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# Effect of $Eu_2CuO_4$/Yttrium-stabilized $Z_rO_2$ buffer layers on $YB_2Cu_3O_{7-x}$ thin films grown on Si substrates

X.L. Li[a,*], J. Gao[b], H.Y. Wong[b], Z.H. Mai[a]

[a] *Institute of Physics, Chinese Academy of Sciences, Beijing 100080, PR China*
[b] *Department of Physics, The University of Hong Kong, Pokfulam Road, Hong Kong, PR China*

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**Abstract**

The microstructure and crystallinity of epitaxial $YB_2Cu_3O_{7-x}$ (YBCO) thin films grown on a silicon using a buffer of $Eu_2CuO_4$ (ECO)/Yttrium-stabilized $Z_rO_2$ (YSZ) were investigated by X-ray high-resolution diffraction, small angle reflection, and reciprocal space map, as well as atomic force microscopy. The results showed that YBCO films with a buffer of ECO/YSZ were well oriented in the [00L] direction perpendicular to the substrate surface. The rocking measurements for the YBCO films grown on ECO/YSZ buffered Si show a smaller value of the full widths at half maximum (~2.07°) in comparing with that of the YBCO with a single YSZ buffer (~4.48°). Moreover, the surface morphology of YBCO films with an ECO/YSZ buffer is significantly improved. The average size of grains on the surface was much smaller, indicating that growth of YBCO on Si with such a buffer of ECO/YSZ is highly epitaxial.


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*Keywords:* X-ray scattering; Superconducting material; YBCO; Buffer layer

## 1. Introduction

Silicon has been widely used in semiconductor electronic industry. Highly epitaxial $YB_2Cu_3O_{7-x}$ (YBCO) films grown on silicon with very smooth surface and interfaces are of importance for applications like superconductor/semiconductor hybrid devices, high-frequency devices, superconducting quantum interference devices, and superconducting antennas. Attempts to make YBCO thin films directly on Si were unsuccessful as the severe reaction and poor lattice matching take place between Si and YBCO [1,2]. To overcome these problems much effort has been made to search suitable buffer materials such as yttrium-stabilized $ZrO_2$ (YSZ) [3], MgO [4], $CeO_2$ [5], to block the interaction between YBCO film and Si substrate. Transition temperatures $T_c = 86$ to 88 K and critical current density of $2.2\times10^6$ $Acm^{-2}$ at 77 K have been achieved in YBCO films grown on Si with an YSZ buffer [3]. However, the epitaxy and surface morphology of these films are still poor.

In our previous work, we investigated microstructures of YBCO thin films grown on YSZ substrates with or without an $Eu_2CuO_4$ (ECO) buffer layer [6] and with a buffer of ECO/YSZ [7]. In this letter, we further report the effect of an ECO/YSZ buffer on the microstructures of YBCO films grown on silicon. The results show that the epitaxy and crystallinity of YBCO thin films are considerably enhanced by the ECO/YSZ buffer layer, demonstrating advantages of such a novel buffer structure.

## 2. Experimental details

The thin film samples were prepared by off-axis RF magnetron sputtering [8]. In brief, a sintered stoichiometric YBCO ceramic disc with a diameter of 50 mm and thickness of approximately 4 mm was used as the target. To fabricate

* Corresponding author.
*E-mail address:* bluelixl@163.com (X.L. Li).

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oxide films, a mixed gas of argon and oxygen with a pressure ratio $P_{Ar}/P_{O_2} \cong$ 3/1–4/1 was used as the sputter gas. The Si (001) single crystal wafer was used as substrate and mounted to the heater using silver glue. The deposition temperatures for YBCO, YSZ, ECO layers were approximately 740, 720, and 750 °C, respectively. After deposition, the grown films were annealed in-situ at 450 °C for about 20 min in oxygen at $10^{-5}$ Pa. To study the influence of the ECO/YSZ buffer on the quality of YBCO films, the results were compared with that obtained from YBCO films deposited directly on Si with or without a single buffer of YSZ. Three type of samples were studied: sample A, YBCO (160 nm)/Si; sample B, YBCO (160 nm)/YSZ (40 nm)/Si, and sample C, YBCO (160 nm)/ECO (40 nm)/YSZ (40 nm)/Si. The nominal thickness is estimated by counting the growth time (the thickness=growth rate × growth time).

The high-resolution X-ray diffraction, X-ray small angle reflection, and X-ray reciprocal space map were performed on a high-resolution X-ray diffractometer (Bruker D8 Advance) at room temperature with Cu–K$\alpha_1$ radiation. The beam size was $0.2 \times 1$ mm$^2$. The experimental data of reflectivity were simulated using a model described in Ref. [9]. The surface morphology and roughness were evaluated by atomic force microscopy (AFM) (NanoScope IIIa scanning probe microscope, DI Company, USA) in contact mode. The tips used were gold film coated $Si_3N_4$ tips with spring coefficient $k$=0.06–0.58 N/m and the pixel is 256 in each line.

## 3. Results and discussions

Fig. 1 shows the X-ray diffraction spectra of three samples. For the sample YBCO/Si, only a weak YBCO (005) peak appears except the substrate peaks, indicating a poor crystallinity of the YBCO layer deposited directly on a Si substrate. In contrast, for the samples YBCO/YSZ/Si and YBCO/ECO/YSZ/Si, only (00L) peaks of YBCO, YSZ and ECO sub-layers can be found. No reflection of other crystallographic orientation or secondary phases are visible, indicating that the YBCO, YSZ and ECO layers are well oriented with the [00L] direction perpendicular to the substrate surface. As well known, the full width at half maximum (FWHM) of rocking curves reflects the crystalline quality of films. Fig. 2 shows the rocking curves of the YBCO (005) peak for samples YBCO/YSZ/Si and YBCO/ECO/YSZ/Si. The rocking curve for the sample YBCO/Si is too broad to be drawn in the figure. From Fig. 2 the values of FWHM of the YBCO (005) peak for the samples YBCO/YSZ/Si and YBCO/ECO/YSZ/Si are ~4.48° and ~2.07°, respectively. It clearly demonstrates the enhancement in the epitaxy and crystallinity of the grown YBCO by using a buffer of ECO/YSZ on silicon. On the other hand, it seems that there might be a strong mosaic structure in the sub-layers as the FWHMs for all samples are rather broad (>2°).

The X-ray small angle reflection is sensitive to the electron density and interfacial roughness of the each layer in a multilayer structure. Thus it can provide a powerful and non-destructive tool to investigate microstructures of thin films. The information of the multilayer structure such as the thickness and the interface roughness can be obtained by fitting the experimental data using a certain structural refinement model [9]. Fig. 3 shows the X-ray small angle

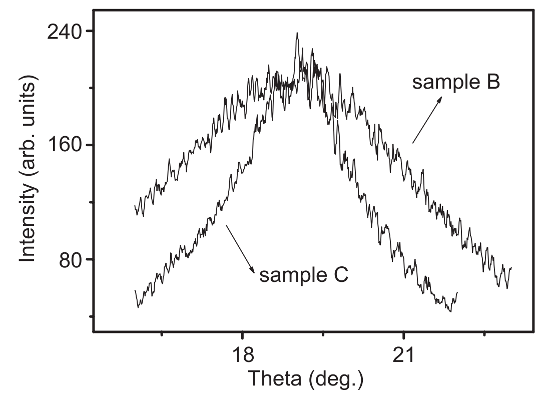


Fig. 2. Rocking curves of YBCO (005) diffraction peaks of the sample B (YBCO/YSZ/Si) and the sample C (YBCO/ECO/YSZ/Si).

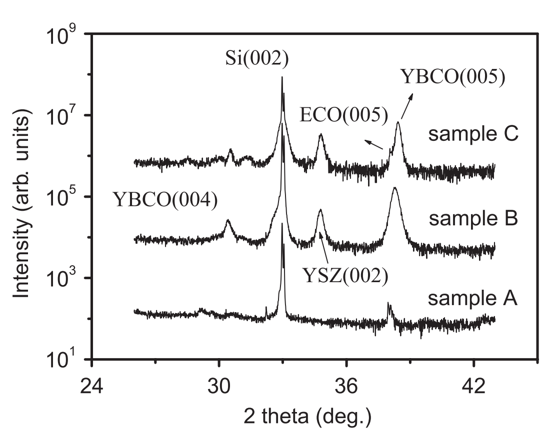


Fig. 1. *X-ray diffraction spectra* of the sample A (YBCO/Si), the sample B (YBCO/YSZ/Si) and the sample C (YBCO/ECO/YSZ/Si).

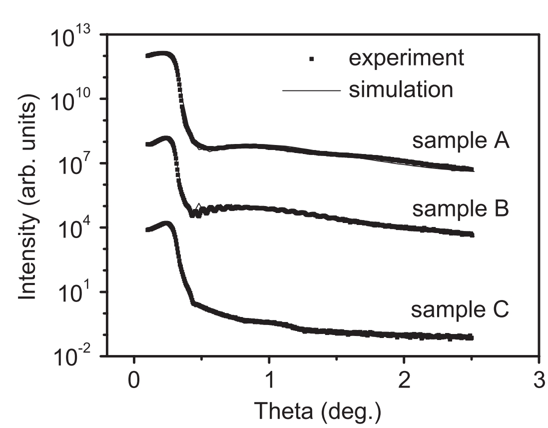


Fig. 3. X-ray reflectivity profiles of the sample A (YBCO/Si), the sample B (YBCO/YSZ/Si) and the sample C (YBCO/ECO/YSZ/Si).