Effect of $BaHfO_3$ Concentration on the Microstructure of $YBa_2Cu_3O_{7-x}$ Thin Films

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1. Introduction

Non-superconducting inclusions in $YBa_2Cu_3O_{7-x}$ (YBCO) act as effective flux pinning centers that enhance the critical current density (J_c). It is well known that incorporating the perovskite-type compounds ($BaMO_3$, where M = Sn, Hf, or Zr) into YBCO leads to the spontaneous formation of nanorods, which improve J_c under magnetic fields aligned with the c-axis. While the amount of $BaMO_3$ added affects the microstructure and flux pinning properties, few studies have investigated how the BHO content influences the inhomogeneities in YBCO films, where J_c degradation tends to be suppressed. In this study, we examine the structural and morphological changes in YBCO films as a function of BHO content.

2. Experimental Methods

YBCO + 3% BHO and YBCO + 7% BHO films were deposited on $SrTiO_3$ (001) single-crystal substrates by pulsed laser deposition (PLD). The deposition was conducted at 900 °C under an oxygen partial pressure of 400 mTorr with a repetition rate of 5 Hz. Cross-sectional and plan-view samples were prepared using a focused ion beam (FIB) or ion milling. The samples were analyzed by transmission electron microscopy (TEM) and scanning transmission electron microscopy (STEM).

3. Results

Figure 1(a) shows the cross-sectional bright-field TEM image and selected-area electron diffraction pattern of the 3% BHO-added film. Nanorods exhibiting moiré fringes were observed growing continuously from the STO substrate to the film surface. In the electron diffraction pattern, in addition to YBCO Bragg reflections, reflections

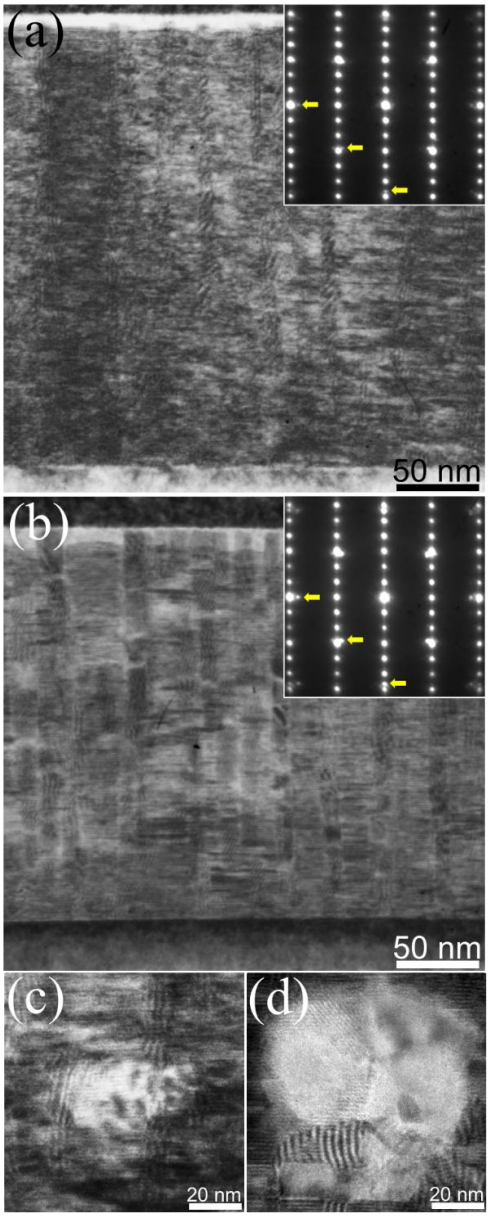

Figure 1. Cross-sectional bright-field TEM images and selected-area electron diffraction patterns of (a) 3% and (b) 7% BHO-added films. Cross-sectional bright-field images of precipitates present in the (c) 3% and (d) 7% BHO-added films.

due to BHO, indicated by arrows, were clearly observed. This suggests the incorporation of BHO nanorods in the YBCO films. As shown in Fig. 2(b), the formation of nanorods was also confirmed in the film with 7% BHO. However, these nanorods were larger in diameter and discontinuous compared to those in the film with 3% BHO. The diameter of the nanorods is larger at the surface than at the substrate. As a result of wide-area observations, both the 3% and 7% BHO-added films exhibited uniformly introduced nanorods as well as inhomogeneous structures identified as precipitates. Figures 1(c) and 1(d) show cross-sectional bright-field images near the precipitates observed in the 3% and 7% BHO-added films, respectively. The size of the precipitates showed dependence on the BHO content, measuring approximately 40 nm in the 3% BHO-added film and around 70 nm in the 7% BHO-added film.

Figure 2 shows HAADF-STEM images of plan-view samples of (a) 3% and (b) 7% BHO-added films. From wide-area observations using HAADF-STEM images, both samples exhibited regions with uniformly distributed BHO nanorods, as well as inhomogeneous structures indicated by circles. The size of these inhomogeneous structures showed dependence on the BHO content, measuring approximately 200 nm in the 3% BHO-added film and around 400 nm in the 7% BHO-added film. Moreover, the 7% BHO-added film exhibited a noticeably higher nanorod density compared to the 3% BHO-added film, further suggesting that the amount of nanorods introduced depends on the BHO content.

4. Conclusion

In the 3% BHO-added film, long and continuous nanorods were formed, whereas in the 7% BHO-added film, the nanorods were shorter and fragmented. The latter nanorods exhibited different diameters near the substrate and near the surface. In addition, inhomogeneous structures were observed in both samples in both cross-sectional and plan-view observations. Furthermore, the amount of nanorods introduced showed a dependence on the BHO content, and a significantly higher nanorod density was confirmed in the 7% BHO-added film compared to the 3% one.

Keywaords: $YBa_2Cu_3O_{7-x}$ (YBCO), $BaHfO_3$ (BHO) nanorods, transmission electron microscopy (TEM)

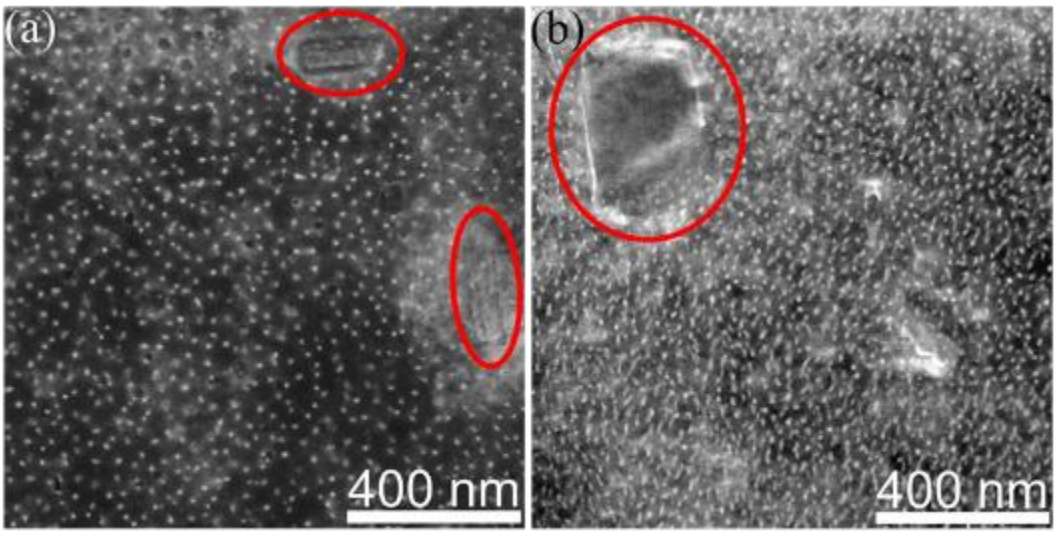

Figure 2. HAADF-STEM images of plan-view samples of (a) 3% and (b) 7% BHO-added films.