Investigation of the energy gap of Y-Ba-Cu-O by point-contact Josephson-junction techniques

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Experimental results on stable point-contact Nb/Y-Ba-Cu-O structures are reported. Reproducible current-voltage characteristics showing Josephson coupling are obtained. Measurements of dV/dI give an estimate for the energy-gap value of the high-T_c superconductor Y-Ba-Cu-O $\Delta = 19.5 \pm 2.0$ mV, corresponding to a ratio $[2\Delta(0)/k_BT_c] = 4.8$ in agreement with previous results obtained by a different technique.

As is well known, the interest of a large part of the scientific community is focused on the properties of the new class of high-T_c superconductors[1] and in particular on Y-Ba-Cu-O compounds.[2] In this paper we shall confine our attention to the latter material.

The importance of the underlying physics, as well as the relevance of potential applications of Y-Ba-Cu-O suggests, as a preliminary step, a careful investigation of all those aspects which allow the necessary characterization of this new class of superconductors.

In this context many experiments have been directed toward the study of weakly coupled superconductors[3-9] both for the intrinsic interest of such systems and for their significant diagnostic power[10] in the analysis of the basic superconducting properties of the material. We report here experimental results concerning Nb/Y-Ba-Cu-O point-contact structures.

The high-T_c superconductor, of composition $YBa_2Cu_3O_{7-\delta}$, was obtained by sintering a compact pellet of the prereacted phase at a temperature of 950 °C in flowing oxygen. The preparation of the phase was realized by grinding Y_2O_3, $BaCO_3$, and CuO powders. The mixture was reacted in a flux of oxygen in a furnace in a SiO_2 crucible at a temperature up to 950 °C for 16 h.[11] The point-contact junction was realized by a Nb point (1 mm diameter) pressed onto the Y-Ba-Cu-O pellet. The contact pressure of the junction was well controlled while in the cryostat by a system suitable for micrometric adjustability.

The vacuum cleaning procedure of the Y-Ba-Cu-O surface turned out to be an essential step for the realization of a good point-contact structure. For this purpose we adopted a fast-atom-bombardment technique which very likely leads to a Y-Ba-Cu-O surface more closely representative of the interior of the bulk samples. Indeed it is interesting to point out that where such a cleaning procedure was adopted, the typical point-contact junction behavior is clearly observed even for quite a small contact pressure. The Josephson effect was repeatedly observed and well reproduced. By increasing the contact pressure the junction resistance decreased typically down to a fraction of Ω and the critical current increased up to ≃0.5 mA. The occurrence of Fiske resonant current steps as well as Josephson current modulation by an externally applied magnetic field was also clearly observed. A set of typical current-voltage characteristics of a Nb/Y-Ba-Cu-O point-contact Josephson junction measured at 4.2 K is reported in Fig. 1. In Fig. 2 dV/dI curves for the same sample as in Fig. 1 are displayed for different contact pressures whereas the dV/dI curves at three different temperatures are shown in Fig. 3. All the dV/dI curves exhibit a rather well-defined structure related to the occurrence of niobium-insulator–normal-metal tunneling (labeled as Nb/N) in parallel with niobium-insulator–Y-Ba-Cu-O (Nb/Y-Ba-Cu-O) tunneling. This can be as-

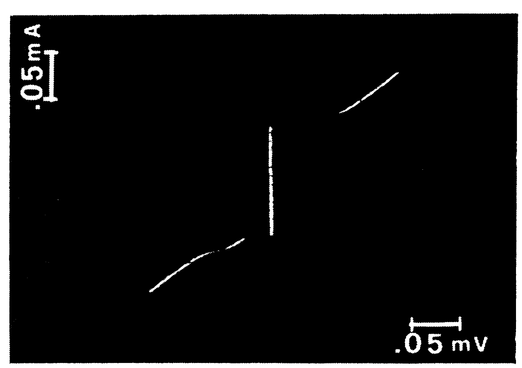

FIG. 1. Typical current-voltage characteristics of a Josephson Nb/Y-Ba-Cu-O point-contact structure.

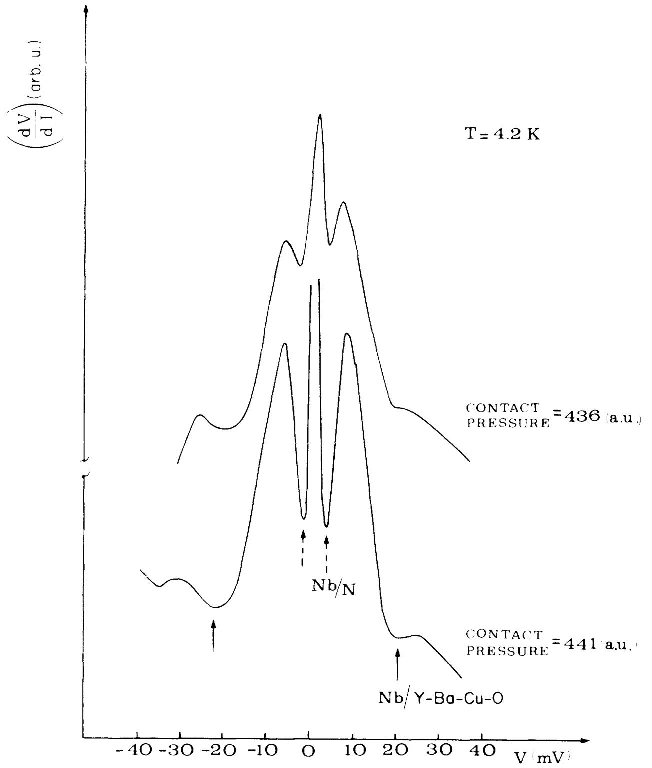

FIG. 2. dV/dI curves of a Nb/Y-Ba-Cu-O point-contact structure at $T=4.2$ K for different contact pressures. The two curves are vertically shifted just for a better display.

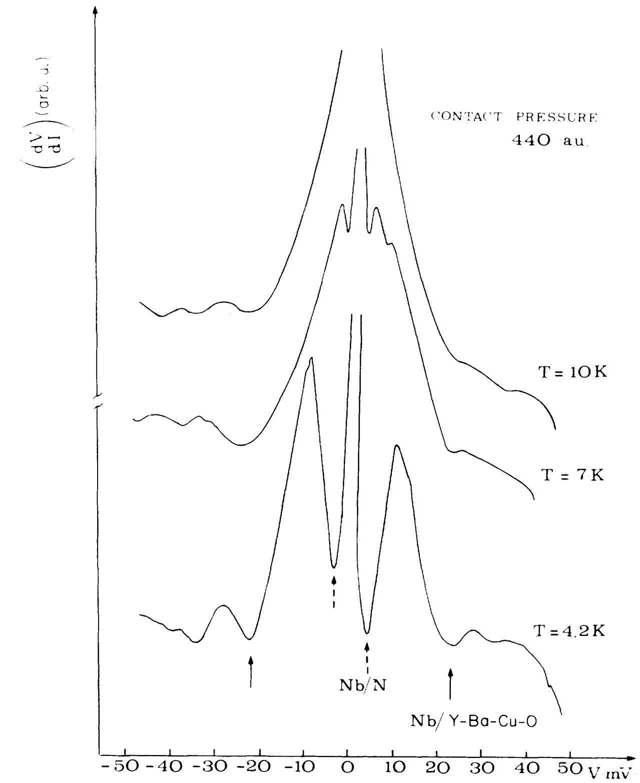

FIG. 3. dV/dI curves of a Nb/Y-Ba-Cu-O point-contact structure, for a given contact pressure, at different temperatures.

cribed to the circumstance that superconductor-superconductor tunneling occurs only in a fraction of the grains over the contact area as also indicated by the relatively low values of the observed Josephson current. The minimum at about $V=21$ mV in the dV/dI dependence can be interpreted as a consequence of the presence of an energy gap of the Y-Ba-Cu-O, namely, $V=\Delta(\text{Nb})+\Delta(\text{Y-Ba-Cu-O})$. As is clear from Fig. 3, the value of V is only weakly temperature dependent, as expected, since in the considered temperature range only $\Delta(\text{Nb})$ (~ 1.5 mV) changes.

Thus, from these data, a gap value for the high-T_c superconductor Y-Ba-Cu-O $\Delta=19.5\pm2.0$ mV can be estimated. Since for the examined sample it was $T_c=92.4$ K ($\Delta T_c=0.8$ K), we inferred $2\Delta(0)/k_BT_c=4.8\pm0.5$ in agreement with the results obtained by other authors employing different techniques. There were other less evident structures present in the dV/dI curves so that the existence of a multigap nature of the material cannot be ruled out,[12] as well as Giavier-Zeller tunneling.[13]

In conclusion, reliable point-contact junctions between Nb and Y-Ba-Cu-O superconducting oxide have been realized which show all the correct features of the Josephson effect. Moreover, although the current-voltage characteristics with a large subgap conductance does not allow an estimation for the gap, a well-defined structure can be observed in the dV/dI curves which can be related to the occurrence of a gap in the Y-Ba-Cu-O density of states at $\Delta=19.5$ mV. Some ambiguity could arise from the possible gap anisotropy and the effective junction area which is not well defined due to the contact with grains of different orientations. The results are in fairly close agreement with other tunneling experiments (e.g., Refs. 4 and 5). The present data show both Josephson effect and gap structure observed in the same sample—a circumstance which should guarantee a greater consistency of the whole picture.

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