A STATUS REPORT ON THE BERKELEY RESEARCH ON HIGH T_c SUPERCONDUCTORS

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ABSTRACT

A brief review of recent Berkeley results on high temperature superconducting oxides is presented.

INTRODUCTION

The discovery of superconductivity above 30K by Bednorz and Müller [1] in La-Ba-Cu-O stimulated considerable research on this system at Berkeley as well as elsewhere. We explored other materials simultaneously and discovered superconductivity in the Y-Ba-Cu-O system independently of but subsequent to the discovery by Wu et al.[2] Our report [3] also described high temperature fluctuations in resistivity around 234K which were suggestive of superconducting filaments in this system. We have attempted to stabilize the high temperature effects with only partial success.

Here we report on: search for isotope effect; resistivity and transport studies; infrared and tunneling measurements of the superconducting gap; measurements of elastic properties; some theoretical explorations; and some further studies of high temperature resistivity anomalies.

SEARCH FOR ISOTOPE EFFECT

In conventional (BCS) superconductors, the importance of electron-phonon coupling is usually well-demonstrated by an isotope effect where $T_c \propto M^{-\alpha}$ with M the ion mass and $\alpha \approx 1/2$. In the high T_c oxides, the oxygen breathing mode is thought to be important in the superconductivity. We have thus searched for an isotope effect in $YBa_2Cu_3O_{7-\delta}$ by replacing ^{16}O with ^{18}O. Resistivity and magnetic susceptibility measurements indicate no isotope shift, that is, $\alpha = 0 \pm .027$ when approximately 90% of the ^{16}O is replaced by ^{18}O [4]. A two square-well model puts limits on the interaction parameters λ^* and μ^* (i.e., $\mu^* \approx \lambda^*/2$).

RESISTIVITY AND TRANSPORT

Reports of superconductivity usually include resistivity versus temperature curves with drops to zero resistivity at T_c. The zero is determined by the sensitivity of the equipment used, and typical upper bounds on the resistivity are 10^{-8} Ω cm. In the present study, a new limit of $\rho < 3 \times 10^{-17}$ Ω cm is established.[5] The measurement which is done at 4.2K consists of a supercurrent in a ring of $La_{1.8}Sr_{0.15}CuO_4$. A SQUID mangetometer is used to measure the flux entering the ring. By establishing a lower limit on the lifetime of the shielding, the present upper bound on ρ is determined. Skin depth effects are neglected, hence this bound is a conservative estimate.

Using the same composition superconducting oxide ($La_{1.85}Sr_{0.15}CuO_4$), electrical resistivity, Hall effect, and thermoelectric power (TEP) measurements were made [6] between 4.2K and 300K. The transition temperature T_c of the sample is 38K.

Resistivity measurements are typical of those reported earlier for these oxides with the characteristic drop to zero at T_c. The Hall coefficient R_H and TEP also drop to zero at T_c. However, measurements of these properties above T_c give some anomalous effects. The essential conclusions are that the carriers are holes with a concentration of 6.0×10^{21} cm^{-3}. There is evidence for unusual phonon-drag effects and inhomogeneous superconductivity in the vicinity of T_c.

Using resistivity measurements,[7] we have also explored T_c for different Y-Ba-Cu-O stoichiometries. The highest superconducting transition temperature we observe is in $YBa_4Cu_5O_y$ with T_{co} = 102K, T_c (midpoint) = 98K, and $T_{cf}(R=0)$ = 97K.

STUDIES OF THE SUPERCONDUCTING ENERGY GAP

A measure of strong coupling in superconductors is the ratio involving the superconducting gap and T_c, $2\Delta/K_BT_c$. The standard weak coupling value using the BCS theory is approximately 3.5. Strong coupled superconductors such as Pb give values larger than 4. Hence, it was expected that the superconducting oxides would have large ratios. At present, the results are ambiguous.

Using the $La_{1.85}Sr_{0.15}CuO_4$ samples discussed above, the infrared studies done at Berkeley [8] gave values of 2.4 for the ratio. Similar results have been reported by other groups [9,10]. The measurements were done in the frequency range 15 to 400 cm^{-1}. The temperature dependence of the gap was also measured and shown to be consistent with the BCS functional form.

In contrast to the infrared results, tunneling studies [11] of $YBa_2Cu_3O_{7-\delta}$ at 4.2K and 77K indicate that the ratio $2\Delta k_BT_c$ = 3.9 at T = 0. Again, the temperature dependence of the gap is consistent with BCS theory.

Since the samples used were polycrystalline, possible anisotropies in the gap are not measured. The point contact tunneling was achieved using a copper tip to form the normal side of the superconductor-insulator-normal tunnel junction. Using a niobium tunnel tip, preliminary superconductor-insulator-superconductor measurements were made at 4.2K. These measurements clearly indicate Josephson tunneling.

ELASTIC PROPERTIES

The Young's modulus Y and internal friction δ of $La_{2-x}Sr_xCuO_4$ were measured [12] for x = 0.15 and x = 0.30. For the x = 0.15 samples, anomalies in Y and δ at T_c = 40K are preceded by a dramatic decrease in Y. This is indicative of a soft phonon mode beginning near 200K. In contrast, for x = 0.30 the softening is absent. The softening is also absent in $YBa_2Cu_3O_{7-\delta}$ [13]. The elastic anomalies observed are similar to those found in the high temperature A-15 superconductors.

In $La_{1.85}Sr_{0.15}CuO_4$, the magnitude of the anomaly in Y is of order $\Delta Y/Y = 10^{-3}$ at T_c. Using thermodynamic arguments, this result can be related to a discontinuity in the specific heat of order 4mJ/Kcm^3 which should be experimentally accessible. Application of a magnetic field reduces the width of the anomaly in the Young's modulus.

SOME THEORETICAL STUDIES

Calculations are in progress to determine the feasibility of ascribing the high values of T_c to the standard electron-phonon BCS mechanism. An evaluation of T_c as a function of the electron-phonon parameter λ and the Debye temperature is done by solving the Eliashberg equations. The results suggest that for moderate values of λ, T_c's in the range of 100K are possible.

In contrast, a consideration of non-phonon mechanisms is also in progress. For example, we find that the demon model in the form proposed by Ihm, Cohen, and Tuan [14] gives T_c's in the 100K range for parameters consistent with the electronic structure of the superconducting copper oxides. These results are preliminary. The implications of a zero oxygen isotope effect is also under study.

HIGH TEMPERATURE ANOMALIES

Since the original report of resistance anomalies at 234K,[3] we have found similar structure in a variety of samples. The existence of these anomalies appears to depend on sample composition as well as the method of preparation. We are not able to reproduce them at will even in the same sample suggesting that in the measuring process superconducting links are broken.

Many other studies of the superconducting oxides are being done at Berkeley. The present report describes only a fraction of the activity.

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