Critical temperatures of $YBa_2Cu_3O_{7-y}$ at pressures up to 210 kbar

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At pressures P up to 210 kbar the critical temperature vs pressure curves for the single crystal and ceramic samples of $YBa_2Cu_3O_{7-y}$ were found to be nonlinear in nature. The value of the derivative dT_c/dP correlates with the value of T_c at $P = 0$: For single crystals with lower values of T_c the value of dT_c/dP is higher.

The study of high-T_c superconductors at high pressures, beginning with the study by Chu *et al.*,[1] has generated considerable interest. Most of the studies, however, are restricted to a relatively low range of pressures up to 20 kbar (40 kbar in Ref. 2), so that the question of the behavior of the critical temperature T_c at high pressures remains open to a certain extent.

Totally completed transitions to the superconducting state, whose width increases slightly upon compression, are recorded in experiments with hydrostatic pressure. The situation changes at pressures higher than 50 kbar. At these pressures the Bridgman anvils are used in the experiments, where the size of the samples is generally limited. The width of the transitions to the superconducting state in this case is greater than that in the experiments with hydrostatic pressure. In many experiments the transitions are recorded against the background of an increasing (or a very slightly decreasing) resistance as a result of a cooling[3–5] and they reach completion at nearly 4.2 K. In Refs. 6 and 7 the transitions to the superconducting state were completed at high temperatures, but the data obtained in these experimental studies differ markedly: In Ref. 6, T_c of $YBa_2Cu_3O_{7-y}$ increases from 96 K to 107 K upon the increase in pressure from 0 to 149 kbar and in Ref. 7, T_c of the $YBa_2Cu_3O_{7-y}$ single crystals

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passes through a flat maximum at $P \approx 50$ kbar when the pressure is increased in the range 0–100 kbar.

In our experimental study we have measured R as a function of T of the single-crystal and ceramic samples of $YBa_2Cu_3O_{7-y}$ in the temperature range 300–1.5 K in magnetic fields up to 30 kOe and pressures up to 210 kbar. The resistance of the samples with dimensions $30 \times 30 \times 300$ μm was measured by the four-contact method. As electrodes we used 10-μm-thick platinum strips.

Figure 1a shows curves for the transition to the superconducting state of the $YBa_2Cu_3O_{7-y}$ ceramic samples at various pressures. For clarity, the origin on the temperature scale is shifted by 10 K for each curve. The values of T_c are indicated by curves. We see that although R decreases to zero as a result of the superconducting transition, the shape of the curves changes appreciably in comparison with similar

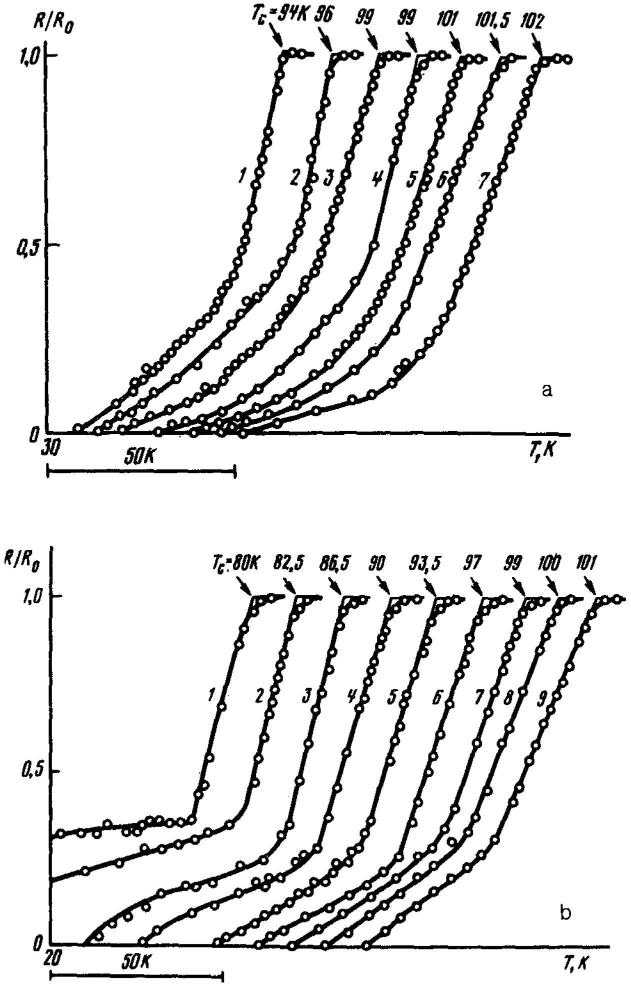

FIG. 1. Curves for the transitions to the superconducting state of the ceramic samples (a) and single-crystal samples (b) of $YBa_2Cu_3O_{7-y}$ for various pressures, (a)—P, kbar: 1—61; 2—67; 3—87; 4—97; 5—119; 6—150; 7—170. (b)—P, kbar: 1—36; 2—46; 3—53; 4—75; 5—86; 6—93; 7—100; 8—120; 9—140.

curves obtained under hydrostatic conditions. In the pressure range $P < 100$ kbar the superconducting transition is preceded by a small increase in the resistance. At $P > 100$ kbar, the resistance R decreases slightly as a result of cooling. In a 30-kOe magnetic field the shape of the superconducting transition curves changes: The onset of T_c shifts very slightly and the end of the linear segment shifts by 10–15 K.

At relatively low pressures the resistance of $YBa_2Cu_3O_{7-y}$ single crystals (Fig. 1b) decreases sharply upon a superconducting transition, but not to zero. Upon an increase in pressure, the slope of the linear parts of the superconducting transition curves remains essentially constant over a broad pressure range ($30 \lesssim P \lesssim 100$ kbar) and the transitions to the superconducting state terminate, shifting up the temperature scale.

The highly diffuse transition of the polycrystalline samples to the superconducting state and the nonvanishing resistance of the single crystals at low pressures are apparently attributable to the strong nonuniformity (with respect to T_c) of small-size samples, in which the effects associated with the properties of the surface may play a key role. The surface is known to be the most vulnerable part of high-T_c superconductors, since all the processes associated with the disruption of the structure (oxygen diffusion, intrusion of water vapor and carbon dioxide, etc.) occur primarily at the surface. The strong variations in the magnitude of the energy gap along the surface of the $YBa_2Cu_3O_{7-y}$ samples, which were detected by the tunnel-spectroscopy method[8] by moving the sensor along the surface, are apparently related to this circumstance.

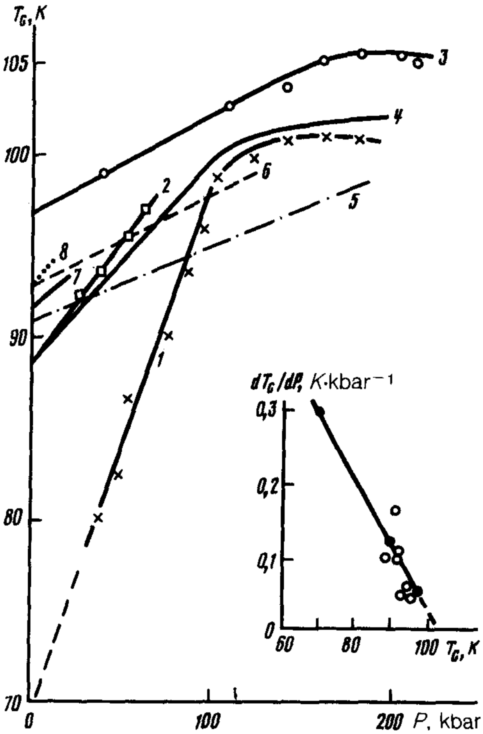

FIG. 2. Plots of T_c vs the pressure for the single-crystal samples (curves 1–3) and ceramic samples (curve 4) of $YBa_2Cu_3O_{7-y}$; curve 5—data of Ref. 3, curve 6—Ref. 4, curve 7—Ref. 9, and curve 8—Ref. 10. The filled circles in the inset represent our results obtained for single-crystal samples.

Figure 2 shows curves of T_c vs pressure for $YBa_2Cu_3O_{7-y}$ plotted from the data obtained by us (curves 1–3 are for single crystals and curve 4 is for the ceramics) and from the data found in the literature (curve 5—Ref. 3; curve 6—Ref. 4; curve 7—Ref. 9; curve 8—Ref. 10). On the basis of these data it can be assumed that the plots of T_c vs P for the $YBa_2Cu_3O_{7-y}$ compound have the following shape over a broad pressure range. With an increase in pressure, T_c increases linearly. The rate at which T_c varies then decreases gradually and goes down to zero at a certain critical pressure. How T_c varies at higher pressures is yet to be determined, although the behavior of this curve (does T_c remain constant or does it decrease after passing through a maximum?) is, in our view, of fundamental importance in determining the mechanism describing the change in T_c upon compression. The pressure at which $T_c(P)$ reaches a maximum value correlates with the pressure at which a structural transition occurs from the orthorhombic phase to the tetragonal phase.[11,12]

Another curious feature of the T_c vs P curves is the fact that the derivative dT_c/dP of the $YBa_2Cu_3O_{7-y}$ orthorhombic phase apparently depends strongly on T_c at $P=0$. Samples with lower values of T_c have the maximum value of dT_c/dP. A rough estimate of the dT_c/dP vs T_c curve for various samples is shown in the inset of Fig. 2.

An explanation for the link between dT_c/dP and T_c could be the redistribution of oxygen among the various positions in the lattice, as a result of which the oxygen concentration in the layers responsible for the superconductivity increases. The redistribution should obviously lead to a strong dependence of T_c on P in the initially oxygen-deficient samples and to its absence in samples with a maximum concentration. There are, however, no structural-analysis data now which would indicate that a redistribution could occur.

The observed dT_c/dP vs T_c curve, on the other hand, can be explained on the basis of the hypothesis that the electron-lattice coupling near the temperature T_m of the structural transitions can be increased.[13,14] To reconcile these data with this hypothesis, we must assume that the electron-lattice coupling near T_m increases in the case of a higher oxygen deficiency (low T_c). From this standpoint, a sharp increase of T_c in oxygen-deficient samples due to compression is a consequence of the decrease of T_m due to pressure.[14]

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