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Review

Epitaxial growth of $Gd_2Zr_2O_7/Y_2O_3$ buffer layers for $YBa_2Cu_3O_{7-\delta}$ coated conductors

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ABSTRACT

A biaxial textured buffer layer architecture was developed on Ni-5 at.% W (NiW) tapes applying Y_2O_3 as seed layer and $Gd_2Zr_2O_7$ (GZO) as barrier layer deposited by reel-to-reel DC reactive magnetron sputtering and pulsed laser deposition, respectively. X-ray diffraction measurements revealed an epitaxial growth of GZO films in a large range of substrate temperatures using Y_2O_3 as seed layer. The X-ray in-plane alignment of the buffer is less than 5°. Atomic force microscopy shows a homogeneous and flat GZO layer surface with a roughness RMS of about 2.5 µm in 5 µm × 5 µm area. $YBa_2Cu_3O_{7-\delta}$ superconducting films grown on the $Gd_2Zr_2O_7/Y_2O_3$ buffered NiW metallic tape exhibited an inductively measured critical current density J_c of about 0.8 MA/cm^2, demonstrating the suitability of the simplified buffer layer stack for coated conductors.

Contents

1. Introduction 15
2. Experimental 16
3. Results and discussion 16
4. Conclusions 18
Acknowledgments 19
References 19

1. Introduction

Coated conductors based on the high temperature superconductors $RE$$Ba_2Cu_3O_{7-\delta}$ (REBCO; RE = Y, Nd, Sm or other rare earths) are expected to be suitable for practical application at liquid nitrogen temperature due to their high performance and the potential low cost of both raw materials and preparation techniques. The basic requirement for power and energy applications of coated conductors is to realise biaxial textured REBCO films on flexible substrates to overcome the weak link behaviour of the grain boundaries in this material. A number of technologies have been developed to realize biaxial textured superconducting films on metallic substrates, including Ion Beam Assisted Deposition [1,2] and Rolling Assisted Biaxially Textured Substrate (RABiTS) [3,4]. Among them, the RABiTS approach is attractive due to the availability of long textured substrates, the feasibility of a controlled buffer growth and the potential for cost-effective processing such as chemical solution deposition (CSD) or metal organic deposition (MOD) for all functional layers [5,6].

Typically, a coated conductor architecture includes three layers: the metallic substrate, the buffer layers and the REBCO superconductor. The buffer layers on the metallic substrate (which is typically a Ni–W alloy) have two main functions for coated conductors based on the RABiTS technique: (i) preventing Ni or O atoms diffusion during the REBCO processing at high temperature; (ii) transferring the texture from substrate to superconducting layer. Different oxide materials have been successfully used as buffer layers to fulfil these requirements.

By now, the most popular buffer architectures used in coated conductor based on the RABiTS approach are multi-buffer layer stacks such as $CeO_2/YSZ/Y_2O_3$ [7,8], in which Y_2O_3 acts as the seed layer on the Ni tape, YSZ as the chemical barrier layer preventing atoms diffusion, and CeO_2 as the cap layer improving the lattice

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matching between YSZ and REBCO. Although 2G superconductor tapes based on such multi-layer buffer architectures are commercial, due to its high cost and complex process, more effective buffer materials are required to simplify the architecture for RABiTS-based coated conductors.

Recently, several oxides with a pyrochlore or perovskite structure such as $La_2Zr_2O_7$, $Ce_2Y_2O_7$, $LaMnO_3$ or $Gd_2Zr_2O_7$ (GZO) were investigated as single buffer layer in our group by pulsed laser deposition (PLD) or by magnetron sputtering (MS) [9–13]. Among those, GZO is proven to be a good buffer layer material. Compare with YSZ lattice parameter −6.06% mismatching, GZO lattice parameter matches better with YBCO (−3.49% mismatch), indicating a cap layer may be unnecessary. It should be mentioned that GZO was also used as a buffer layer in the IBAD approach for coated conductors [14,15]. Furthermore, GZO films combined with a Y_2O_3 seed layer resulting in a GZO/Y_2O_3 buffer architecture were also investigated by CSD [16] or electrodeposition [17] on Ni–W RABiTS tapes.

In our work, Y_2O_3 seed layers were prepared by the MS technique on Ni-5 at.% W (NiW) metallic substrates. GZO buffer layers were subsequently grown on these seed layers by PLD to build the final GZO/Y_2O_3 buffer layer architecture. The epitaxial growth and properties of the GZO/Y_2O_3 double layer were investigated with X-ray diffraction (XRD), Optical Microscopy (OM) and Atomic Force Microscopy (AFM). The performances of this buffer architecture for coated conductors were also tested using a 300 nm thick $YBa_2Cu_3O_{7-\delta}$ (YBCO) film deposited by PLD.

2. Experimental

Highly textured NiW RABiTS tapes (Evico GmbH, thickness 70 μm, width 10 mm) were used as metallic substrates, showing a cube textured fraction of 98% and an in-plane full width at half maximum (FWHM) of 6.0°, respectively.

The meters long Y_2O_3 seed layers were prepared using DC reactive sputtering in a home-made reel-to-reel system. Optimized deposition conditions were used such as a substrate temperature of 800 °C, a sputtering power of 80 W, a H_2O partial pressure of $1–4 \times 10^{-2}$ Pa and Ar-5% H_2 forming gas leading to a total pressure of 1 Pa. The FWHM values for X-ray in-plane scans of the Y_2O_3 seed layers are less than 4.5°.

GZO buffer layers were prepared on Y_2O_3 seeded NiW substrate with size about 10 mm × 10 mm by a PLD-450 equipment (KrF, λ = 248 nm, f = 5 Hz, E = 2.4 J/cm^2), where each pulse leads to a GZO film thickness of about 0.04 nm. The GZO was deposited in an Ar:O_2 mixture with a total background pressure of 4 Pa and an oxygen partial pressure of 0.15 Pa.

The YBCO layers were prepared by PLD using a substrate temperature of 810 °C, a background oxygen pressure of 0.3 Pa and an oxygen loading step under 400 Pa during cool down. More details can be found elsewhere [10,11].

X-ray diffraction θ–2θ scans (Rigaku D/Max2550, Cu Kα, λ = 1.54185 Å) and pole figures (Philips X'Pert PRO, Cu Kα, λ = 1.54185 Å) were measured to evaluate the biaxial alignment of the grown films. Optical Microscopy (BX51M) and Atomic Force Microscopy (Nanofirst 3600A) was used to investigate the surface structure of the GZO buffer layers. A cross-section of the sample was prepared using the focused ion bean technique (FIB, FEI Quanta 200 3D), which was imaged afterwards in the TEM (Philips Tecnai F-20). The critical temperature was measured by a standard four-probe method in a Quantum Design PPMS-9 system. The critical current density J_c of the YBCO coated conductor was examined by inductive measurement using a Cryoscan by Theva.

3. Results and discussion

Different substrate temperatures were used to evaluate the epitaxial growth of GZO on Y_2O_3 seed layers. The number of 3500 pulses for GZO was kept constant for this sample series leading to a film thickness of about 140 nm. Fig. 1 shows the X-ray θ–2θ diffraction patterns of the grown layers. They demonstrate that no additional phases are formed except the desired GZO. In particular, no NiO is detected for all samples. Since the lattice parameters of GZO and Y_2O_3 are almost similar, it is not possible to distinguish between them in the X-ray diffraction patterns. In general, the GZO films show (001) reflections only indicating a strong (001) texture for all substrate temperatures investigated. Additionally, the width of the GZO (004) peak is with a value of about 0.7° significantly broader for a substrate temperature of 500 °C compared to samples deposited at higher temperatures, where a value of about 0.25° was measured. This is an indication for an improved crystallinity of the films grown at higher temperatures. In contrast, a lower growth temperature results in a smaller grain size and a higher number of defects leading to a significant peak broadening and a reduced intensity.

The microstructures of GZO buffer deposited at different substrate temperature were investigated by OM and AFM. Fig. 2 shows the surface OM morphologies of selected GZO/Y_2O_3 films. The GZO films deposited at higher temperatures are homogeneous without any cracks. The large grains of the NiW-substrate are still visible through the transparent layer. Some small delaminated areas were observed at lower temperatures, which might be originated by stress. Therefore a substrate temperature of about 700 °C was chosen to grow optimized GZO films.

Fig. 3 shows the AFM image of the GZO/Y_2O_3 film deposited at a substrate temperature of 700 °C. Again, a homogeneous GZO surface morphology is observed with a root mean square roughness (RMS) value of about 2.5 nm on a $5 \times 5\ \mu m^2$ area, which is an improvement compared to GZO layers deposited on NiW without Y_2O_3 seed layer. The improved surface morphology might be beneficial for subsequent epitaxial growth of superconducting layer [18].

Pole figure measurements were performed to verify the epitaxial growth of the GZO layer and to quantify the in-plane alignment. Fig. 4 gives the XRD φ-scan and corresponding (222) pole figure for a GZO film grown on the Y_2O_3 seeded NiW metallic tape at a temperature of 700 °C. The four symmetric peaks in the pole figure reveal that the GZO/Y_2O_3 double layer exhibits a strong biaxial texture with the in-plane FWHM value of about 4.9°, which is a signif-

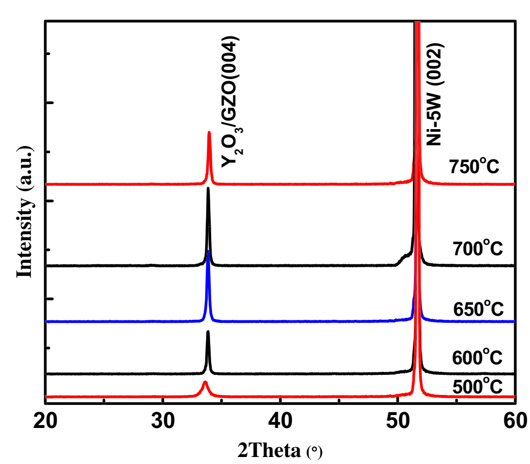

Fig. 1. X-ray θ–2θ diffraction patterns of GZO films deposited at different substrate temperatures on RABiTS Ni-5 W tapes with Y_2O_3 seed layers.