dependence is characteristic for two Josephson junctions which are connected in parallel (the Mercerau effect). In Fig. 2b the characteristic is not modulated 100% because the junctions in the circuit are not identical.[12]

The calculations to evaluate the effective width of the Josephson junctions: $L_{\rm eff} = \Phi_0/[\Delta_{\rm lf} 2\lambda(T)]$ [$\Delta_{\rm lf}$ is the period of the low-frequency oscillations of the type $|\sin(x)/x|$, and $\lambda(T)$ is the penetration depth of the magnetic field, where $\lambda \gg \xi$ is the

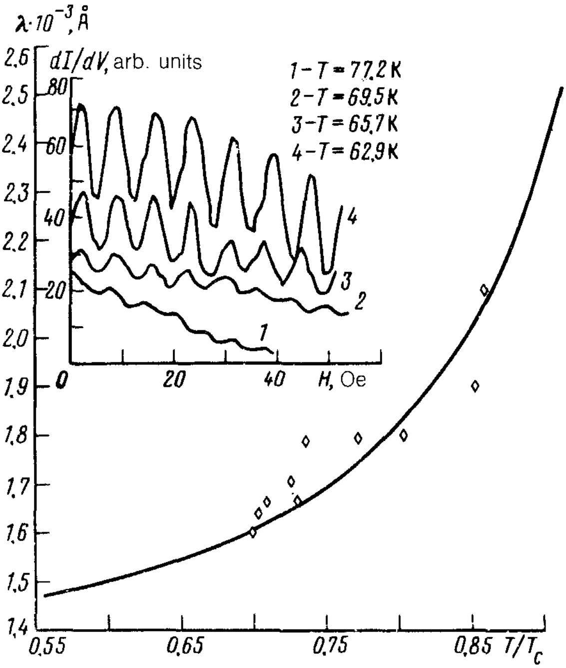

FIG. 3. The temperature dependence of the penetration depth λ of the magnetic field. The solid curve was plotted in accordance with the theory (see the text proper). The inset shows the $dI/dV|_{V=0}$ (H) curves (the Mercerau oscillations) plotted at various temperatures for a double-contact interferometer with an effective circuit diameter of ~ 8 μm.

coherence length and $\lambda(0) = 1400$ Å[13)]] showed that $L_{\rm eff}$ is no greater than the characteristic size of the grains in the ceramic ($\sim$10–50 μm). We evidently have two parallel junctions when the barrier is punctured twice near the point of contact of two superconducting grains which are tightly pressed to each other. The effective height of the circuit which spans the junctions in this case is approximately equal to $2\lambda(T)$. In such junctions the Mercerau oscillation frequency increases with increasing temperature, which stems from the increase in the penetration depth of the magnetic field $\lambda(T)$ (the inset in Fig. 3). This effect makes it possible to calculate $\lambda(T)$ from the temperature dependence of the Mercerau oscillation period and allows us to compare the dependence we have obtained with the theoretical dependence: $\lambda(T) = \lambda(0)[1 - (T/T_c)]^{-1/2}$ (Ref. 12), in the temperature interval $T = 60$–80 K (Fig. 3).

At the inerferometer which we have used to find the Mercerau oscillations (shown in Fig. 3), the effective width of the junctions $L_{\rm eff}$ is $\sim$0.54 μm and the effective cross section of the circuit spanning the two junctions is ~ 8 μm.

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