Critical temperatures of $Tl_2Ba_2Ca_2Cu_3O_x$ at pressures of up to 190 kbar

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(Submitted 15 May 1989)
Pis'ma Zh. Eksp. Teor. Fiz. **49**, No. 12, 668–671 (25 June 1989)

A nonmonotonic dependence of the superconducting transition temperature T_c on the pressure P at pressures of up to 200 kbar has been observed in ceramic samples of $Tl_2Ba_2Ca_2Cu_3O_x$. At $P\sim 40$ kbar a low-temperature phase has been found to appear. The derivatives dT_c/dP of the high-temperature phase and the low-temperature phase have been determined.

The effect of pressure on the critical temperature T_c of a superconducting transition of one of the more interesting, recently discovered systems[1] of high T_c superconductors, Tl–Ba–Ca–Cu–O, has heretofore been studied only at hydrostatic pressures ($P\leqslant 8$ kbar).[2] The problem of the behavior of T_c at very high pressure therefore remains unresolved.

In the present letter we report the results of an experimental study of the temperature dependence of the electrical resistance R of some ceramic samples of $Tl_2Ba_2Ca_2Cu_3O_x$ in the temperature interval 300–1.5 K and at pressures of up to 190 kbar. The pressure was produced by the Bridgman anvil method. The resistance of the samples measuring $\sim 300\times 30\times 30$ μm was recorded by the four-contact method. As the electrodes we used 10-μm-thick platinum strips.

The initial samples with the nominal composition $Tl_2Ba_2Ca_2Cu_3O_x$, whose characteristics were determined by an x-ray analysis, had several phases. Despite this circumstance, in the case of bulk samples we recorded single-stage curves for the transition to the superconducting state. The state at which we measured zero resistance in these samples was reached at tempratures above 105 K.

The $R(T)$ curves of small samples differ from those of large samples at different pressures (Fig. 1). The superconducting transitions were recorded against the background of an increase in the resistance R of a semiconductor. As the pressure is raised, the increase in r of the semiconductor becomes less pronounced.

Figure 2 shows several curves for the transition to the superconducting state of one of the test samples of $Tl_2Ba_2Ca_2Cu_3O_x$ at various pressures.

At relatively low pressures of up to ~ 40 kbar, the resistance during the superconducting transition decreases sharply, but does not vanish. After a partial transition to the superconducting state the resistance R increases at low temperatures (curves *1* in Fig. 2). With a further increase in the pressure above $P\sim 40$ kbar (curves *2–8* in Fig. 2), the transition to the superconducting state acquires a two-stage nature. In addition

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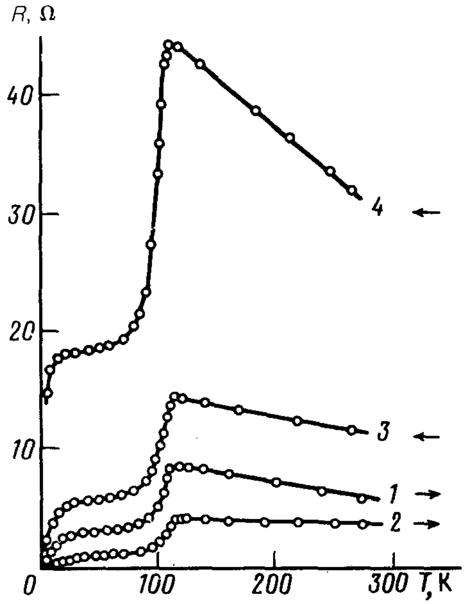

FIG. 1. Temperature dependence of the resistance $R(T)$ of a $Tl_2Ba_2Ca_2Cu_3O_x$ sample at various pressures P, kbar: *1*—56; *2*—162; *3*—84; *4*—65. The curves measured after increasing the pressure are marked by an arrow pointing to the right and the curves measured after decreasing the pressure are marked by an arrow pointing to the left.

to the high-T_c regions of the superconducting transitions characteristic of this compound ($T_c \sim 110$ K), we see regions of superconducting transitions with considerably lower critical temperatures ($T_c \sim 20$ K). If it is assumed that the superconductivity with lower T_c is characteristic of a certain low-temperature phase, then it can be inferred from the data we have obtained that it appears at a pressure $P \sim 40$ kbar and remains at higher pressures.

At $T = 4.2$ K the critical current density of a low-temperature phase is $j_{cl} = 10$ A/cm^2 and is greater than 500 A/cm^2 for the high-temperature phase and that of the high-temperature phase is greater than 500 A/cm^2, in fair agreement with the published data.[3] Variation of pressure seemed to have no effect on the critical current which appeared to remain constant.

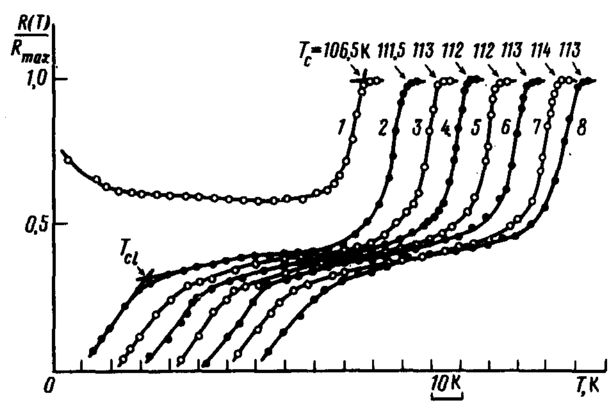

FIG. 2. Curves for the superconducting transitions of a $Tl_2Ba_2Ca_2Cu_3O_x$ sample, measured after increasing the pressure P, kbar: *1*—23; *2*—67; *3*—103; *4*—129; *5*—136; *6*—151; *7*—172; *8*—191. For clarity, the origin of the temperature scale is shifted by 10 K for each curve. R_{max} is the resistance of the sample at the beginning of the transition.

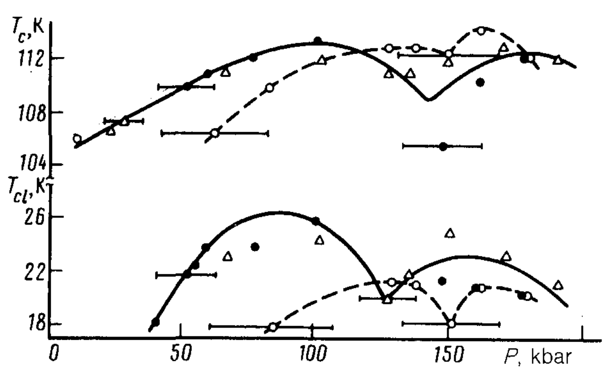

FIG. 3. T_c and T_{cl} vs the pressure. The solid curve corresponds to an increase in the pressure and the dashed curve corresponds to a decrease in the pressure. The filled and open circles give the data for a sample upon increasing and then lowering the pressure *P*. The triangles give data for another sample upon increasing the pressure.

The superconducting transition temperature of the low-temperature phase (T_{cl}) and of the high-temperature phase (T_c) was determined from the point at which the linear segments of the superconducting-transition curves crossed the lines which approximate the $R(T)$ dependence before the onset of the superconducting transition. The values of T_c are shown by the arrows in Fig. 2. The behavior of the critical temperature under pressure has several peculiarities (Fig. 3). The T_c-vs-P curve of the high-T_c phase of the $Tl_2Ba_2Ca_2Cu_3O_x$ samples is nonmonotonic in nature. Upon application of pressure in the pressure range up to 70 kbar, T_c increases linearly at the rate $dT_c/dP = 0.12$ K/kbar. This value of the derivative is in order-of-magnitude agreement with the value $dT_c/dP = 0.2$ K/kbar, obtained in the study of the ceramic samples of Tl–Ba–Ca–Cu–O at hydrostatic pressures in 8 kbar (Ref. 2). Upon further increase in the pressure, T_c reaches a maximum value, falls off, goes through a minimum in the pressure interval 130–150 kbar, and then increases again. The inverse curve plotted when the pressure is reduced (the dashed curve) is generally similar in nature. The minimum on the $T_c(P)$ curve may stem from the structural transition.

The specific behavior of the low-temperature phase is not only the appearance of superconductivity at a pressure of about 40 kbar but also an appreciably more rapid increase in T_c in the initial pressure interval 40–60 kbar. The higher value of dT_{cl}/dP of the low-temperature phase, which is near the insulator-metal transition, in comparison with that of the derivative dT_c/dP of the high-temperature phase, is consistent with the correlation between T_c and dT_c/dP determined previously for $YBa_2Cu_3O_{7-y}$ samples.[4] This effect could conceivably be the result of the diminishing influence of the localization of the carriers, in a manner similar to that in amorphous semiconductors.[5]

The shape of the $T_{cl}(P)$ curve resembles the corresponding $T_c(P)$ curve, and its characteristic features lie in approximately the same pressure range. This surprising circumstance seems to suggest that there is an intimate relationship between the high-temperature phase and the low-temperature phase.

An unambiguous interpretation of the data obtained by us requires x-ray structural analysis under pressure.

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Translated by S. J. Amoretty