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Pressure Effect on the Superconducting Transition Temperature of La-Sr-Cu-O System

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Effect of pressure on the superconducting transition temperature of La-Sr-Cu-O system has been studied up to 5.9 kbar with the use of a conventional clamp cell method. The transition temperature T_c where the resistivity vanishes increases linearly in response to the applied pressure p within the observed range, namely $dT_c/dp=0.2$ K/kbar, and the onset temperature of the superconductivity seems to increase more sensitively with the pressure.

Very recent discovery of the superconductivity in La-Ba-Cu-O quarternary compounds with very high transition temperature[1] has strongly stimulated the extensive studies in this field. The observation of Meissner effect has been carried out by Bednorz et al.,[2] by the group of the University of Tokyo,[3,4] and by Sato et al.,[5] and it has been found that almost complete Meissner effect is observable for a single phase compound with K_2NiF_4 type structure.[5] A variety of chemical compositions and preparation conditions have been examined for the La-M-Cu-O (M=Ba, Sr and/or Ca) system and it has been realized that the transition temperature of superconductivity depends on not only the chemical compositions but also the sintering conditions in a sensitive way.[5,14] The highest onset transition temperature T_{ci} and the zero resistivity temperature T_{cf} observed so far for the La-Sr-Cu-O system by the present authors´ group are 43.0 K and 36.5 K at ambient pressure, respectively. Single crystals have also been prepared[5] and the results of the detailed studies of the single crystals will be reported elsewhere.

Effect of pressure on the superconducting transition temperature T_c has been studied for various superconductors.[6] T_c of conventional metals usually decreases with increasing pressure. Ternary graphite intercalation compounds, such as C_8KHg and C_8RbHg, also show negative coefficient of T_c with pressure.[7] In case of $BaPb_{1-x}Bi_xO_3$, a maximum of T_c was observed at 4 kbar.[8] $(BEDT\text{-}TTF)_2I_3$, an organic superconductor, which has essentially two dimensional character, is known to undergo anomalous pressure dependence around 1 kbar.[9] Black phosphorus with layered structure exhibits a remarkable pressure effect in a very high pressure region.[10]

In this letter, we report the experimental results on the pressure dependence of T_c of the novel high temperature superconductor (La-Sr-Cu-O) system. The structural framework of these compounds is characterized by CuO_6 octahedra which form a layered perovskite structure with La and M (M=Ba, Sr, and Ca) atoms between the layers[6] as shown in Fig. 1. Due to this two dimensional-like structure, the conductivity deduced from the superconducting critical magnetic field H_{c2} has a quite large anisotropy[11] and it may be promising for the present low dimensional superconductor to have rather strong pressure dependence.

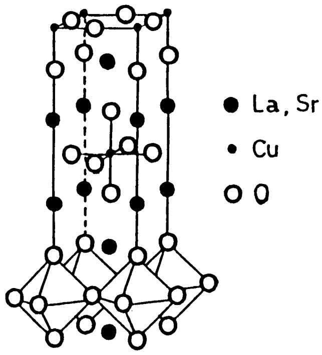

Fig.1. Perspective view of the structure of $(La_{1-x}Sr_x)_2CuO_{4-\delta}$.

We have studied a specimen prepared from La_2O_3, CuO and SrO by sintering at 1150° C. The chemical formula is described as $(La_{1-x}Sr_x)_2CuO_{4-\delta}$ (x=0.075 and δ is undetermined). T_{cf} for this specimen was 34.8 K at ambient pressure. Pressure was applied with the use of a so-called clamp cell made of hardened Be-Cu alloy. The sample was set in the space of a teflon capsule which was filled with silicone oil as the pressure transmitting medium. The pressure at low temperatures was calibrated by a manganin wire pressure gauge under the similar condition. With an assumption that the resistance change of the manganin wire due to pressure at liquid nitrogen temperature is equal to that at room temperature, the pressures at low temperatures were deduced from the net changes of the resistance at liquid nitrogen temperature.[7] Change of the pressures at temperatures lower than nitrogen temperature is negligible.

In the resistivity measurements, temperatures were measured with AuFe-Chromel thermocouple glued tightly by Apiezon N grease on the outside surface of the clamp cell and calibrated at the boiling points of liquid helium and liquid nitrogen. Cooling and heating were carried out so slowly as to assure the thermal equilibrium between the sample and thermocouple. In every case, the data in

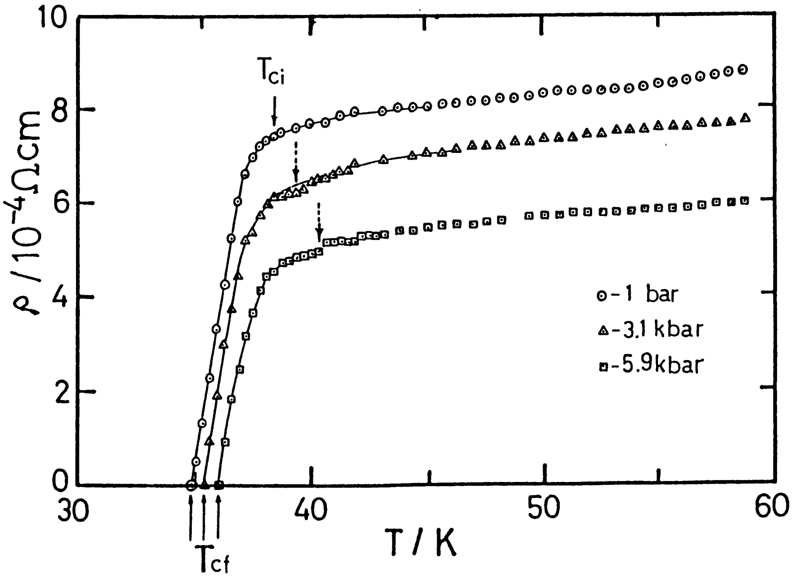

Fig.2. The temperature dependence of the resistivity of $(La_{0.925}Sr_{0.075})_2CuO_{4-\delta}$ under each indicated pressure.

Fig. 2 were taken in the heating process because of its higher reliability.

Figure 2 shows the temperature dependence of the resistivities under the indicated pressures. The values of T_{cf} clearly increase with increasing pressure, which are 34.8 K, 35.4 K, and 36.0 K at 1 bar, 3.1 kbar and 5.9 kbar, respectively. The increase of T_{ci} due to the pressure is larger than that of T_{cf}, namely 38.4 K, 39.4 K, and 40.3 K, respectively (arrowed points in the figure).

The pressure dependences of T_{cf} and the resistivity, ρ, at 58.8 K are plotted in Fig.3. Almost linear relation for both quantities with respect to the pressure was obtained in the present pressure region and the pressure coefficients are $dT_{cf}/dp=0.2$ K/kbar and $d\rho/dp=-4.7\times10^{-5}\,\Omega$cm/kbar, respectively. In this respect, application of pressure may be a prosperous way to realize higher superconducting transition temperatures.

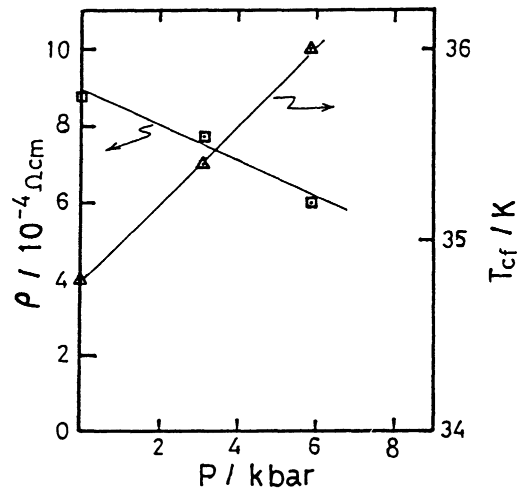

Fig.3. The pressure dependence of the T_{cf} and the resistivity at 58.8 K of $(La_{0.925}Sr_{0.075})_2CuO_{4-\delta}$.

The most plausible explanation of the observed pressure effect could be as follows: Taking into account of the facts that the conductivity increases with increasing pressure and the conduction takes place dominantly in the basal plane of the octahedra[11] (Fig.1), we can conclude that the distance between copper and oxygen atoms in the basal plane becomes shorter under pressure. As Fukuyama and Hasegawa pointed out in their explanation of the variation of T_c with the strontium concentration,[12] the electron-phonon coupling seems to increase with the decrease of the copper-oxygen distance, and accordingly T_c increases under pressure.

Although further detailed studies have to be carried out to explain the observed pressure effect more clearly, we think the present results may give a certain key to understanding the origin of the extraordinary high temperature superconductivity of the present system.

In conclusion, we have observed the pressure dependence of T_c for $(La_{0.925}Sr_{0.075})_2\,CuO_{4-\delta}$ up to 5.9 kbar and the pressure coefficient, dT_{cf}/dp, is 0.2 K/kbar. T_{ci} seems to be more sensitive to the pressure. We have discussed the origin of the present pressure effect very briefly.

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Note added. Quite recently Chu et al. reported the pressure effect on the superconductivity of La-Ba-Cu-O system.[13] Our present specimen is La-Sr-Cu-O system, of which superconducting transition takes place more sharply at higher temperatures. Our sample is a single phase compound of better homogeneity and possibly a bulk superconductor. We have discussed the origin of the pressure effect on T_c more clearly in this letter.

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