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Anisotropic Characteristics of In-plane Aligned a-axis $YBa_2Cu_3O_{7-\delta}$ Thin Films

C. W. Luo, M. H. Chen, C. C. Chiu, K. H. Wu, J. Y. Juang, T. M. Uen, J.-Y. Lin*, and Y. S. Gou

Department of Electrophysics, National Chiao Tung University, Hsinchu 300, Taiwan ROC
** Institute of physics, National Chiao Tung university, Hsinchu 300, Taiwan ROC*

Highly in-plane aligned a-axis oriented $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films with unprecedented transition temperature ($T_c \sim 91.3$ K) have been deposited on (100) $LaSrGaO_4$ substrates using a continuously grown $PrBa_2Cu_3O_{7-\delta}$ (PBCO) template layer by pulsed laser. The anisotropies between b- and c-axis were investigated by transport measurements and atomic force microscopy (AFM). Although, the onset T_c's along b- and c-axis appeared approximately the same, a significant filing was observed in the resistive transition along c-axis. The temperature-dependent of the tailing effect, however, cannot be explained by thermally activated phase-slippage (TAPS) commonly encountered in grain-boundary weak links.

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1. Introduction

The cuprate superconductors exhibit strong anisotropic features due to their layered structure. These anisotropies are reflected in virtually every aspect of superconducting and normal properties. For instance, the electric transport measurement [1], polarization-dependent x-ray absorption spectroscopy [2], and femtosecond time-resolved spectroscopy [3] have all revealed important features of anisotropies relevant to underlying superconductivity mechanism. Although, in these respects single crystalline samples have played important roles, it is sometime easier to work with epitaxial thin films for investigations involving restrictions along certain crystal orientations. For this purpose, a pure a-axis oriented (100) YBCO film with

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good in-plane epitaxy is desirable. In this paper, we report novel process of obtaining a fully in-plane alignment a-axis oriented YBCO thin films with unprecedented superconducting transition temperature $T_c \sim 91.3$ K. Since in these films a- and b-axis are completely distinguishable, the anisotropic transport properties are easily measured to discern the conducting mechanism along b- and c-axis.

2. Experimental

It has been suggested that by using a PBCO buffer layer can facilitate the a-axis nucleation [4] on K_2NiF_4 type (100) $LaSrGaO_4$ (LSGO) substrates [5]. However, due to the low substrate temperature required to form a-axis PBCO layer, the YBCO films obtained were all suffered from significant degradation in Tc. Here we present a modified deposition process, using a KrF excimer laser with a wavelength of 248nm. The energy density and the repetition rate of the laser pulse were 3 J/cm^2 and 5 Hz, respectively. In our process, first, a 50-nm-thick PBCO template was deposited on LSGO substrate at 660 ^{o}C and in 0.1 Torr O_2. Next, without stopping PBCO deposition, the substrate temperature was raised at a rate of 20 ^{o}C/min until it reached 780 ^{o}C. The target was, then, switched to YBCO and set the oxygen pressure at 0.28 Torr immediately. Finally, a 300-nm-thick YBCO was deposited on the PBCO template. After the deposition, the film was cooled in 600 Torr of oxygen to room temperature with heater off.

The films were examined by x-ray diffraction (XRD) to delineate their crystalline orientations. For transport measurements, two bridges perpendicular to each other with 175 μm length and 10 μm width were photolithographically etched on *a single thin film.* The bridges are oriented parallel to the edges of the substrate crystal, one along [001] while the other along [010], both with standard four-probe configuration. The oxygen content of the a-axis YBCO film was manipulated by an encapsulated bulk annealing method [6]. This method is capable of controlling the oxygen content of the a-axis YBCO films precisely and reversibly.

3. Results and discussion

As shown in Fig. 1, the θ- 2θ XRD displays only the (h00) diffraction peaks. The rocking curve of (100) peak shows a full width-at-half-maximum < 0.41 ^{o}, indicating the high degree of crystallinity of these films. The in-plane ordering between b- and c-axis on the surface of LSGO substrate was examined by ϕ-scans using the (102) reflection of YBCO. As

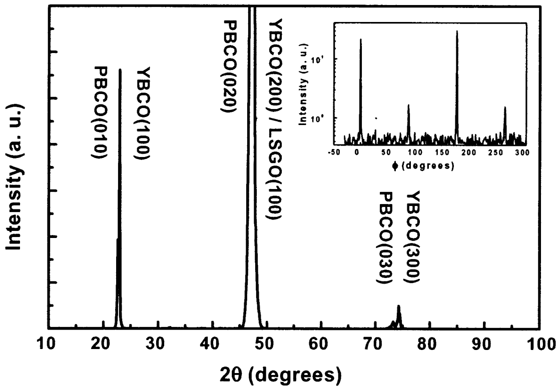

Fig. 1. X-ray diffraction pattern for the YBCO/PBCO thin films deposited on the (100) $LaSrGaO_4$ substrates. The inset shows the ϕ-scan of an in-plane aligned a-axis YBCO film.

shown in the inset of Fig. 1, the degree of in-plane alignment estimated by the ratio between the relative intensities at $\phi = 90^{o}$ and $\phi = 180^{o}$, $I_{\phi = 90^{o}} / \left(I_{\phi = 90^{o}} + I_{\phi = 180^{o}} \right)$, larger than 95 %.

We also used an atomic force microscope (AFM) to examine the surface quality of the a-axis films. Fig. 2 shows the AFM image of the sample. As is evident from the micrograph, oval grains, with 100 $\sim$ 400 nm in length and 40 $\sim$ 160 nm in width, are well-aligned along the same direction. The line-scan profile revealed the peak to valley height difference of about 18 nm and the root-mean-square (RMS) surface roughness was $\sim$ 6 nm over the 2 μm $\times$ 2 μm scanned area.

It is noted that by an encapsulated bulk annealing method [6], the onset of transition temperature, T_c (R = 0), along b-axis can be raised from 88.7 K (as-deposited) to 91.3 K. Additionally, the transition width, ΔT_c (90 % to 10 % value), reduces from 1.1 K to 0.72 K. The results indicate that the as-deposited film may have been slightly oxygen-deficient. Fig. 3 shows the temperature dependence of resistivity curves along b- (ρ_b) and c-axis (ρ_c) of a-axis oriented YBCO thin films.

In the normal state, ρ_c and ρ_b decrease with decreasing temperature, showing a metal-like behavior. The resistive (ρ_c / ρ_b) anisotropy at 100 K is $\sim$ 11.4, and decreases with increasing temperature. Furthermore, ρ_b sharply drops at about 92.2 K to zero. Along c-axis, however, unlike a

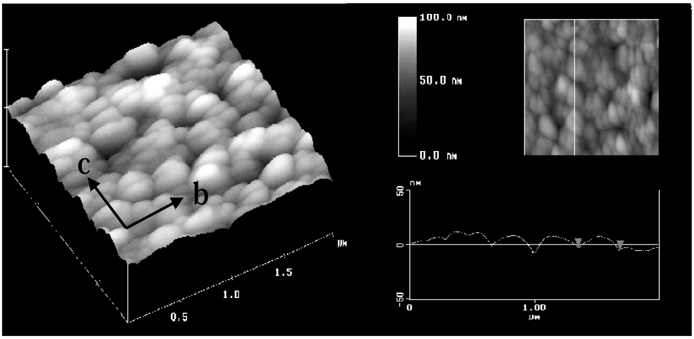

Fig. 2. AFM image of the surface of an a-axis YBCO thin film.

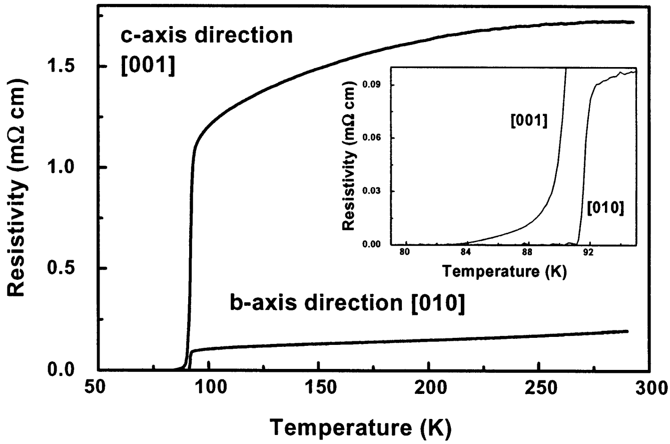

Fig. 3. Resistivity versus temperature curves along b- and c-axis of an a-axis YBCO thin film. The inset shows part of the transition curves on an enlarged scale.

pronounced semiconductor-like temperature dependence commonly reported in single crystals, it shows only a direction from linear dependence with much larger resistivity. This, nonetheless, is similar to previous thin film results reported by Fuchs et al. [7]. In addition, a transition tail appeared below 90 K and persisted down to zero resistance at 80.6 K. This tail, however, cannot be fitted satisfactorily by the thermally activated phase slippage (TAPS) commonly contributed to grain-boundary weal links [8,9]. Investigations are currently underway in attempt to delineate these peculiar behaviors.

4. Summary

A high T_c (= 91.3 K) and nearly full in-plane alignment, > 95 %, a-axis oriented YBCO thin films have been grown on (100) LSGO substrates using PBCO templates prepared by a novel deposition process. These samples unique opportunities for investigating physical property anisotropies along major crystalline axes in addition to the transport anisotropy reported here [10].

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