Enhanced Film Quality of Y-Ba-Cu-O by Using Eu-Cu-O Buffer Layer on Sr-Ti-O Substrates

W.H. Tang and J. Gao

***Abstract*—Eu_2CuO_4 (ECO) has been used as a buffer layer for growing of $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films on $SrTiO_3$ (STO) (100) substrates. The epitaxy, crystallinity and surface of YBCO thin films have been significantly improved by using ECO buffer layer as investigated by x-ray diffraction, rocking curves, scanning electron microscope, surface step profiler and x-ray small angle reflection. The best value of the full width at half maximum of the YBCO (005) peak can be greatly reduced down to less than 0.1 degree. The scanning electron microscope photos indicate very smooth surface for the YBCO thin films. The average roughness is less than 5 nm over a wide scanning region of 2000 μm. The results of x-ray small angle reflection indicate a very clear and flat interface between YBCO and ECO layers. Our results suggest that ECO should be a good barrier candidate for fabricating high-T_c superconductor junctions.**

***Index Terms*—High Temperature Superconductors, Materials Processing, Sputtering, Superconducting Films**

I. INTRODUCTION

Compared with those 123-phase compounds, the 214-phase compounds show higher stability in crystal structure and have no structural phase transition below the deposition temperature or when the oxygen content changes. moreover, the thin films of 214-phase compounds always show excellent crystallinity and very smooth surface. By using $La_{1.85}Sr_{0.15}CuO_4$ (LSCO) with 214-T phase structure as a buffer layer, the growth of $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films on yttrium stabilized ZrO_2 (YSZ) substrates can change from island growth mode to the layer-by-layer one.[1] Nd_2CuO_4 (NCO) with 214-T' phase structure had also been proved to significantly improve the initial epitaxy of YBCO thin films. [2] The in-plane lattice parameter of LSCO is $a \sim 3.79$ Å, and that of NCO is $a \sim 3.94$ Å. A compressive or an expansive stress could be arisen when YBCO thin film is grown on the LSCO or NCO buffer layer. The in-plane lattice parameter of Eu_2CuO_4 (ECO) ($a \sim 3.89$ Å) just lies between those of LSCO and NCO. Thus, we can compare the stress effects coming from different buffer layers on the superconducting properties of YBCO thin films. The lattice mismatch between ECO and YBCO is the smallest among the above mentioned three 214 compounds. So the ECO could be a better buffer layer for the growth of high-T_c superconducting thin films. Besides, ECO shows a semiconducting behavior, with high value of resistivity at low temperature, it could also be a good barrier for fabricating high-T_c Josephson junctions with high I_cR_n value. In this work, ECO thin films have been grown on STO (100) substrates by magnetron rf sputtering method. The films were investigated by x-ray diffraction, rocking curves and scanning electron microscope,etc.

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II. EXPERIMENTAL

YBCO thin films and ECO buffer layers were deposited on STO (100) substrates by an off-axis rf sputtering system [3]. The deposition temperature referred hereafter to as the substrate temperature T_s measured by a k-type thermocouple inserted into the stainless substrate heater. The substrate was stuck on the heater by silver paste. The substrate temperature was 730 ~ 750 °C. The deposition gas was a mixture of argon and oxygen with different pressure ratios ($P_{Ar}/P_{O2} \sim 3$-4). The YBCO thin film and ECO buffer layer were grown by using the same deposition conditions. The x-ray diffraction was performed on the Siemens D5000 x-ray diffractometer with CuKα radiation (λ=1.5405 Å). The crystallinities of YBCO and ECO thin films were examined by measuring their rocking curves of (005) and (006) diffraction peaks respectively. The surface of YBCO thin films was characterized by a Dektak3ST surface step profiler and a Cambridge 440 scanning electron microscope (SEM).

The temperature dependence of resistance was measured by a standard DC four-probe method using a closed-cycled cryogenerator. A platinum resistance thermometer was used to measure the temperature. The cooling rate was well controlled to be less than 1 K/min. A well-defined micro-bridge (50 μm in width, 100 μm in length) was patterned by using photolithography technique for determining the superconducting critical current of YBCO thin films. A 5 μV criterion was used to define the superconducting critical current I_c.

III. RESULTS AND DISCUSSIONS

Fig.1 shows the x-ray diffraction (XRD) pattern for one typical YBCO thin film with ECO buffer layer on STO (100) substrate. From the XRD pattern, only (00*l*) peaks for YBCO

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thin film and (*002l*) peaks for ECO buffer layer were observed. It is suggested that YBCO thin film and ECO buffer layer were grown along *c*-axis orientation. The insert of the Fig.1 shows the rocking curves of the (005) peak for YBCO thin film and the (006) peak for ECO buffer layer, respectively. Both rocking curves indicate very small values of the full width at half maximum (FWHM), smaller then 0.10 degree for both YBCO thin film and ECO buffer layer. Small FWHM values result from excellent crystallinities of YBCO thin film and ECO buffer layer. Fig. 2 shows the rocking curves for the YBCO thin films (a) without and (b) with ECO buffer layer. It is found that the FWHM value for the YBCO thin film with ECO buffer layer is generally smaller than that without ECO buffer layer, indicating that the use of ECO buffer layer can improve the crystallinity of YBCO thin films.

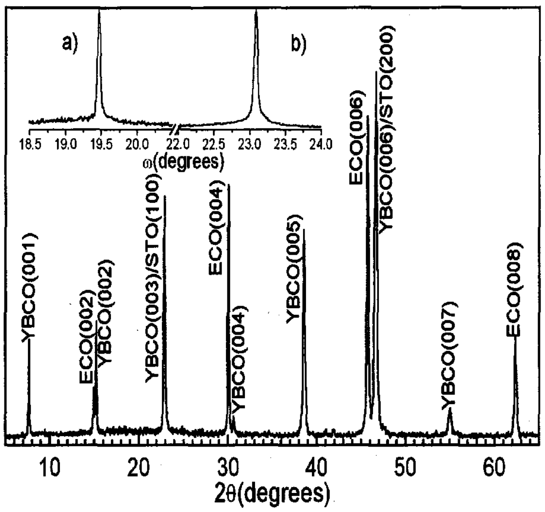

Fig. 1. Typical x-ray diffraction pattern for the YBCO thin film with ECO buffer on STO(100) substrate. The insert shows the rocking curves of (005) peak for YBCO thin film a) and (006) peak for ECO buffer layer b), respectively.

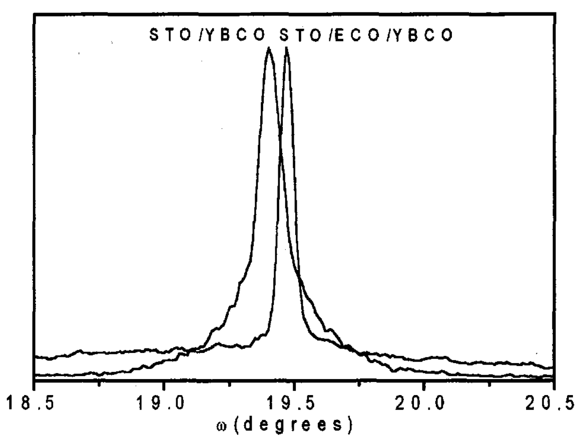

Fig. 2. The rocking curves for the YBCO thin films without and with ECO buffer layer.

The surface roughness and morphology of YBCO thin films was characterized by a surface step profiler and a scanning electron microscope. The vertical resolutions of the surface step profiler are 1Å/65kÅ, 10Å/655kÅ and 20Å/1310kÅ. Considering the flatness of the substrate, we first measured the average roughness of the YBCO thin film on the STO substrate for ten times at random places, and got a mean value of the average roughness for the YBCO thin film on the STO substrate, and then removed the YBCO thin film and ECO buffer layer from the STO substrate by acid etching and cleaned the substrate to get another mean value of the average roughness for the raw substrate. The difference of the mean values of the average roughnesses for the YBCO thin film on substrate and for the raw STO substrate was defined as the average roughness of the YBCO thin film. The average roughness of YBCO thin film over a wide scanning region of 2000 μm is less than 5 nm.

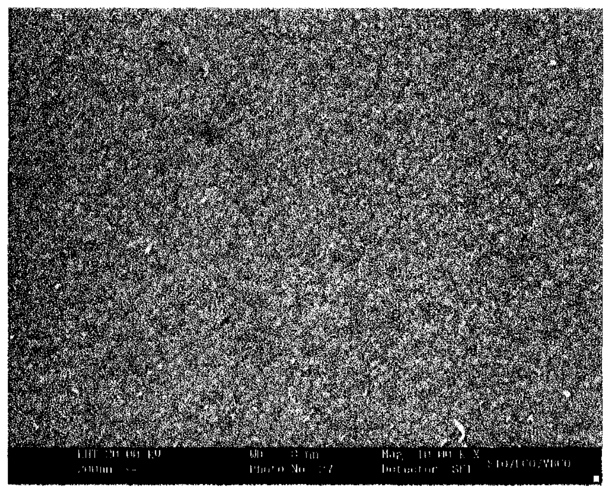

Fig. 3. The surface morphology SEM photo for the YBCO thin film with ECO buffer layer. The thickness of YBCO thin film is ~160 nm, and the thickness of ECO buffer layer is ~40 nm.

Fig.3 shows the surface morphology SEM photo for the YBCO thin film with ECO buffer layer. The photo shows very smooth surfaces. The use of ECO buffer layer could change the growth mode of YBCO thin film from island mode to layer-by-layer mode. The excellent surface of YBCO thin film with ECO buffer layer could be a result of layer-by-layer growth. Gao et al. reported that by using $La_{1.85}Sr_{0.15}CuO_4$ as a buffer layer the growth of YBCO thin film on YSZ substrates can change from an island growth mode to a layer-by-layer mode.[1]

We have studied three compounds with 214 phase structure, i.e. $La_{1.85}Sr_{0.15}CuO_4$,[2] Nd_2CuO_4[2] and Eu_2CuO_4 as buffer layers for the growth of YBCO thin films. All of them show good surface and crystallinity, and greatly improve the film quality of YBCO thin films. However, the currently used buffer layers of the doped 123-phase compounds, such as, Ca-doped $PrBa_2Cu_3O_y$ [4] and Nb-doped $YBa_2Cu_3O_y$ [5] often cause poor surface morphology and crystallinity. This is due to that the outgrowths are easy formed for the thin films of the 123-phase compounds. In general, a good buffer layer for growing high T_c superconducting thin films should have a stable crystal having good lattice matching with the superconducting material. The buffer layer will not react with the grown superconducting thin films and has no significant inter-diffusion. Also a good buffer layer should present a very smooth surface without outgrowths or other surface structures. Combined all above requirements, the 214-phase compounds could be a very good candidate buffer to improve the growing high T_c superconducting thin films on various substrates.

The interfaces of ECO/STO and YBCO/ECO were investigated by the x-ray small angle refection. Both interfaces of ECO/STO and YBCO/ECO are very sharp and flat. No interdiffusion layer was observed. The mean surface roughnesses for the ECO/STO and the YBCO/ECO interfaces are 3 Å and 9 Å, respectively. Detailed interface characterizations by the transmitting electron microscope and the x-ray small angle refection are under going currently.

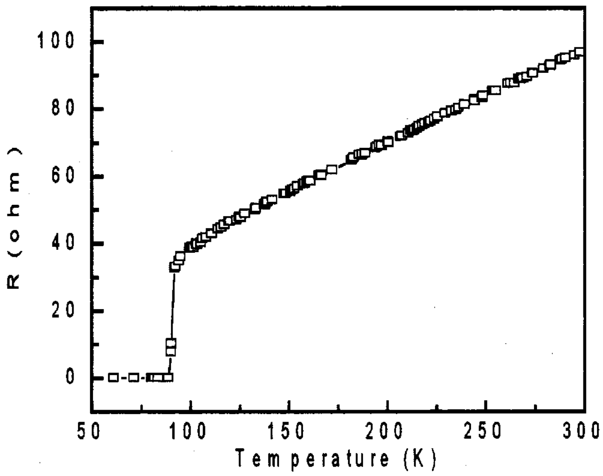

Fig. 4. Typical resistance curve against temperature for 100 nm YBCO thin film with 100 nm ECO buffer layer on STO substrate.

The superconducting properties of YBCO thin films are also improved by the ECO buffer layer. The YBCO thin films with the ECO buffer layers exhibit higher the zero resistance superconducting transition temperature T_{c0}, normally higher than 87 K. One typical resistance curve against the temperature for the YBCO thin film of 100 nm is shown in Fig.4.

The superconducting critical current density was measured across a bridge with a width of 50 μm. The critical current density at 77 K under zero field is 2~4x10^6 A/cm^2, which is similar to the reported value for YBCO thin films on STO substrates.

IV. CONCLUSION

Eu_2CuO_4 (ECO) has been used as a buffer layer for growing of $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films on $SrTiO_3$ STO(100) substrates. The epitaxy, crystallinity and surface of YBCO thin films have been significantly improved by using ECO buffer layer as shown by the results as investigated by x-ray diffraction, rocking curves, scanning electron microscope, surface step profiler and x-ray small angle reflection. The best value of the full width at half maximum of the YBCO (005) peak can be greatly reduced down to less than 0.1 degree. The average roughness is less than 5 nm in the region of 2000 μm. The results of x-ray small angle reflection indicate a very clear and flat interface between YBCO and ECO layers. Our results suggest that ECO should be a good barrier candidate for fabricating high-T_c superconductor junctions.

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