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Effects of YSZ Buffer Layer Surface Morphology on Superconducting Performance of YBCO films Deposited by Pulsed Laser Deposition on NiW Tapes

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Abstract. YSZ buffer layers and YBCO superconducting layers were grown on biaxially textured NiW tapes by a reel-to-reel pulsed laser deposition (PLD) technique. It was found that orientation and surface morphology of YSZ buffer layers were very sensitive to deposition parameters, especially to oxygen pressure and laser repetition rate. Relationships between microstructure, surface morphology of YSZ buffer layer and PLD deposition parameters were systematically studied using X-ray diffraction (XRD) and scanning electron microscopy (SEM). The effects of surface morphology of YSZ buffer layer on the superconducting performance of YBCO layer were investigated. As increasing oxygen pressure from 0.5 to 10 mTorr, the surface morphology of YSZ buffer layer became better first and then worse, however, it deteriorated with the increase of laser repetition rate. It was found that the surface morphology of YSZ buffer layer had great influence on the superconducting transport properties of YBCO layer. Under optimized experimental condition, high quality YBCO layer with critical current density J_c above 4×10^6 A/cm^2 was obtained at 77 K and self field.

1. Introduction

Second generation high temperature superconductors (2G-HTS) have attracted much interest worldwide due to its potential application prospects in the fields of transportation, power transmission, medical equipment, new energy, and so on. In the past years, great progress has been made in the fabrication of $REBa_2Cu_3O_{7-x}$ (REBCO) tapes with remarkable superconducting performance [1, 2]. Three main technical routes have been developed for the fabrication of REBCO tapes, including inclined substrate deposition (ISD), ion beam assisted deposition (IBAD), and rolling-assisted biaxially textured substrates (RABiTS). Among them, the RABiTS approach has been demonstrated to be one of the most promising routs for industrially producing HTS tapes that it is fast, cost-effective, and easier to control buffer layers growth.

So far, various oxide materials have been employed as a single buffer layer for REBCO coated conductors, for example, $La_2Zr_2O_7$, $LaMnO_3$, and so on [3, 4]. However, two kinds of multilayer buffer architectures of CeO_2/YSZ/CeO_2/Ni and CeO_2/YSZ/Y_2O_3/Ni are still the most stable and widely used buffer-layer architectures. It has been reported that the superconducting performance of YBCO layer was not only dependent on the pure (001) orientation of CeO_2 seed layer, but also very sensitive

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to its surface morphology [5]. In this paper, we fabricated a series of YSZ barrier layers on RABiTS tapes by PLD method under different oxygen pressures and laser repetition rates. Relationships between surface morphology of YSZ barrier layer and superconducting transport properties of YBCO layer were studied.

2. Experimental

The substrates used in this study were rolling assisted biaxially textured (RABiTS) Ni-5%W tapes with 10 mm width and 50 μm thickness from EVICO GmbH in Germany. RABiTS tapes were annealed in an atmosphere of forming gas (3%H_2 + 97%Ar) to prevent oxidation of the nickel substrate prior to deposition. Then CeO_2 seed layer, YSZ barrier layer, and CeO_2 cap layer were prepared on RABiTS tapes in a multi-target reel-to-reel pulsed laser deposition (PLD) system, which were reported in previous paper detailedly[6].

Ceramic YSZ target with desired composition of ZrO_2 doped with 8 mol% Y_2O_3 was used for ablation. Laser ablation was performed using a Lambda Physik LPX 220 KrF excimer laser with the wavelength and pulse duration of 248 nm and 20 ns. The incident angle of laser beam was 45°. The laser energy and substrate temperature were 280 mJ and 750 °C. The target-substrate distance and tape speed were 6.5 cm and 6 m/h. The oxygen pressure was varied from 0.5 mTorr to 10 mTorr. The laser repetitio n rate was varied from 80 Hz to 140 Hz.

After the deposition of buffer layers, the YBCO films with thickness of 400 nm were then fabricated on the buffer layers with different YSZ layers at 800 °C under a pure oxygen pressure of 200 mTorr. The laser energy of 350 mJ and laser repetition rate of 60 Hz was used. The YBCO films were quickly cooled to room temperature.

The orientation and texture of the YSZ and YBCO films were analyzed by a Bruker D8 Discover X-ray Diffractometer with a General Area Detector Diffraction System (GADDS), with Cu Kα radiation operated at 40 kV and 40 mA, including θ-2θ scan, in-plane ϕ-scan and out-of-plane ω-scan rocking curve measurements. The surface morphology of the films was determined by a high-resolution field emission scanning electron microscope (FESEM), FEI Sirion 200 with 5 kV accelerating voltage applied to the electron beam.

The critical current (I_c) values were measured at 77 K by the conventional DC four-probe method with the electric field criterion of 1μV/cm. The thickness of YBCO film was measured by a Bruker DektakXT stylus step-profilometer.

3. Results and discussion

Figure 1(a) shows the X-ray θ-2θ scans for YSZ films deposited at different oxygen pressures. All the YSZ films were deposited at the same laser repetition rate of 120 Hz. The diffraction peaks at 33.10° was attributed to the (002) planes of CeO_2 seed layer films. It was observed that all the YSZ films exhibited two diffraction peaks at 2θ equals to 29.78° and 34.74°, which were corresponding to (111) and (002) planes of YSZ cubic structures (JCPDS 30-1468), respectively. As the oxygen pressure increased from 0.5 mTorr to 10 mTorr, the intensity of (002) peak decreased sharply, by contrast, the intensity of (111) peak increased first and then decreased. The in-plane full width at half maximum (FWHM) values of (002) peak were 5.68°, 5.70°, 7.05°, and 7.41° for YSZ films deposited at oxygen pressure of 0.5, 1, 5, and 10 mTorr, respectively.

Figure 1(b) shows the X-ray diffraction θ-2θ scans for YSZ films deposited at different laser repetition rates. All the YSZ films were deposited at the same oxygen pressure of 0.1 mTorr. It can be seen that pure (002) oriented YSZ films were fabricated at the whole laser repetition rate range of 80 Hz to 140 Hz, and the intensity of (002) peak increased with the increase of laser repetition rate. Compared figure 1(a) with (b), it was found that the structure of YSZ was very sensitive to the oxygen pressure. At low oxygen pressure of 0.1 mTorr, the YSZ films had a pure (002) orientation. When the oxygen pressure was above 0.5 mTorr, the YSZ films had mixed (111) and (002) orientations.

Figure 1(c) shows a typical XRD pattern of 400 nm thick YBCO film deposited on the optimized YSZ buffer layer. In the XRD pattern, only (00*l*) peaks from YBCO film were observed, which indicated that the YBCO film had a pure c-axis orientation and high epitaxial quality. The in-plane FWHM value for YBCO (103) was 6.12°.

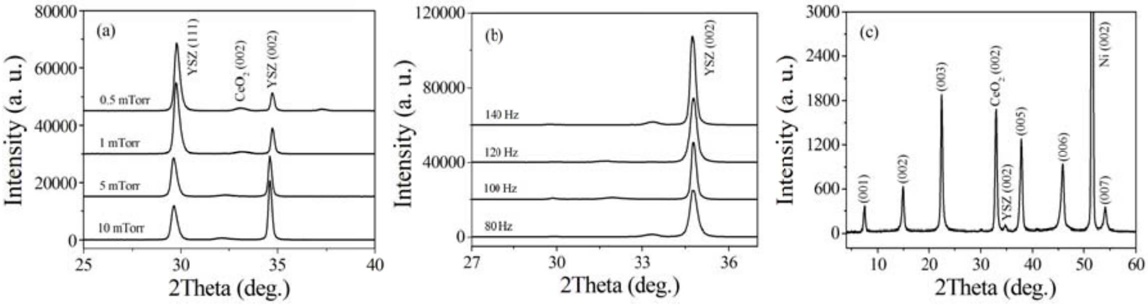

Figure 1. X-ray θ-2θ scans of YSZ films deposited at different (a) oxygen pressures and (b) laser repetition rates, and (c) YBCO film deposited on the optimized YSZ buffer layer.

Figure 2 exhibits SEM images of YSZ films deposited at different oxygen pressures. When the oxygen pressure was 0.5 mTorr, several particles (acicular and hill-and-valley-like structures), as well as cracks were formed on the film surface. The smoother and crack-free surface with little particles developed at 1 mTorr (figure 2b). However, as the oxygen pressure increased above 5 mTorr (figure 2c), rough surface with crack appeared again. Further increase of oxygen pressure to 10 mTorr, the number of particles increased greatly (figure 2d). The rough surface was probably due to the deposition of large ionic clusters. At high oxygen pressure, zirconium ions in the plasma gas can easily react with oxygen molecules because of reduced mean free path of gas particles, which could induce the increase of the number of large ionic clusters.

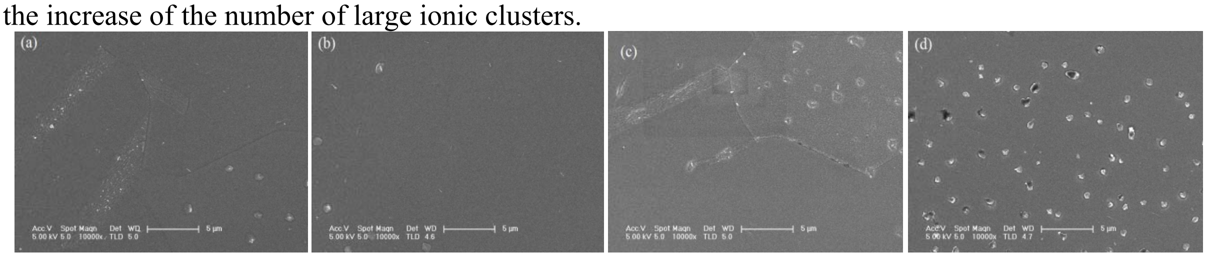

Figure 2. SEM images of YSZ films deposited at different oxygen pressures. (a) 0.5 mTorr, (b) 1 mTorr, (c) 5 mTorr, and (d) 10 mTorr.

Figure 3 exhibits SEM images of YSZ films deposited at different laser repetition rates. It can be seen that all the YSZ films were dense without cracks. However, particles appeared in all YSZ films. With increasing the laser repetition rate from 80 Hz to 140 Hz, the number of the particles increased, and large YSZ particles were easily formed along the Ni grain boundaries. These large particles generally resulted from splashing taking place during the PLD processing [7]. The rapid local heating of the target by the laser beam caused large particulates to splash onto the substrate.

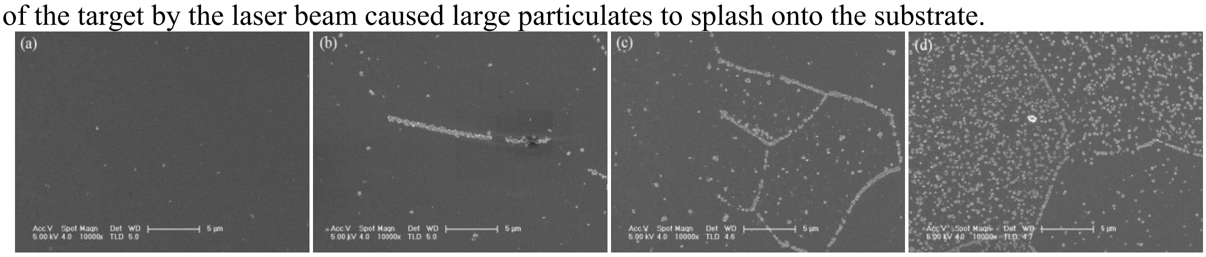

Figure 3. SEM images of YSZ films deposited at different laser repetition rates. (a) 80 Hz, (b) 100 Hz, (c) 120 Hz, and (d) 140 Hz.

YBCO films with thickness of 400 nm were deposited on different YSZ buffer layers under the optimized condition. The critical current (I_c) values of YBCO films were measured at 77 K and self-field by the conventional four-probe method. The critical current density (J_c) was calculated from the cross sectional area of the YBCO layer. I-V curves of the fabricated YBCO films were shown in figure 4. As shown in figure 4a, I_c values of 60 A/cm, 70 A/cm, 65 A/cm, and 36 A/cm were measured for YSZ films deposited at oxygen pressure of 0.5 mTorr, 1 mTorr , 5 mTorr, and 10 mTorr, respectively. As oxygen pressure increased from 0.5 mTorr to 1 mTorr, the J_c increased from 1.5×10^{-6} A/cm^2 to 1.75×10^{-6} A/cm^2. When oxygen pressure was above 5 mTorr , the J_c decreased to 9×10^{-5} A/cm^2 finally. With increasing the laser repetition rate of YSZ buffer layer from 80 Hz to 140 Hz, the I_c increased from 60 A/cm to 180 A/cm, and the corresponding J_c increased from 1.5×10^{-6} A/cm^2 to 4.5×10^{-6} A/cm^2. These results indicated that the superconducting transport properties of YBCO films were largely dependent on the surface morphology of YSZ buffer layers.

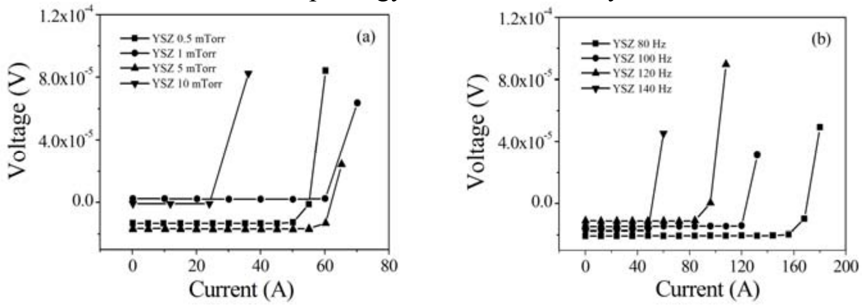

Figure 4. End-to-end I-V characteristics of the YBCO films deposited on YSZ buffer layers with different (a) oxygen pressures and (d) laser repetition rates.

4. Conclusions

In this work, we have investigated the influence of oxygen pressure and laser repetition rate on the structure and surface morphology of YSZ films deposited on RABiTS by PLD. We found that the orientation and in-plane texture of the YSZ films were very sensitive to the oxygen pressure. Pure (002) oriented YSZ films were obtained at 0.1 mTorr. The in-plane texture of YSZ films became better as the oxygen pressure decreased. It was found that the superconducting transport properties of YBCO films were dependent on not only structure but also surface morphology of YSZ buffer layer. As the surface morphology of YSZ buffer layer improved, the I_c and J_c of YBCO films increased. On the optimized YSZ buffer layer with pure (001) orientation and smooth surface, the YBCO film exhibited high c-axis oriented and excellent superconducting properties with J_c of 4.5×10^{-6} A/cm^2 under 77 K and self field.

5. Acknowledgements

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