Changes in superconducting and other electrical properties of $Bi_2Sr_2CaCu_2O_x$ at high pressures

E. A. Alekseeva, I. V. Berman, N. B. Brandt, A. A. Zhukov, I. L. Romashkina, and V. I. Sidorov
M. V. Lomonosov Moscow State University

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A reversible nonlinear decrease in the transition temperature T_c has been observed during the compression of $Bi_2Sr_2CaCu_2O_x$ single crystals at pressures up to 160 kbar. This decrease correlates with a change in the temperature dependence of the resistance in the temperature range $T_c < T < 300$ K.

For samples of the Bi-Sr-Ca-Cu-O system, with a superconducting transition temperature $T_c \sim 80–90$ K, the value of T_c increases during hydrostatic compression. For $Bi_2Sr_2CaCu_2O_x$ single crystals with $T_c \sim 80$ K, the baric derivative is $dT_c/dP = 0.2$ K/kbar at pressures up to 15 kbar (Ref. 1) or 20 kbar (Ref. 2). For polycrystalline samples, the derivative dT_c/dP can take on smaller values, down to $dT_c/dP = 0.11$ K/kbar (Ref. 3).

In the case of a quasihydrostatic pressure, however, polycrystalline

$Bi_2Sr_2CaCu_2O_x$ samples exhibit a decrease in T_c with a baric derivative $dT_c/dP = -0.15$ K/kbar (Ref. 4). The superconducting transition during cooling was detected in that case against the background of a semiconducting increase in the resistance, $R(T)$. At $P \sim 80$ kbar, the superconducting transition became indistinguishable against this background. The presence of a semiconducting background on the $R(T)$ curves can have a significant effect on the accuracy of the results which are found. For example, in a study of polyphase ceramic Bi-Sr-Ca-Cu-O samples with $T_c(P=0) \sim 80$ K it was found[5] that T_c increases slightly at pressures up to 120 kbar, while the relative amount of superconducting phase decreases.

Similar results on the "disappearance" of superconductivity have been found by several investigators[6,7] for the La-Sr-Cu-O system. These results have been attributed to a pressure-induced structural conversion. However, x-ray studies have revealed no structural transformation in $Bi_2Sr_2CaCu_2O_x$ at pressures up to 500 kbar (Ref. 8). It may be that the disappearance of superconductivity from the Bi-Sr-Ca-Cu-O samples is due to either structural damage caused by shear deformation induced by a nonhydrostatic pressure or contact phenomena.

In this letter we are reporting a study of the dependence of R on T for $Bi_2Sr_2CaCu_2O_x$ single crystals over the temperature range 1.5–300 K at pressures up to 160 kbar. The pressure was produced by the Bridgman-anvil method. A thin layer of silver paste was brazed to fabricate low-resistance contacts in flowing oxygen on a sample with dimensions of $300 \times 30 \times 30$ μm^3. The times and temperatures of this deposition were chosen in some special experiments. Soft platinum strips were pressed against contact regions with an area no greater than 30×30 μm^2. The contact resistance did not exceed 0.1 Ω. The resistance R was measured by the four-terminal method with a measurement current $\leqslant 100$ μA.

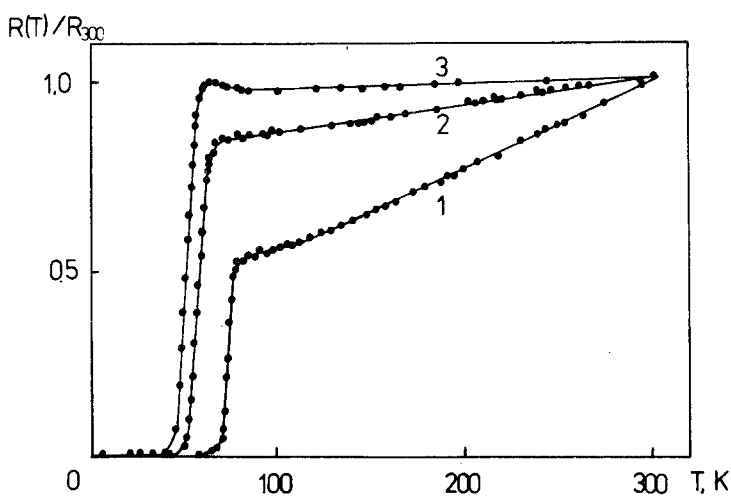

FIG. 1. Temperature dependence of the normalized resistance $R(T)R_{300}$ of a $Bi_2Sr_2CaCu_2O_x$ sample at various pressures P: *1*—66; *2*—143; *3*—158 kbar.

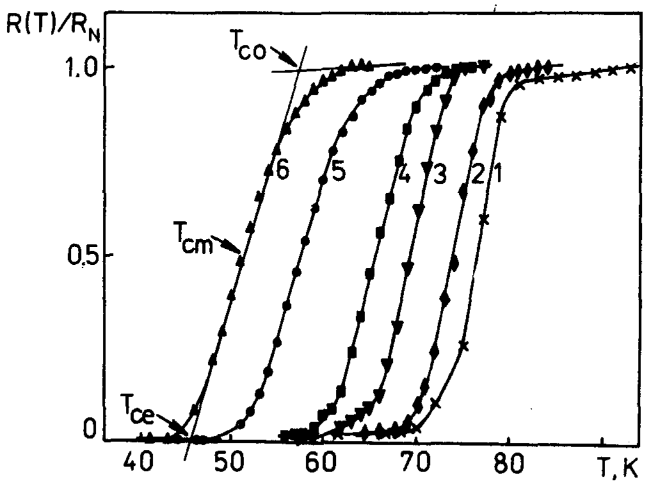

FIG. 2. Superconducting transition curves, normalized to the resistance in the normal state, R_N, of a $Bi_2Sr_2CaCu_2O_x$ sample for various pressures *P*: *1*—52; *2*—66; *3*—91; *4*—115; *5*—143; *6*—158 kbar.

The resistance at room temperature, R_{300}, is increased by a factor of several units by the pressure; it goes through a maximum at ~ 30 kbar and then falls off to roughly its original value. It then remains basically constant at pressures above 50 kbar. The resistivity at $P > 50$ kbar is $\rho \sim 5$–10 m$\Omega\cdot$cm.

Upon the transition to the superconducting state, *R* decreases abruptly, essentially to zero, while at $T > T_c$ the resistance exhibits a metallic behavior (Fig. 1). As the pressure is raised, the change in the resistance upon cooling from 300 K to T_c decreases, and at $P > 150$ kbar the superconducting transition is preceded by a slight increase in $R(T)$. This change in the nature of the $R(T)$ curves is completely reversible as the pressure is applied and removed.

In contrast with some studies published previously, in which T_c was measured at $P > 20$ kbar, in the present study we detected essentially complete superconducting transitions over the entire pressure range up to 160 kbar (Fig. 2). The width of the superconducting transition, ΔT, increased reversibly form 6 K at $P \sim 50$ kbar to 12 K at $P \sim 160$ kbar. The method for determining T_c on the basis of the onset, the middle, and the end of the superconducting transition (T_{co}, T_{cm}, and T_{ce}, respectively) is illustrated by the arrows in Fig. 2.

Figure 3 shows T_c as a function of *P*. The different symbols show data on T_{cm} for different samples; the tops and bottoms of the vertical error bars correspond to T_{co} and T_{ce}. It can be seen from Fig. 3 that the nature of the $T_c(P)$ curves depends on the value of T_c at $P = 0$. For all the samples studied, the $T_c(P)$ dependence is nonlinear. For the samples with the higher values of T_c, the $T_c(P)$ dependence apparently goes through a maximum at the beginning of the pressure range. The pressure region in which this maximum occurs is approximately the same as that for the maximum on the $R_{300}(P)$ curve. For the samples with the lower values of T_c, this maximum is replaced by a plateau, and the nonlinearity of the $T_c(P)$ curve becomes more obvious,

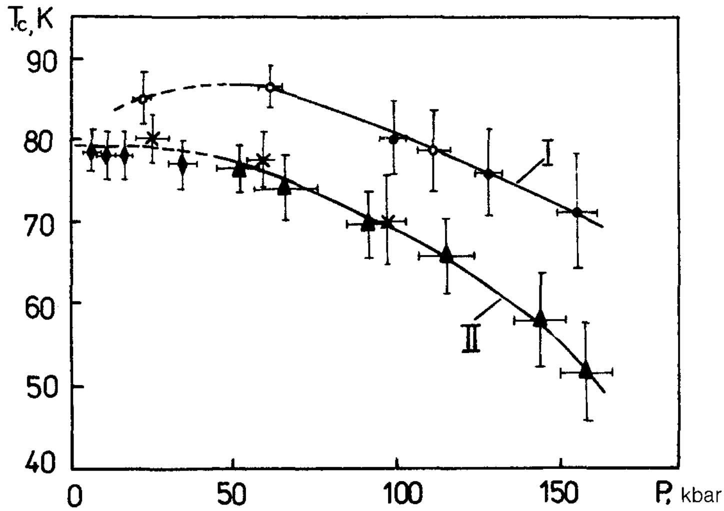

FIG. 3. T_{co},T_{cm}, and T_{ce} versus the pressure for $Bi_2Sr_2CaCu_2O_x$ single crystals.

particularly at high pressures. The values of $dT_c/dP \sim -0.15$ K/kbar at $P \sim 80$ kbar agrees with that found in Ref. 4. Note that the curves which we found are completely reversible (the filled and open circles in Fig. 3 were obtained as the pressure was respectively raised and lowered). The increase in the rate at which T_c decreases as the pressure is raised thus cannot be a consequence of a destruction of the sample. The relationship between T_c at $P = 0$ and the nature of the $T_c(P)$ curves which we mentioned above agrees qualitatively with the data found in Ref. 9 for the pressure interval 30–60 kbar.

It also follows from these results that the superconductivity of $Bi_2Sr_2CaCu_2O_x$ single crystals persists at pressures up to 160 kbar, so the disappearance of the superconductivity during compression which was observed in Refs. 4 and 5 was apparently a consequence of an imperfect contact between the electrodes and the sample.

The nonlinear decrease in T_c observed in the present study (curves I and II in Fig. 3) over a wide pressure interval and the increase in the derivative dT_c/dP at high pressures (curve II in Fig. 3) are atypical of most high-T_c superconductors, for which T_c generally increases during compression;[10] in fact, these results are atypical of most classical superconductors.

The decrease in T_c induced by pressure correlates with the change in the nature of the $R(T)$ dependence at $T > T_c$ (Fig. 1). The change in the nature of the $R(T)$ curves above T_c during the compression of $Bi_2Sr_2CaCu_2O_x$ is similar to the change in the $R(T)$ curves of classical amorphous semiconductors as the metal-insulator transition is approached.[11] This analogy suggests that the correlation between the decrease in T_c and the change in the shape of the $R(T)$ curves of the $Bi_2Sr_2CaCu_2O_x$ samples during compression might also be associated with a pressure-induced conversion of the electron energy spectrum of $Bi_2Sr_2CaCu_2O_x$ to an insulating nature.

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