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ELECTRICAL PROPERTIES OF HIGH T_c SUPERCONDUCTORS UNDER HIGH PRESSURES

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ELECTRICAL PROPERTIES OF HIGH T_c SUPERCONDUCTORS UNDER HIGH PRESSURES

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Pressure has played a significant role in the recent developments of high transition temperature (T_c) superconductors. Chu and coworkers[1,2] found very early on that the T_c in LaBaCuO compounds increased with pressure with a rather large coefficient of dT_c/dP of 9 K/GPa. These results led Chu and coworkers to substitute Ba with Sr[1] and later replace La with Y.[3] In both cases they found that T_c increased as a result of the substitution. The large pressure coefficients of T_c in these materials also posed a stringent test of any theories attempting to explain the superconductivity in these materials. Here we report electrical resistance measurements in these new superconductors at pressures up to 16 GPa.

Our measurements were performed on single-phase but polycrystalline samples of $La_{1.85}Ba_{0.15}CuO_4$, $La_{1.85}Sr_{0.15}CuO_4$ and $YBa_3Cu_4O_{7.5}$. The samples were typically small fragments of about 200 microns across obtained by crushing larger pellets which have been characterized by x-ray, resistivity and magnetic susceptibility measurements at ambient pressure. Quasi-hydrostatic pressure was applied with a diamond anvil high pressure cell. The technique for loading the sample into the cell

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for electrical measurements have been described elsewhere.[4] The sample was surrounded by $CaSO_4$ powder as the pressure medium and the pressure was determined by the standard ruby fluorescence technique.[4] Diamond anvils of three different sizes have been utilized to cover these three pressure ranges: 0-5 GPa, 2-10 GPa and 3-20 GPa. The resistance of the sample was determined by a quasi-four-probe technique via two loops of copper wires.[4] Electrical contact between the copper wire and the sample was achieved by pressure. This contacting procedure was probably responsible for the residual resistance found in some of our samples below T_c. Since this residual resistance was independent of pressure it did not affect our accuracy in determining T_c.

Figure 1(a) shows the room temperature pressure dependence of the resistance R in $La_{1.85}Sr_{0.15}CuO_4$ and $YBa_3Cu_4O_{7.5}$. In case of LaSrCuO we found very little change in R with pressure until about 7 GPa. At about 7 GPa R started to decrease rapidly with pressure and at the same time the superconducting transition in the R vs T curve started to disappear. Such sudden change in R and the disappearance of the superconducting transition can be explained by pressure induced phase transitions. Although x-ray diffraction studies in the LaSrCuO compounds observed no phase transition up to 20 GPa,[5] the possiblility of an electronic phase transitions could not be ruled out. In YBaCuO R showed a similar decrease at around 4 GPa. In this case R decreased by about two orders of magnitude between 4 and 6 GPa which can only be accounted for by a phase transition. In addition R showed another smaller abrupt decrease around 9 GPa. When the pressure was released from 16 GPa we found that the resistance remained unchanged at a relatively low value indicating that the sample has been permanently altered, possibly due to conversion into a low resistance metastable phase.

Figure 1(b) shows the pressure dependence of the superconducting transition temperature T_c in LaBaCuO and LaSrCuO. We have defined T_c as the temperature corresponding to the mid-point of the resistance drop associated with the superconducting transition. Earlier experiments have shown rapid increases in T_c with pressure up to only 2 GPa.[1,6-8] Below 2 GPa we found that T_c increased with an average rate of about 2.5 K/GPa in LaSrCuO. Between 2 and 4 GPa this rate decreased to less than 1 K/GPa. Between 4 and 6 GPa T_c remained almost constant at the maximum value of ~46.3 K. The results in LaBaCuO is qualitatively similar to LaSrCuO with T_c showing a tendency to saturate at higher pressures. Qualitatively the pressure dependence of T_c in LaSrCuO is very similar to that of La_3S_4 reported by Filing et al.[9] In the latter case it has been shown that the initial increase in T_c with pressure was due to increase in the density-of-states in the Fermi level induced by pressure. The subsequent decrease in T_c at higher pressure was due to decrease in the electron-phonon interaction as the phonons were hardened by pressure. Since the mechanisms responsible for superconductivity in the high T_c materials are still unclear, it would be premature to interpret our results with conventional theory based on electron-phonon interactions.

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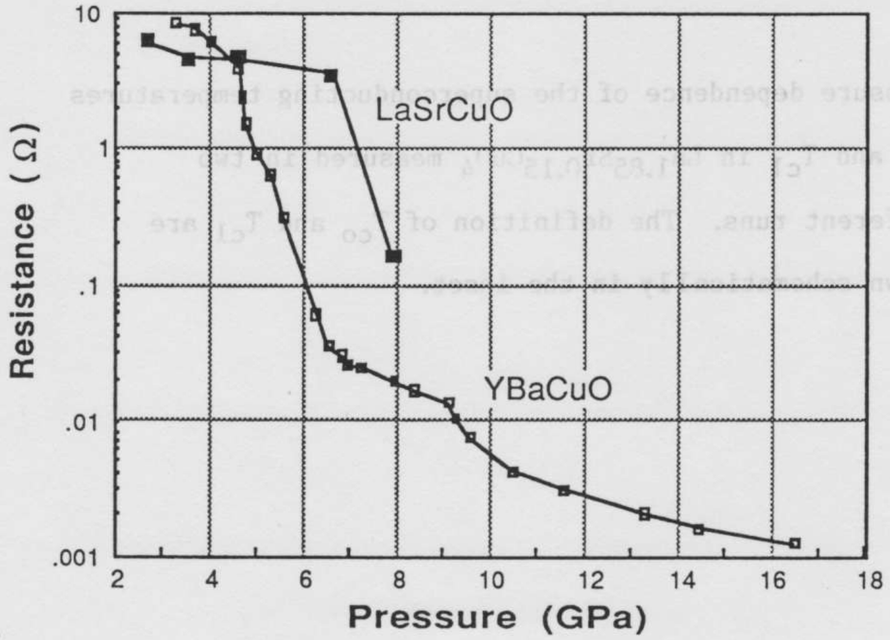
FIGURE CAPTION

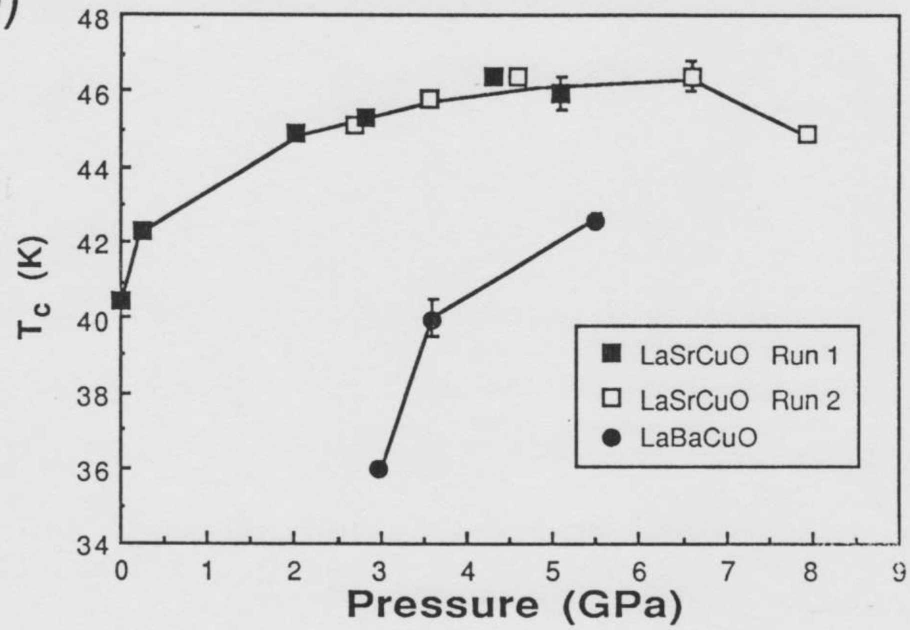
Fig. 1 Pressure dependence of the superconducting temperatures T_{co} and T_{c1} in $La_{1.85}Sr_{0.15}CuO_4$ measured in two different runs. The definition of T_{co} and T_{c1} are shown schematically in the inset.

a)



10
1
.1
.01
.001
Resistance (Ω)
LaSrCuO
YBaCuO
2
4
6
8
10
12
14
16
18
Pressure (GPa)

b)



48
46
44
42
40
38
36
34
Tc (K)
LaSrCuO Run 1
LaSrCuO Run 2
LaBaCuO
0
1
2
3
4
5
6
7
8
9
Pressure (GPa)