Anisotropy of the Resistivity in the $a$-$b$ Plane of a Superconducting YBa$_2$Cu$_3$O$_{7-\delta}$ Single Crystal

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We have measured the in-plane longitudinal resistivities $\rho_a$ and $\rho_b$ as functions of temperature and magnetic field. The measurements were all made on the same detwinned single crystal of YBa$_2$Cu$_3$O$_{7-\delta}$ (YBCO). Defining $T_c$ to be at the onset of resistance, it is the same for $\rho_a$ and $\rho_b$ in a magnetic field ranging from 0 to 3.5 T. In zero field, $T_c = 93.4$ K, so the oxygen doping of the crystal was approximately optimal. In the mixed state, the anisotropy ratio of the resistivities ($\rho_a/\rho_b$) decreases with decreasing $T$ or $H$, and the chain conductivity ($\sigma_\delta - \sigma_a$) is smaller than the plane conductivity ($\sigma_a$). Both $\sigma_a$ and $\sigma_\delta$ increase with decreasing temperature, and so does ($\sigma_\delta - \sigma_a$).

KEY WORDS: YBa$_2$Cu$_3$O$_{7-\delta}$; single crystal; resistivity; anisotropy.

1. INTRODUCTION

A great deal of effort has been expended to study high-$T_c$ superconductors in the mixed state (i.e., in a penetrating magnetic field). The sign reversal of the Hall resistivity is one of the novel phenomena that have attracted attention. Dorsey et al. [1] and Kopnin et al. [2] have suggested analyzing the Hall effect data in terms of the Hall conductivity rather than the Hall resistivity. The study on the Hall conductivity requires knowledge of the resistivities $\rho_a$ and $\rho_b$. This usually requires a measurement of $\rho_a$ or $\rho_b$ and knowledge of the anisotropy ratio $\rho_a/\rho_b$. In this paper we report on this ratio in the mixed state, with all the data obtained on a single sample.

A high-quality crystal is essential for this anisotropy study. Even though the quality of YBCO single crystals has been steadily improving, there are still large variations from laboratory to laboratory. We define $T_c$ as the temperature of onset of resistivity. Different crystals, even if they are made in the same batch, often have different values of $T_c$ and resistivity $\rho(T, H)$, precluding one from using two different crystals to look accurately at the anisotropy ratio $\rho_a/\rho_b$. Therefore, a direct comparison between $\rho_a(T, H)$ and $\rho_b(T, H)$ should be made, using data obtained on the same crystal.

2. EXPERIMENT AND RESULTS

A single crystal of YBa$_2$Cu$_3$O$_{7-\delta}$ was grown in an yttria-stabilized zirconia crucible by using a flux method [3]. The as-grown crystal was oxygenated at 500°C for 2 weeks in flowing O$_2$. A diamagnetic transition temperature of 92.8 K with a transition width (10–90%) of 0.25 K was measured with a Quantum Design 1-Tesla SQUID (superconducting quantum interference device) magnetometer.

We used the same sample to measure the resistivities along the $a$- and $b$-axes. It was 40 $\mu$m thick, and was cleaved to a rectangular shape ($0.7 \times 0.4$ mm$^2 \times 40$ $\mu$m) and detwinned at 450°C to produce the desirable orientations. The details of the detwinning process are described elsewhere [4]. Contacts for attaching gold wires were made by evaporating gold onto the crystal and heating it at 500°C for...
6 hours in flowing O₂. Gold diffuses less than 0.2 μm into the sample during this process [5]. All of the contact resistances were less than 1 Ω. The T_c of the crystal was unchanged after detwinning and annealing it in flowing O₂ to relieve possible induced strains from the detwinning. The longitudinal resistivity was measured with a four-terminal geometry at a frequency of 37.8 Hz and a current of 1 mA flowing parallel to the longer edge (parallel to the b-axis). After the resistivity measurement along the b-axis was completed, the orientation of the Cu–O chains in the sample was changed by applying uniaxial pressure on the shorter edge at 450°C. The sample was then annealed in the same way, and the resistivity was measured with current flowing along the a-axis. The contacts for the gold wires were unaltered throughout all the measurements.

Figure 1 shows the resistivity along a-axis (ρ_a) and b-axis (ρ_b) vs. T for our optimally oxygenated crystal of YBa₂Cu₃O₇₋δ in zero magnetic field near T_c. The zero-resistance transition temperature is the same along the a- and b-axis; T_c = 93.4 K. The resistive transition width (10–90%) from ρ_a is 0.15 K. Note that the temperature resolution is 10 mK. The resistivity ρ_a(T, H) measured with H parallel to the c-axis is shown in Fig. 2. The transition to the resistive state is abrupt. The transition width is less than 0.25 K below 3 T.

The resistivity ratio ρ_a/ρ_b vs. T at H=0 above T_c is shown in Fig. 3. The values for T>95 K range from 1.9 to 2.1, similar to ones reported by Friedmann et al. [6]. Figure 4 shows the resistivity ratio ρ_a/ρ_b vs. T for several values of the applied magnetic field with H || c-axis. The ratio ρ_a/ρ_b is reduced to the range 1.2–1.8 as T decreases below T_c. This result is consistent with [7], where Harris et al. used two untwinned YBCO crystals (one for ρ_a and the other for ρ_b) with values of T_c that were different by 0.3 K. The difference between the T_c values of their two crystals makes it difficult to assess the significance of their ρ_a/ρ_b