Rapid Communication

Onset of Superconductivity at 107 K in YBa$_2$Cu$_3$O$_{7-\delta}$ at High Pressure

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Received 1 March 1988/Accepted 16 March 1988

Abstract. Electrical resistivity $\rho$ measurements under pressure have been carried out on the high-temperature superconductor YBa$_2$Cu$_3$O$_{7-\delta}$ as a function of temperature $T$ between 1 and 300 K at various pressures between 8 kbar and 149 kbar. The superconducting transition temperature $T_c$ increases almost linearly with pressure at the rate $dT_c/dP \approx 0.13$ K/kbar. The onset of $T_c$, defined as the temperature at which $\rho(T)$ drops to 90% of its extrapolated normal state value, increases from $\sim 95$ K at 8 kbar to 107 K at 149 kbar. These results suggest that higher pressures will yield yet higher values of $T_c$.

PACS: 74.70 Vv

During the past year, the maximum superconducting transition temperature $T_c$ has risen from $\sim 23$ K for the A15 compound Nb$_3$Ge, where it had remained since 1973 [1], to $\sim 95$ K for the compound YBa$_2$Cu$_3$O$_{7-\delta}$ ($\delta=0.1$) [2], which has an orthorhombic oxygen-deficient perovskite-like crystal structure [3], and the isostructural series of rare earth (R) compounds RBA$_2$Cu$_3$O$_{7-\delta}$ (except for the compounds with R = Ce, Pr, and Tb, which are not superconducting above 4.2 K) [4]. The dramatic increase of the maximum $T_c$ to its present value of $\sim 95$ K occurred through a series of developments starting with the discoveries of superconductivity with $T_c \sim 30$ K in (La$_{1-x}$Ba$_x$)$_2$CuO$_{4-\delta}$ ($x \approx 0.075$) [5,6] and $T_c \sim 40$ K in (La$_{1-x}$Sr$_x$)$_2$CuO$_{4-\delta}$ ($x \approx 0.075$) [7,8], and the increase of $T_c$ with pressure to onset values, depending on the definition of the $T_c$ onset, ranging between $\sim 40$ and $\sim 50$ K, for materials in the La-Ba-Cu-O system [9,10]. Measurements of $T_c$ under pressure have been reported for multiphase samples in the Y-Ba-Cu-O system [11] and RBA$_2$Cu$_3$O$_{7-\delta}$ compounds, with R = Y, up to $\sim 10$ kbar [12], and R = Y, Gd, Er, and Yb, up to $\sim 18$ kbar [13]. In the study the multiphase Y-Ba-Cu-O samples [11], $T_c$ was found to increase from less than 90 K to about 91.5 K at 17.6 kbar, while for the studies on the RBA$_2$Cu$_3$O$_{7-\delta}$ compounds [12,13], the largest increase in $T_c$ occurred for the compound YBA$_2$Cu$_3$O$_{7-\delta}$ in which $T_c$ increased from 88 K at zero pressure to 92.5 K at 18.2 kbar. In this communication, we report measurements of $T_c(P)$ in YBA$_2$Cu$_3$O$_{7-\delta}$ to $\sim 149$ kbar, using a clamped Bridgman anvil device, which reveal a nearly linear increase of $T_c$ in which the $T_c$ onset increases from $\sim 95$ K at 8 kbar to $\sim 107$ K at 149 kbar. To our knowledge, this is the highest value of $T_c$ yet reported for a material known to

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exhibit a confirmed bulk superconducting transition. A brief account of this work was given in the Proceedings of a recent conference [14].

Experimental Details

Electrical resistivity measurements under pressure were made on a bar-shaped specimen of YBa$_2$Cu$_3$O$_{7.6}$ that was cut from a polycrystalline sintered pellet prepared in the manner described in [15]. A self-clamping Be-Cu device was used to generate and retain quasihydrostatic pressures up to 160 kbar between opposed tungsten-carbide Bridgman anvils. The sample and a Pb manometer were placed in series with one another between two disks of steatite, which served as the pressure transmitting medium, surrounded by a pyrophillite ring-shaped gasket. The two current and four voltage leads of Pt were attached to the sample and Pb manometer with Ag loaded epoxy, and the voids between the steatite and the sample, manometer and electrical leads were filled with talc. Pressures were inferred from the $T_c$ of the Pb manometer [16], and the temperature of the self-clamping high pressure device was varied between 1 and 300 K, using a He$^4$ cryostat. The four-lead electrical resistivity measurements were made using a standard phase sensitive detection technique at a frequency of 220 Hz.

Results and Discussion

Electrical resistance $R$ vs temperature data for YBa$_2$Cu$_3$O$_{7.6}$ at four different pressures ranging from 8 kbar to 149 kbar are shown in Fig. 1. In the normal state at temperatures greater than $T_c$, the $R(T)$ curves are nearly linear at all four pressures, with negative temperature coefficients of resistivity $\alpha = (1/\rho)(d\rho/dT)$ at the two lower pressures and nearly zero $\alpha$-values at the two higher pressures. The increase of $\alpha$ with pressure between 8 kbar and 90 kbar and the decrease of $R$ with pressure may be partly due to changes in sample geometry, since the density of the sintered material is only about 80% of the theoretical density after the final sintering step. The decrease of the value of $R$ with pressure reveals that the YBa$_2$Cu$_3$O$_{7.6}$ compound becomes more metallic under pressure. The negative value of $\alpha$ at 8 kbar indicates that the YBa$_2$Cu$_3$O$_{7.6}$ compound is slightly deficient in oxygen.

The effect of pressure on the superconducting transition can be seen more clearly in Fig. 2 where the electrical resistivity $\rho$, normalized to its value at 120 K, is plotted vs temperature between 40 and 120 K. The shape of the resistive superconductive transition curve does not change with pressure, although the width of the transition decreases slightly with pressure. We define the transition temperature $T_c$ as the value at which the resistivity drops to 50% of its extrapolated normal state value and the transition width $\Delta T_c$ as the difference between the temperatures at which $\rho$ drops by 90% and 10% of its extrapolated normal state values; i.e., $T_c = T(50\%)$ and $\Delta T_c = T(90\%) - T(10\%)$. The transition width is rather large with $\Delta T_c \approx 20$ K, which is probably primarily due to the pressure inhomogeneity in the high pressure cell, since a