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Effect of the thickness of CeO_2 buffer layer on the YBCO coated conductor

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Abstract-- **Three group samples with difference thickness of CeO_2 capping layer deposited by PLD were studied. Among them, one group CeO_2 films were deposited on stainless steel tape coated with IBAD-YSZ and CeO_2 buffer layer (CeO_2/IBAD-YSZ/SS); other two groups of $CeO_2/YSZ/Y_2O_3$ multi-layer were deposited on NiW substrates for fabrication of YBCO coated conductor through RABiTS approach. The pulsed laser deposition (PLD) and DC magnetron sputtering were employed to deposit these buffer layers. On the top of buffer layer, YBCO film was deposited by PLD. The effect of thickness of CeO_2 film on the texture of CeO_2 film and critical current density (J_c) of YBCO film were analyzed. For the case CeO_2 on CeO_2/IBAD-YSZ/SS, there was a self-epitaxy effect with the increase of CeO_2 film. For YSZ/Y_2O_3/NiW which was deposited by PLD or DC magnetron sputtering, there is not self-epitaxy effect. However, the capping layer of CeO_2 film deposited by PLD improved the quality of buffer layer for YSZ/Y_2O_3 which was deposited by DC magnetron sputtering, therefore increased the J_c of YBCO film.**

1. INTRODUCTION

YBCO tape that includes a multi-layer buffer layer on either a textured oxide layer deposited on a polycrystalline substrate or a textured substrate is expected to satisfy the requirements of the practical application of HTS devices operating in liquid nitrogen temperature. Mainly, two methods have been developed for the deposition of biaxially textured YBCO film on flexible metallic substrates. The first method [1, 2] consists in the deposition of biaxially textured buffer layer on randomly oriented tapes through an ion-beam-assisted-deposition (IBAD) process. The second method (RABiTS) involves the use of a biaxially textured metallic substrate, and the texture of the metallic substrate is transferred to the buffer layer up to the superconducting film through epitaxial deposition [3, 4].

Nickel was the most extensively utilized biaxially textured substrate in RABiST approach. However, the ferromagnetism and the low strength after the recrystallization of the Ni substrate represent the main obstacles towards potential applications. Therefore, in the last few years, new Ni-based alloy substrates (Ni–V, Ni–Cr, Ni–Cu, Ni–Fe, Ni–W) were developed [5, 6].

In our project, $CeO_2/YSZ/Y_2O_3$ architecture has been used as buffer on biaxially textured Ni or Ni alloy tapes. The pulsed laser deposition (PLD), DC magnetron sputtering and thermal evaporation were employed to deposit these buffer layers. Usually, the capping layer of CeO_2 was thin in RABiTS approach in order to achieve the good in-plane texture and avoid cracks. Recently, SRL-Nagoya Coated Conductor Center (NCCC)[7] has used IBAD and PLD method to fabricate buffer layers for coated conductor. It was found that CeO_2 deposited by PLD on the IBAD seed layer effectively increased the in-plane alignment with the increase of the thickness of CeO_2 buffer layer. The IBAD seed layer can be YSZ or $Gd_2Zr_2O_7$ (GZO). This effect was called the self-epitaxy method. As reported by them, the first CeO_2 layer of 100nm thickness had the grain size of a few tens of nanometer, which inherited from the IBAD seed layer. However, the structure was abruptly changed after the CeO_2 film growth over 100 nm in thickness. In this region, the grain size was about 1 μm.

In this paper, we have investigated the effect of the thickness of CeO_2 film deposited by PLD on the in-plane texture and the J_c of YBCO coated conductor for both IBAD and RABiST samples.

2. EXPERIMENT

In PLD system, the stoichiometric Y_2O_3, YSZ, CeO_2 and YBCO ceramic targets of 2 inch diameter were ablated by an exicmer KrF pulsed laser (LPX220i with wavelength 248nm from Lambda Physik). The biaxially textured Ni-3at%W substrates with the size of 3×10 mm^2 were attached with a silver paste on the target holder (also the heater) which was directly facing the target. The deposition temperature was measured by a thermocouple located in the heater block.

The particulars of the deposition system were: fixed laser beam at an angle of 60° to the normal of target; target-substrate distance 65mm; target rotation 25rpm; background pressure 1 x 10^{-6} Torr. The deposition conditions were: laser repetition rate 3~20Hz; the size of the laser spot on target 5×1mm^2; and the pulsed laser energy density on the target 2 - 3 J/cm^2.

Y_2O_3 and YSZ buffer layers were also deposited by DC magnetron sputtering in one chamber in succession.

The substrate was heated by halogen lamps. Pure Y and (Zr+ Y) metallic targets were sputtered in mixed atmosphere of Ar and water vapor for Y_2O_3 and YSZ film deposition, respectively.

The X-ray diffraction system of D8 DISCOVER with GADDS (general area detector diffraction solution) from Bruker was used to analyze the orientation of films. XRD θ-2θ scan, ω-scan and ϕ-scan have been done with sample oscillation using a 1/4-circle Eulerian cradle xyz stage. Atomic force microscopy (AFM) was used to examine the surface morphology of CeO_2 buffer layer.

3. RESULTS AND CHARACTERIZATION

IBAD template (CeO_2/IBAD-YSZ/SS) manufactured in Germany was used. the FWHM (full width at half maximum) of ϕ-scan (Δϕ) of YSZ and CeO_2 was about 10.4° and 8.5°, respectively. Ni–3at%W tapes (NiW) with biaxial texture manufactured by the standard cold rolling and recrystallization process were provided by Oxford Superconducting Technology. The in-plane and out-of-plane texture of NiW substrates used in this work were valued by the FWHM of ϕ-scan (Δϕ) and ω-scan (Δω). The NiW substrates possess sharp biaxial texture with in-plane and out-of-plane textures of Δϕ = 7 ~ 9° and Δω = 7 ~ 8°.

Three group samples with difference thicknesses of CeO_2 capping layer deposited by PLD were studied. Fig.1 gives the schematic of the three group samples.

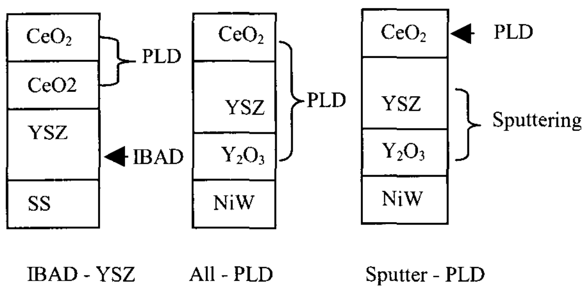

Fig. 1. Schematic illustration of the three group samples.

Firstly, CeO_2 films with different thicknesses from 25 nm to 800nm were deposited on CeO_2/IBAD-YSZ/SS by PLD (named as IBAD - YSZ sample). The deposition condition was: deposition temperature of 780°C; 0.1mTorr O_2; 200mJ/pulse laser energy and 10Hz laser repetition. XRD ϕ-scan were used to examine the orientation of CeO_2 films. The FWHM value of XRD ϕ-scan for (111) plane was gradually decreased with the increase of the CeO_2 film thickness from 25 nm to 800nm, indicating that there was an effect of increasing the in-plane alignment with the increase of the thickness of CeO_2 buffer layer. During YBCO deposition the heater temperature was 760 - 780°C, and the oxygen pressure in the chamber was 200mTorr. The laser repetition rate was 10Hz and the laser energy density on target was about 3 J/cm^2. Following deposition, the YBCO film was quickly cooled to 550°C under deposition pressure, and then kept for 20 min under oxygen pressure of 500 Torr. The thickness of YBCO films was about 250 nm. The T_{c0} of YBCO films on NiW was about 86~89K and the J_c was increased with the increase of the in-plane alignment of CeO_2 which was resulted from the increase of CeO_2 thickness (seen Fig.2)

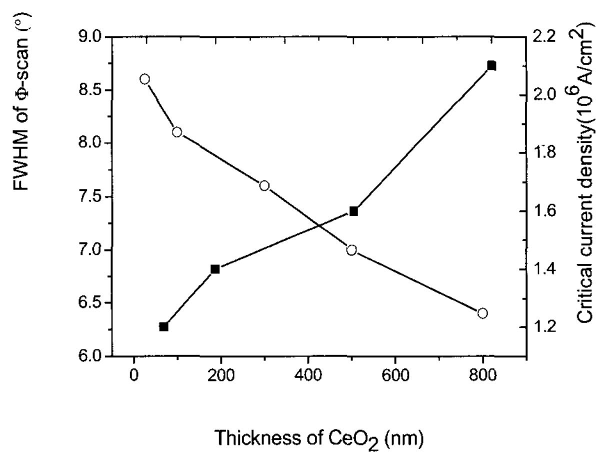

Fig. 2. The relationship between the FWHM of ϕ-scan, the thickness of CeO_2 film and the critical current density. The CeO_2 capping layers were deposited on CeO_2/IBAD-YSZ/SS.

Two other groups of CeO_2/YSZ/Y_2O_3/NiW samples were prepared and analyzed. The difference of these two group samples were from the deposition method of YSZ and Y_2O_3 buffer layers. One group (named as All-PLD samples) was that both Y_2O_3 and YSZ were deposited by PLD; another (named as Sputter - PLD samples) was that they were deposited by DC magnetron sputtering.

For All - PLD samples, the CeO_2/YSZ/Y_2O_3 buffer layer was prepared sequentially by PLD without breaking the vacuum. The deposition conditions of the first Y_2O_3 layer on NiW substrates were at 650 °C, 200mTorr Ar + 4% H_2 forming gas with 10Hz, 200mJ/pulse laser energy until 150nm thickness. The YSZ with the thickness of 250nm was deposited at 780°C, 0.1mTorr O_2 with 20Hz, 200mJ/pulse laser energy. Then the CeO_2 layer as capping layer was deposited at the same temperature as YSZ, 0.1mTorr O_2 with 10Hz, 200mJ/pulse laser energy with the series thicknesses of 25nm, 50nm, 100nm, 200nm, 400nm and 800nm.

For Sputter-PLD samples, the YSZ/Y_2O_3 buffer layer was prepared sequentially by DC magnetron sputtering. The deposition conditions of the Y_2O_3 layer on NiW substrates were at 800 °C, 0.8 mTorr water vapor + 5 mTorr Ar. The deposition rate of Y_2O_3 was about 24nm/min and the thickness of Y_2O_3 was 100nm. The YSZ with the thickness of 300nm was deposited at 800°C, 1mTorr water vapor + 5 mTorr Ar. Then the CeO_2 layer as capping layer was deposited under the same condition as All-PLD sample with the series thickness of 25nm, 50nm, 100nm, 200nm and 400nm.

For both these two group samples, the FWHM value of XRD ϕ-scan for (111) plane did not change much with the increase of the CeO_2 film thickness, indicating that the in-plane alignment was not improved with the increase of the thickness of CeO_2 buffer layer. In other words, there was no self-epitaxy effect for samples made using RABiST approach within this thickness range of CeO_2 film. The $\Delta\phi$ of CeO_2 (111) of All - PLD samples were about 8.2°. Compared with the $\Delta\phi$s of YSZ and Y_2O_3, there is no self-epitaxy effect of CeO_2 film. AFM was used to examine the surface of samples. The surface morphologies of the samples of different group were different (Fig.3). The AFM images of CeO_2(400nm)/IBAD-YSZ/SS in Fig.3 (a) suggested the CeO_2 film had larger grain. Further research will be conducted to study the reason there is self-epitaxy effect only on top of IBAD seed layer. Fig. 4 shows the XRD ϕ-scan analysis of YBCO/CeO_2(400nm)/YSZ/Y_2O_3/NiW. The J_c was about 1.1 ~1.6 MA/cm^2 at 77K and self-field.

On the other hand, the $\Delta\phi$ of CeO_2 (111) of Sputter - PLD samples were about 7.8°, but the J_c of YBCO film was lower than All - PLD samples. The best J_c is 0.9MA/cm^2 for YBCO sample with 200 nm CeO_2 buffer layer (see Fig. 5).

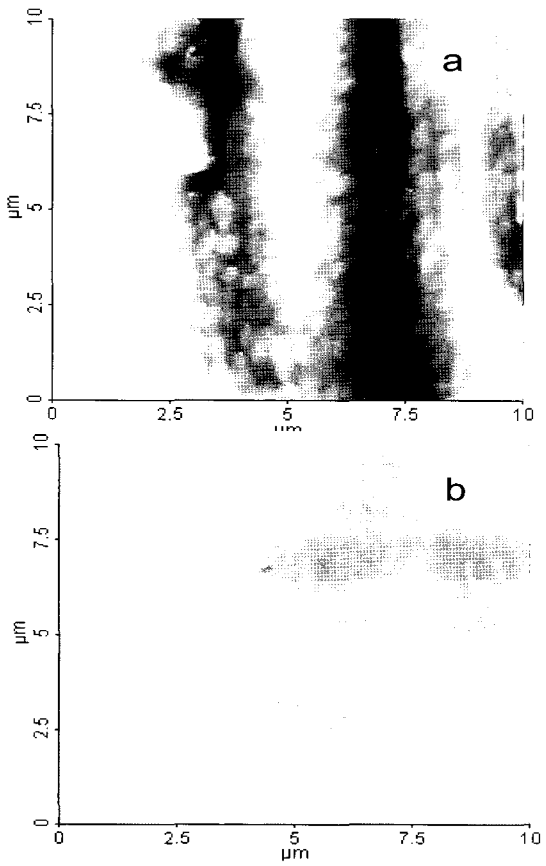

Fig. 3. AFM images of CeO_2 buffer layer: (a). CeO_2 (400nm)/IBAD-YSZ/SS; (b). CeO_2 (400nm)YSZ/Y_2O_3/NiW all by PLD.

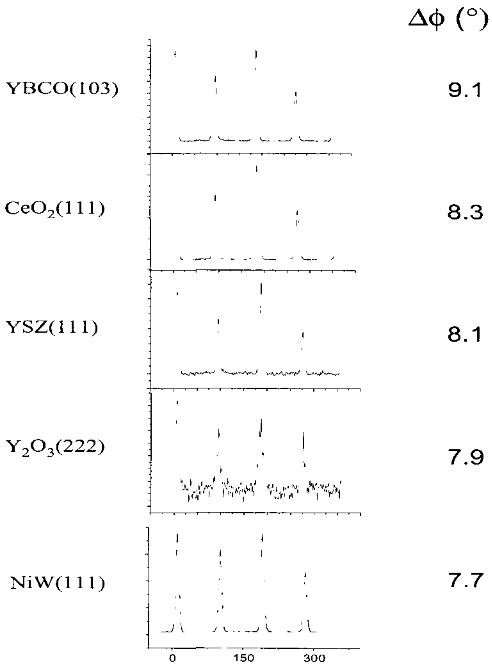

Fig. 4. XRD diffraction ϕ-scan analysis of YBCO/CeO_2(400nm)/YSZ/Y_2O_3/NiW, in which all buffer layers were deposited by PLD.

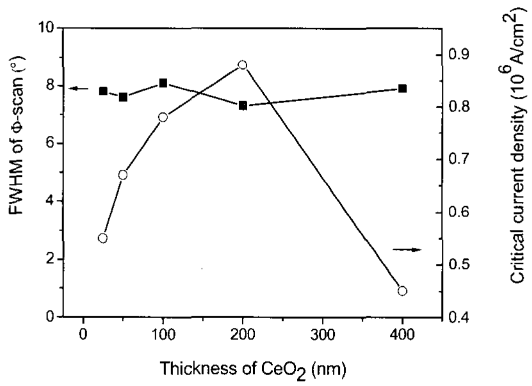

Fig. 5. The relationship between the FWHM of ϕ-scan, the thickness of CeO_2 film and the critical current density. The YSZ and Y_2O_3 buffer layers within YBCO/CeO_2/YSZ/Y_2O_3/NiW were deposited by DC sputtering.

4. SUMMARY

In this work, CeO_2 capping layer with different thickness was deposited on top of CeO_2/IBAD-YSZ/SS by PLD and the self-epitaxy effect was observed. Then the effects of thickness of CeO_2 film on the texture of CeO_2 film and critical current density (J_c) of YBCO film made using RABiST approach were studied. Two other groups of CeO_2/YSZ/Y_2O_3/NiW samples were deposited and analyzed. In one group, both was that both Y_2O_3 and YSZ were deposited by PLD; in another group was that they were deposited by DC magnetron sputtering.

There is no self-epitaxy effect in the YBCO coated conductor made by RABiTS approach with the CeO_2 thickness less than 400 nm. The superconducting property of All-PLD sample was better than Sputter-PLD sample when the thickness if CeO_2 was same in the thickness range of CeO_2 investigated in this work.

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