Anisotropy of the superconducting transition temperature in a Bi-Sr-Ca-Cu-O single crystal

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The electrical resistance and magnetic susceptibility of a $Bi_2Sr_{3-x}Ca_xCu_2O_{8+y}$ single crystal have been measured. The superconducting transition temperature is observed to be anisotropic with respect to the *c* axis of the crystal.

The new high-temperature superconducting materials which contain bismuth[1] are distinguished from the well-known system not only by the magnitude of the superconducting transition temperature T_c but also by the circumstance that the high-temperature superconductivity persists as the composition is varied over a wide range.

In this letter we report measurements of the electrical resistance and magnetic susceptibility of a $Bi_2Sr_{3-x}Ca_xCu_2O_{8+y}$ single crystal with respect to the *c* axis.

The $Bi_2Sr_{3-x}Ca_xCu_2O_{8+y}$ single crystal was synthesized from a molten solution in which the solvent was cupric oxide. The temperature interval of the crystallization was 1070–1270 K, and the melt was cooled at a rate of 5 K/h. A sample with dimensions of $6\times8\times0.9$ mm was obtained in the form of a wafer of irregular shape. The sample was then annealed in air at 1150 K for 30 h.

The magnetic susceptibility was measured in an alternating magnetic field $H\sim8$ A/m at a frequency of 77.7 kHz with the help of an attached gauge, which consisted of magnetizing and measuring coils with respective diameters of 5 and 3 mm. The voltage induced in the measuring coil by the sample was canceled in two components at 85 K. In this case the change in the signal occurred only upon a change in the magnetic susceptibility of the sample ($\Delta U\sim\Delta\chi$). The measurements were carried out in a magnetic field directed parallel to or perpendicular to the *c* axis of the crystal. In the former case the gauge was applied to the plane of the sample, and in the second it was applied to a lateral face of the sample.

The dc resistance was measured by a four-contact method; the contacts, applied to the surface of the sample with silver paste, were positioned as in Ref. 2: in pairs in the *a-c* plane on two sides of the crystal. This arrangement made it possible to measure the resistance of the sample in the directions parallel to and perpendicular to the *c* axis of the crystal with the same contacts.

Figure 1 shows the temperature dependence of the relative change in the magnetic susceptibility $[(\Delta\chi/\Delta\chi_{85}) = (\chi_{4.2} - \chi/\chi_{4.2} - \chi_{85})]$ from the measurements with $\mathbf{H}\parallel c$ and $\mathbf{H}\perp c$. We see from this figure that in a magnetic field directed parallel to the *c* axis the magnetic susceptibility changes sharply as the temperature is lowered from 80 K. From 70 K on down, the changes become slower, and a tail stretches down to 25 K. The value found for T_c from the position of the point at which the magnetic

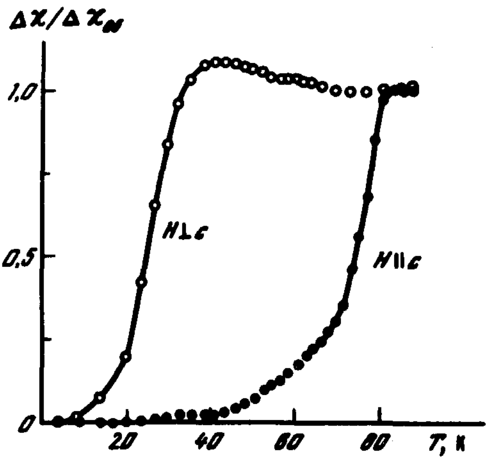

FIG. 1. Temperature dependence of the relative change in the magnetic susceptibility in the cases H ∥ c and H ⊥ c.

susceptibility has changed by a factor of two is 74 ± 3 K. The width of the transition, taken as the interval between the 0.9 and 0.1 points, is 27 K.

In the case in which the magnetic field is directed perpendicular to the c axis, the changes in the magnetic susceptibility begin at 40 K; in this case we find $T_c = 26 \pm 5$ K and a transition width of 15 K.

Figure 2 shows the temperature dependence of the relative change in the resistance $[(\Delta R / \Delta R_{85}) = (R - R_{4.2} / R_{85} - R_{4.2})]$ for the cases in which the current **I** is directed parallel to and perpendicular to the c axis. In the case **I** ⊥ c, the temperature dependence of $\Delta R / \Delta R_{85}$ remains metallic in nature down to 80 K; beginning at 80 K, we see a transition—similar to that in the case of the change in the magnetic susceptibility in the case **H** ∥ c—with $T_c \neq 76 \pm 3$ K and a width of 26 K.

In the case **I** ∥ c, the behavior of the resistance is of a semiconducting nature

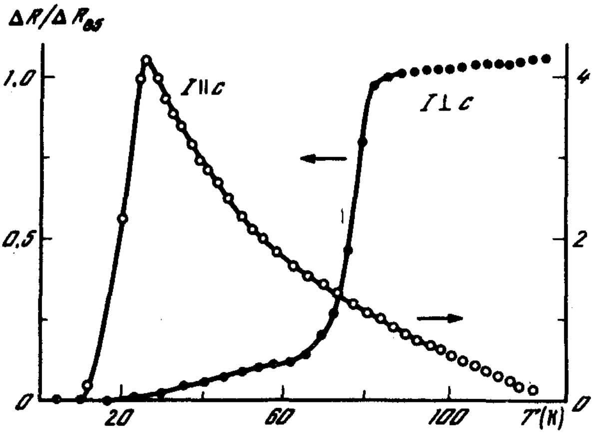

FIG. 2. Temperature dependence of the relative change in the electrical resistance in the cases **I** ∥ c and **I** ⊥ c.

down to 26 K; at 26 K, the resistance begins to decay sharply. This decay has not terminated even at 4.2 K. We make the rough estimate $T_c \sim 16$ K.

A similar behavior was observed in Ref. 2 for the resistances parallel to and perpendicular to the c axis before the superconducting transition temperature. This behavior was explained there in terms of the presence of separate metal layers. The data of Ref. 3 also indicate an anisotropy of the conductivity in $YBa_2Cu_3O_{7-y}$ superconductors.

In summary, it follows from the results of this study that there is a superconducting transition temperature for the directions parallel and perpendicular to the c axis in the $Bi_2Sr_{3-x}Ca_xCu_2O_{8+y}$ single crystal.

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