

# OPTIMIZATION OF CeO<sub>2</sub> BUFFERS FOR HIGH-QUALITY YBCO FILMS

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## Introduction

YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7-y</sub> (YBCO) thin films are technologically important materials for the development of resistive fault current limiters [1], microwave devices [2] and power cables and motors [3]. Moreover, CeO<sub>2</sub> thin films are frequently employed as buffer layers for the growth of high-quality YBCO films on sapphire (Al<sub>2</sub>O<sub>3</sub>) and metal substrates, due to its chemical stability as an intermediate layer, and its good lattice matching with YBCO which allows the epitaxial growth of *c*-axis-oriented films. To obtain high-quality films for applications, we have conducted a comprehensive work on the development and optimization of CeO<sub>2</sub> buffers to obtain the best properties of YBCO films.

## Experimental

We used a large-area pulsed laser deposition (PLD) chamber in conjunction with a KrF excimer laser ( $\lambda = 248$  nm) operated at an energy density of  $\sim 1$  J/cm<sup>2</sup> on the target surface to deposit the films. All films were deposited using the same target-substrate distance of  $\sim 14$  cm and an oxygen pressure of 175 mTorr. The substrate temperature was fixed at 700°C for the growth of CeO<sub>2</sub>. After deposition, CeO<sub>2</sub> buffers were annealed *ex-situ* at 1050°C in O<sub>2</sub> atmosphere for varied annealing times (“dwell” time at 1, 10, 20, and 60 minutes) in a box furnace. Depending on the annealing condition, CeO<sub>2</sub> buffers can be modified from very porous (micron-sized pores) to extremely smooth surface interspersed with a high density of nanopores, and with varying degrees of RMS strain. To study the effect of the CeO<sub>2</sub> modification on YBCO films deposited by various methods, we investigated the properties of YBCO films deposited by PLD and trifluoroacetate (TFA)-assisted metalorganic deposition (MOD).

## Results and Discussion

High-temperature annealing (1050°C) has been found to significantly smoothen the very rough and

granular surfaces of the as-grown CeO<sub>2</sub> layers (surface roughness *rms*  $\sim 5$ – $10$  nm) to atomic flatness (*rms*  $\sim 0.5$  nm), refer to Fig. 1. A rather unique characteristic of the CeO<sub>2</sub> layers is the development of pores when subjected to prolonged high-temperature annealing. For very short annealing periods (10–20 minutes), the surface morphology becomes atomically flat, interspersed with a high density of ‘nanopores’ with sizes  $\sim 40$ – $100$  nm in diameter (Fig. 1(c)). Extending the annealing period to 60 minutes leads to a surface subtended with enlarged pores  $\sim 0.2$ – $0.5$   $\mu$ m in diameter (Fig. 1(d)). Compared to the YBCO thin films deposited by PLD on as-grown CeO<sub>2</sub>, those on annealed CeO<sub>2</sub> exhibited better homogeneity of  $J_c$

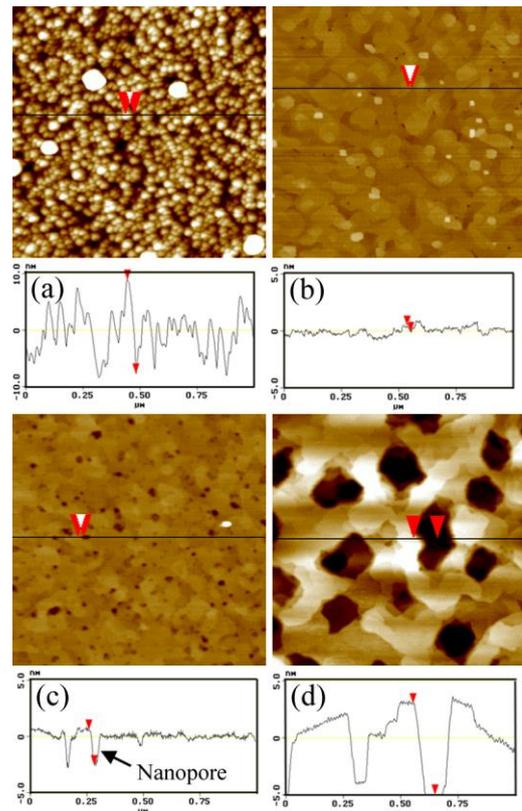


Fig. 1. AFM height images and corresponding line profiles of CeO<sub>2</sub> buffer layers. (a) as-grown; (b) annealed at 1050°C for 10 minutes; (c) annealed at 1050°C for 20 minutes; (d) annealed at 1050°C for 60 minutes, showing the resultant porous morphology. AFM image size = 1  $\mu$ m  $\times$  1  $\mu$ m.

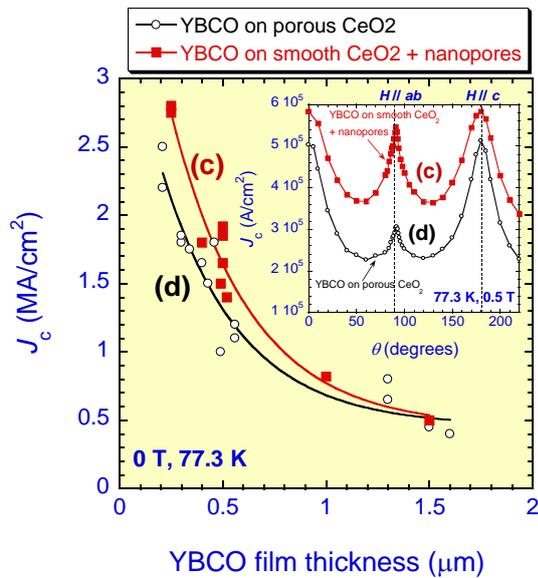


Fig. 2.  $J_c$  as a function of film thickness. In the plot, (c) and (d) refer to YBCO films deposited on porous  $\text{CeO}_2$  (refer to Fig. 1(d)), and smooth  $\text{CeO}_2$  containing a high density of nanopores (refer to Fig. 1(c)), respectively. Inset: angular dependence of  $J_c$  at  $H = 0.5$  T.

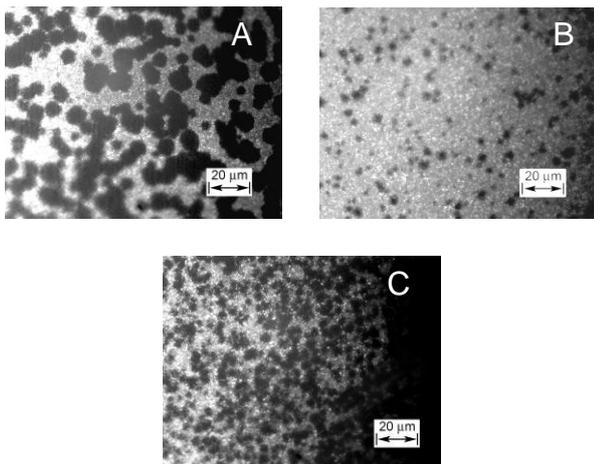
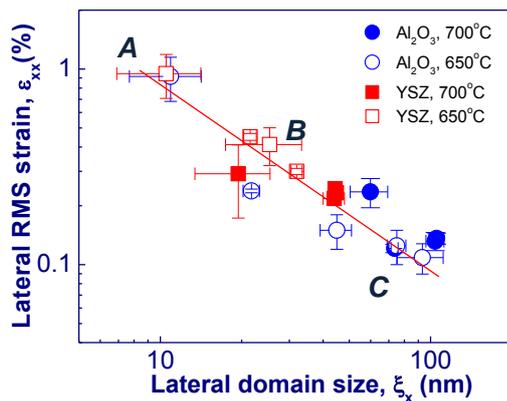


Fig. 3. Top plot: Relationship between lateral grain size and lateral RMS strain of 20 nm (001) ceria films deposited on (001) YSZ and r-cut sapphire. Bottom: optical micrographs of 1.2  $\mu\text{m}$  YBCO films quenched after 10% conversion at 0.6 nm/s YBCO growth rate on corresponding ceria buffers.

and lower porosity. Higher self-field and in-field  $J_c$  were obtained for YBCO thin films deposited on

$\text{CeO}_2$  having smooth surfaces interspersed with nanopores. Transmission electron microscopy (TEM) and atomic force microscopy (AFM) results indicated that the nanopores influence the creation of dislocations which contribute to  $c$ -axis-correlated pinning.

$\text{CeO}_2$  buffer morphology was found to influence the nucleation behavior of YBCO-MOD films. For comparison, some  $\text{CeO}_2$  buffers were also prepared on YSZ substrates. Buffers with grains smaller than 10 nm have very high RMS strain (as determined from x-ray reciprocal space mapping [4]); however such small grains are often terminated with (111) facets, thus are unsuitable for nucleation of  $c$ -axis oriented YBCO.  $\text{CeO}_2$  grain growth can be induced by either elevated growth temperature or by post-annealing. This explains the very low nuclei density in sample A (Fig. 3). Structure of YBCO layer at the early stages of the growth is shown to depend on structural properties of the ceria buffer, *i.e.*, lateral grain size and RMS strain. Only small-grained, strained ceria buffers are capable of nucleating well-ordered YBCO almost instantly (sample C in Fig. 3). This emphasizes the role of special nucleation sites—locations on the substrate that provide low-energy attachment for YBCO nuclei.

## Conclusion

High-temperature annealing is employed to study the effect of surface modification of  $\text{CeO}_2$  buffers on the properties of YBCO films. Enhanced flux pinning properties were obtained on YBCO-PLD films using annealed  $\text{CeO}_2$  surfaces containing a high density of nanopores. Furthermore, we have demonstrated that  $\text{CeO}_2$  buffers are excellent materials for studying the nucleation kinetics and performance of YBCO films prepared by MOD. The rate of YBCO nucleation and structure of the nuclei is influenced by the characteristics of the  $\text{CeO}_2$  buffer surface, such as lateral grain size and lateral RMS strain. Our results show that the best buffers exhibit high YBCO nucleation rates and produce YBCO nuclei with the least cation disorder.

## References

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