c-axis thermal expansion of the $Tl_2Ba_2CaCu_2O_x$ superconductor

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The low-temperature *c*-axis thermal expansion of a thin-film sample of the superconducting material $Tl_2Ba_2CaCu_2O_x$ was measured to 10 K. Based on standard ac resistance measurements, the material exhibits a detectable drop at 110 K and zero resistance at 78 K. Careful x-ray measurements between 10 and 300 K reveal a uniform, monotonic *c*-axis expansion of about 0.4%, similar to what has been previously found for $La_{1.9}Ba_{0.1}CuO_4$ and $YBa_2Cu_3O_7$. Although anomalous *c*-axis thermal expansion has been recently reported in $YBa_2Cu_3O_{7-\delta}$, a careful search in the vicinity of T_c failed to reveal anything unusual in this material.

I. INTRODUCTION

In the absence of a clear theoretical explanation of superconductivity in the new class of high-T_c, ceramic superconductors, a wealth of research is underway to provide extensive experimental data. Recently, Srinivasan *et al.*[1] reported an anomalous variation in the length of the *c* axis of $YBa_2Cu_3O_{7-\delta}$ ($\delta=0.01$–0.15) through the superconducting transition. Although the origin of this anomaly is not understood, Srinivasan *et al.*[1] argue that it is consistent with other anomalous behavior found in $YBa_2Cu_3O_{7-\delta}$, viz., in the nuclear quadrupole resonance frequencies as reported by Riesemeier *et al.*,[2] in positron-annihilation lifetimes as reported by Ming-Kang Teng *et al.*,[3] and in sound velocity measurements as reported by Srinivasan, Ramachandran, Seshadri, and Ananda Ramdass.[4] Given the similarity in the structures of all the newer higher-T_c materials, i.e., they are all distorted perovskites with alternating metal and copper oxide layers, the experiments described in this work were undertaken to search for a possible similar anomaly in $Tl_2Ba_2CaCu_2O_x$.

II. EXPERIMENTAL PROCEDURES

Thin films of $Tl_2Ba_2CaCu_2O_x$ were prepared by evaporating a bulk sample of same composition in vacuum with an electron beam. The reactants were deposited on a polished (100) face of an MgO single crystal maintained at 300 °C. The films were then annealed in air at 840 °C. Complete details of the preparation procedures are given elsewhere.[5]

The presence of superconductivity was confirmed by standard low-frequency, four-terminal ac techniques with pressure contacts forming the electrodes and a current of approximately 5 μA. A small, but detectable drop in the resistance was observed at 110 K and a zero resistance at 78 K. The structure of the material is consistent with that reported by Zandbergen *et al.*[6] for $Bi_2Ba_2CaCu_2O_x$.

Due to the layered nature of these structures, upon deposition, the metal oxide planes tend to align themselves with the polished (100) surface of the single-crystal MgO substrate. This was confirmed by an x-ray-diffractometer scan made with the film normal coincident with the diffraction vector; only (00*l*) reflections were observed in the spectrum. Independently centering the MgO (200) and (400) and the superconductor (00*l*) reflections on an automated diffractometer showed the two principal reciprocal-lattice vectors to be coincident to within 0.06°. Because of this configuration, it was not possible to make precision measurements of (*hk*0) reflections from the thin film. Thus, the thermal expansion of the other axes could not be determined. However, the anomalous behavior found in $YBa_2Cu_3O_{7-\delta}$ was restricted to the *c* axis.

For purposes of measuring the *c*-axis thermal expansion, the sample was mounted with thermally conducting grease on the cold stage of a Helitran cryogenic refrigerator. This refrigerator system is coupled to a computer controlled x-ray diffractometer in a manner similar to that previously described.[7] A calibrated Si-diode thermometer is also bonded to the low-temperature block, and coarse temperature control is achieved by regulating the flow rate of He fluid from a remote storage Dewar. Fine control is accomplished with an electrical heater and feed-

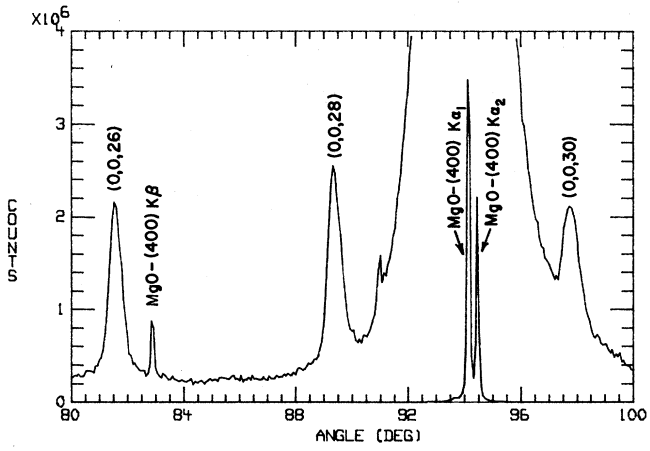

FIG. 1. X-ray-diffraction spectrum showing the three (00*l*) peaks ($l=$ 26, 28, and 30) of $Tl_2Ba_2CaCu_2O_x$ and the MgO (400) peaks as excited by the Cu $K\beta$ radiation at 82.89°, by the Cu $K\alpha_1$ radiation at 94.14°, and by the Cu $K\alpha_2$ radiation at 94.53°. The ordinate scale is for the MgO (400) $K\alpha$ peaks; the ordinate scale is reduced by 10^3 for the second plotting of the same spectrum.

back circuit using either a Pt or Ge sensor, depending on the temperature range. The measured temperatures are estimated to be accurate and stable to within ± 0.5 K.

The sample was illuminated with radiation from a Cu x-ray tube and the scattered radiation measured with a NaI(Tl) detector through a graphite monochromator. Data were collected at fixed temperatures in a step-scanning mode over the range from 80° to 100° in 2θ. In this region, the three (00l) peaks ($l = 26$, 28, and 30) are recorded. Also recorded within this angular range is the MgO (400) peak as excited by the Cu $K\beta$ radiation at 82.89°, the Cu $K\alpha_1$ radiation at 94.14°, and the Cu $K\alpha_2$ radiation at 94.53°. As may be seen in Fig. 1, the intensity of the MgO $K\alpha$ peaks is 3 orders-of-magnitude greater than that of the other peaks. The MgO $K\beta$ peak is discriminated against by the graphite monochromator, but nevertheless, it is observable. The presence of these MgO peaks provide a convenient calibrant. A correction for small displacements in the sample, which may occur during thermal cycling, was made by using the known thermal expansion of MgO.[8]

III. RESULTS AND DISCUSSION

Although the c-axis temperature dependence can be determined from any of the three measured $Tl_2Ba_2CaCu_2O_x$ (00l) reflections, only the (0,0,28) data were used because they exhibited the least scatter. The fractional change in the c axis is plotted in Fig. 2. For purposes of comparison, similar data obtained earlier from a bulk sample of superconducting $La_{1.9}Ba_{0.1}CuO_4$ are plotted on the same figure.[9] The solid curve in the figure is based on measurements on $YBa_2Cu_3O_{7-\delta}$ taken from the work of Horn *et al.*[10] Clearly, within the combined experimental error, as reflected by the scatter in the data, the c-axis thermal expansivities of each of these superconductors are equivalent.

The data fail to reveal any unusual behavior in the c-axis thermal expansion. It is further noted that the size of the c-axis expansion anomaly seen by Srinivasan *et al.*[1] is well within the detection limits of these measurements. Between 82 and 102 K, Srinivasan *et al.*[1] find a discontinuous change in the c-axis length in excess of 3.5%, almost ten times greater than the thermal expansion seen here. Srinivasan *et al.*[1] have noted that others have not observed this anomalous behavior and suggest that different annealing treatments may be a cause for the contradictory results. In conclusion, we find no evidence of anomalous behavior in the c-axis thermal expansion of $Tl_2Ba_2CaCu_2O_x$ and the linear thermal expansivity in this direction amounts to about 0.4% for each of the high-T_c superconductors, $La_{1.9}Ba_{0.1}CuO_4$, $YBa_2Cu_3O_7$, and $Tl_2Ba_2CaCu_2O_x$.

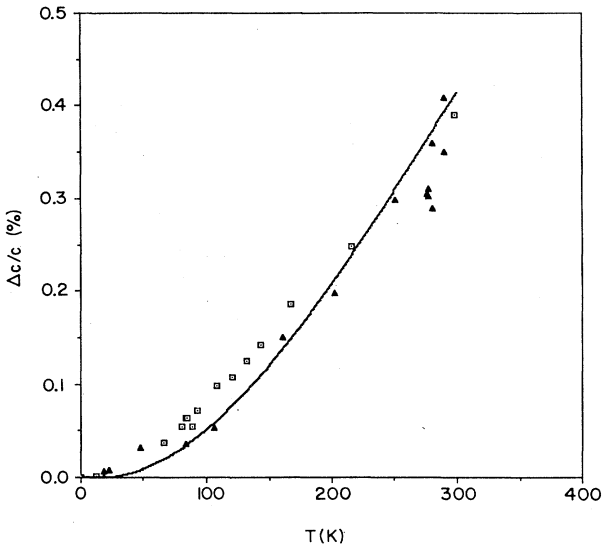

FIG. 2. Fractional change in the c-axis length as a function of temperature for $Tl_2Ba_2CaCu_2O_x$ (squares), for $La_{1.9}Ba_{0.1}CuO_4$ (triangles) from Ref. 9, and for $YBa_2Cu_3O_7$ (solid curve) from Ref. 10.

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