Texture Development of MgO Buffer Layers Grown by Inclined Substrate Deposition *

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Texture Development of MgO Buffer Layers Grown by Inclined Substrate Deposition

Rachel E. Koritala, Beihai Ma, Dean J. Miller, Meiya Li, Brandon L. Fisher, and U. (Balu) Balachandran

***Abstract*— Biaxially textured magnesium oxide (MgO) films used as template layers for $YBa_2Cu_3O_{7-x}$ (YBCO)-coated conductors have been grown efficiently and consistently by inclined substrate deposition (ISD). Further improvement in texture and a decrease in surface roughness were obtained by depositing a homoepitaxial MgO layer on the ISD MgO layer at an elevated temperature and flat angle. The texture of the ISD layer was studied as a function of thickness by X-ray diffraction and scanning and transmission electron microscopy. Surface roughness of the ISD and homoepitaxial layers was investigated by atomic force microscopy. Based on the results, the optimal thickness of the ISD layer was determined.**

***Index Terms*—buffer layers, electron microscopy, inclined substrate deposition, superconducting films.**

Introduction

THE critical current densities of $YBa_2Cu_3O_{7-x}$ (YBCO) thin films can be improved significantly by depositing the films on biaxially textured buffer layers [1-3]. Several methods have been used to deposit the buffer layers, including ion-beam assisted deposition (IBAD) [4-6], inclined substrate deposition (ISD) [7-9], and rolling-assisted biaxially textured substrates (RABiTS) [10,11]. The ISD process is advantageous with respect to the other methods because it allows faster growth of textured films (20-100 Å/sec) on randomly oriented metal substrates [12]. An additional advantage is the simplicity of ISD since, unlike RABiTS, a complicated heat treatment is not needed to produce textured substrates and, unlike other deposition-based techniques, an assisting ion source is not necessary.

ISD has been used successfully to deposit biaxially textured magnesium oxide (MgO) buffer layers for coated conductor applications [8]. A thickness of ≈ 2 µm for the ISD MgO layer has been used to produce high-quality YBCO films with excellent superconducting properties [9]. It has also been demonstrated that the texture of the ISD MgO layer is good even in films < 2 µm thick [12]. In this study, the texture development of ISD MgO films was investigated further and correlated with surface roughness measurements to deduce an optimal thickness for the layer.

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Experimental

MgO was deposited on both (100) Si and mechanically polished Hastelloy C (HC) substrates. The ISD MgO was deposited between room temperature and 50°C by electron beam evaporation with the substrate inclined at 55° with respect to the vapor source. A schematic representation of the deposition geometry and details of the deposition conditions are described elsewhere [9,12]. Film thickness ranged from 0.07 to 2.4 µm. A homoepitaxial MgO layer (≈ 0.5 µm) was subsequently deposited on the film at an elevated temperature (700°C) and zero-degree inclination angle.

The texture of the MgO films was examined with an X-ray diffractometer (Scintag XRD 2000) using Cu-K_α radiation. Film thicknesses were measured with a profilometer (Veeco Dektak3 ST). In some cases, the thickness was confirmed by cross-sectional scanning electron microscopy (SEM) with a Hitachi S4700 SEM. Film morphology in both plan view and cross section was also studied by SEM. Texture development was investigated by transmission electron microscopy (TEM) with a Philips CM30 operated at 300 keV. Cross-sectional TEM specimens were prepared by gluing two sample pieces together, with deposited sides facing. The specimens were then ground on both sides, dimpled on one side, and ion-milled from both sides. Surface roughness was examined by atomic force microscopy (AFM) with a Dimension 3100 scanning probe microscope.

Results

It was shown previously [13] that the ISD MgO structure is columnar, with the tops of columns truncated by (200) planes. When observed in plan view, as seen in the SEM image Fig. 1a, the column tops of a 1.5-µm thick film exhibit a roof-tile structure with gaps between the columns. AFM, shown in Fig. 1b, confirms this structure and reveals that the root-mean-square (RMS) surface roughness of the ISD film is ≈ 10 nm. The texture of the films, measured by XRD, was shown previously to be good [9].

To improve surface roughness and texture further, a

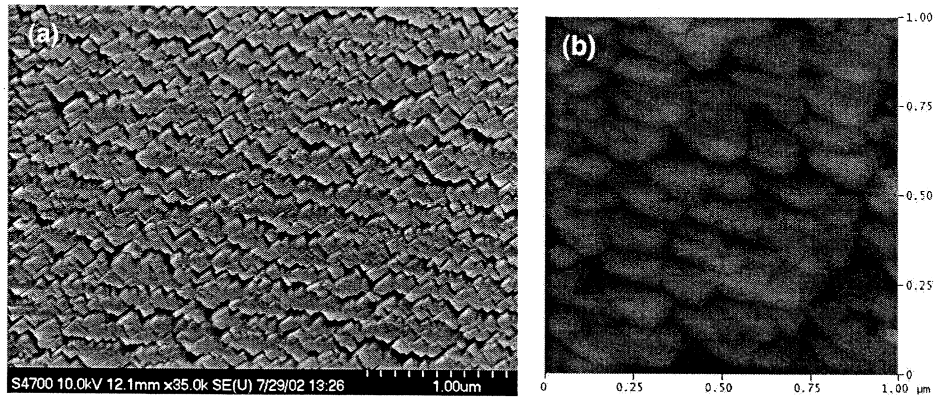

Fig. 1. (a) SEM micrograph and (b) AFM image of 1.5 μm ISD MgO film on Hastelloy C substrate.

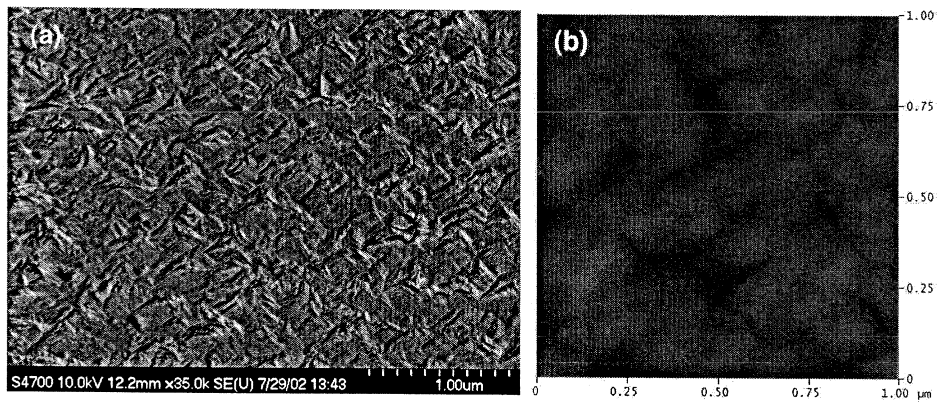

Fig. 2. (a) SEM micrograph and (b) AFM image of 0.5 μm homoepitaxial MgO layer on top of 1.5 μm ISD MgO film.

homoepitaxial MgO layer was deposited on the ISD film. As can be seen in the plan view SEM image, Fig. 2a, the gaps between columns disappear after the homoepitaxial layer is deposited. AFM, (Fig. 2b), demonstrates a decrease in surface roughness to ≈8 nm. Further, XRD reveals an improvement of ≈2° in the full-width half maximum (FWHM) of the MgO (002) ϕ–scan [9].

To investigate the in-plane texture of the ISD layer as a function of thickness, films of various thicknesses (0.07 to 2.05 μm) were deposited, followed by deposition of a

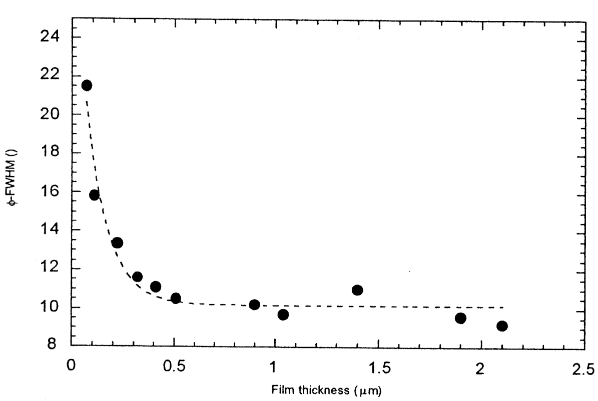

Fig. 3 FWHM of MgO (002) f-scan versus ISD layer thickness.

homoepitaxial MgO layer (≈0.5 μm). Figure 3 shows the FWHM of the MgO (002) ϕ-scan as a function of the ISD layer thickness. From this figure, a significant improvement in texture can be seen as film thickness increases to ≈0.4 μm. Although there is a slight improvement beyond this point, it is apparent that a well-textured film can be grown with a thickness of no more than ≈0.4 μm.

Out-of-plane texture was examined with cross-sectional TEM. Selected area diffraction (SAD) patterns were acquired from several locations in a film with an ISD layer of ≈2.4 μm and an homoepitaxial layer of ≈0.5 μm, as shown in Fig. 4. The FWHM of both {200} and {110} reflections was measured for each thickness. An additional sample with a thinner (≈0.4 μm) ISD layer was also examined to obtain more detailed information near the critical thickness of ≈0.4 μm that was determined from XRD. Results from the FWHM measurements using the (200) reflection of both samples are shown in Fig. 5. Although the improvement in texture appears to be more gradual than that observed by XRD, it is still apparent that the ISD layer reaches an acceptable degree of texture by ≈0.4 μm.

AFM was used to measure the surface roughness of ISD films of various thicknesses. An area of 1 x 1 μm was used for each measurement, and at least three different areas were measured for each thickness. The results, shown in Fig. 6, demonstrate that roughness increases as film thickness increases. The previous result for a film thickness of 2 μm is also plotted [12] and shows an improvement from a roughness

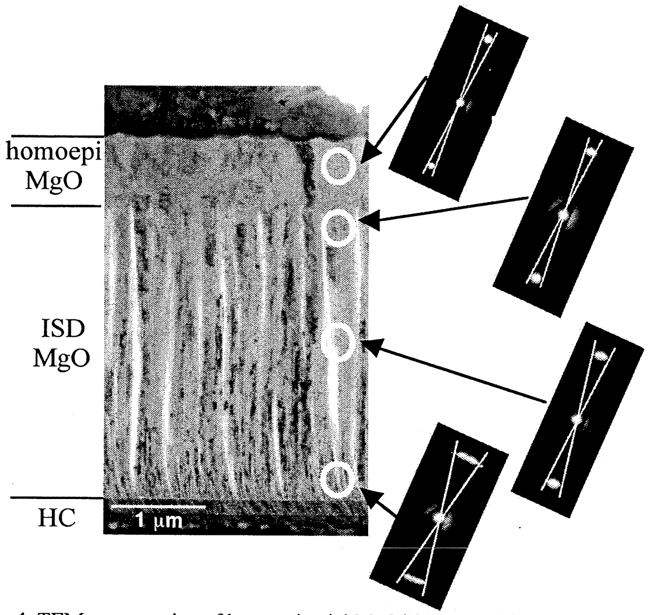

Fig. 4. TEM cross section of homoepitaxial MgO/ISD MgO film on Hastelloy C substrate, and SAD patterns of (200) reflection acquired at locations shown. FWHM of (200) reflections was measured as depicted.

of ≈28 nm to ≈10 nm, demonstrating that smoother ISD films can now be deposited.

Discussion

The results described above demonstrate that it might be possible to use films that are thinner than the 2 μm films used currently, thus decreasing the processing time and total thickness of the coated conductor. Both the XRD and SAD results show that good texture is achieved with an ISD layer thickness of only ≈0.4 μm. Thus, an ISD film of this thickness is likely to provide the necessary biaxial texture for subsequent epitaxial layers.

AFM results show that the surface roughness of the ISD layer decreases as the film becomes thinner. Although the effect of the buffer layer surface roughness on the quality of subsequent layers has not yet been determined, it is likely to influence the structures and consequently the properties of the coated conductor. It has been found, for example, that the substrate morphology of silver substrates has a significant effect on the quality of YBCO films deposited on these substrates [14]. In the case of ISD films, the roof-tile morphology of the ISD structure is likely to affect the nucleation of subsequent layers. As described above, the deposition of a homoepitaxial layer eliminates surface cracks and reduces surface roughness, thereby probably improving the quality of subsequent layers. Further investigation of this effect is necessary.

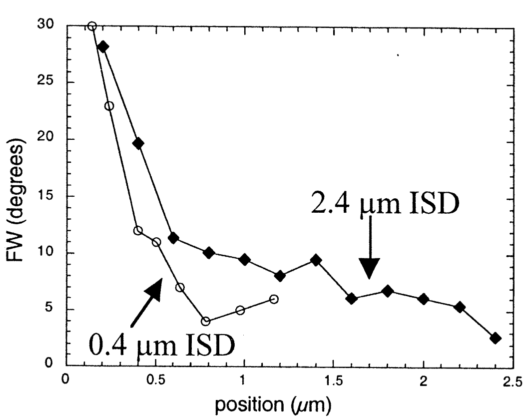

Fig. 5. FWHM of (200) reflection of SAD patterns acquired from various positions in 0.4 μm (open circles) and 2.4 μm (filled diamonds) ISD MgO films.

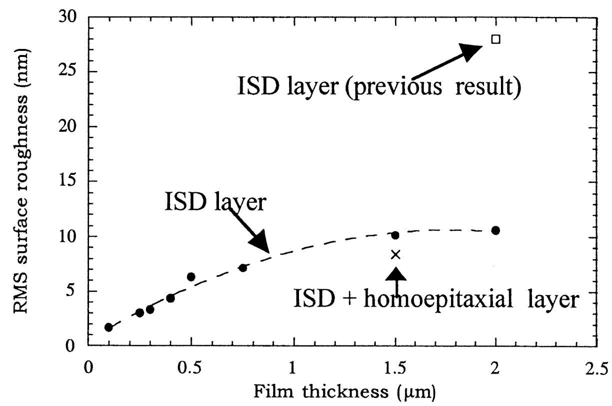

Fig. 6. RMS surface roughness of ISD layers with various thicknesses (•), ISD with homopitaxial layer (x), and previously measured ISD layer (□) [12].

Conclusions

Biaxially textured MgO buffer layers were deposited by ISD. Both in-plane and out-of-plane textures improve as film thickness increases. Both XRD and TEM demonstrate that an acceptable degree of texture is obtained with a film thickness of ≈0.4 μm. Surface roughness increases with thicker ISD films. The deposition of a homoepitaxial MgO layer on top of the ISD layer results in further improvement in texture and decreased surface roughness.

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