Journal of the Korea Institute of Applied Superconductivity and Cryogenics
Vol.6, No.4, (2004), pp.13~16

Meter-long coated conductor by R2R PVD methods on RABiTS template

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Abstract- **Three film deposition systems (pulsed laser deposition, sputtering, and evaporation) equipped with reel-to-reel metal tape moving apparatus were installed and used to make meter-long coated conductor. Buffer architecture of $CeO_2/YSZ/Y_2O_3$ was deposited on Ni alloy using sputtering, evaporation, and PLD. YBCO superconducting layer was continuously deposited on buffered metal tape by PLD. End-to-end critical current (I_c) of 107 A at 77 K, self-field has been achieved in 1 cm-wide tape (thickness 0.6~1.0 μm, tape moving speed 54~72 cm/hr) over 1 meter length.**

1. INTRODUCTION

It is important for practical YBCO coated conductor to secure long length, high performance and low cost for the applications of electric power device. Multiple ways of obtaining texture templates and a variety of films deposition methods are expected to satisfy these requirements.

A typical coated conductor has architecture of biaxially textured metal template/ multiple oxide buffered layers/ superconducting layer/ stabilization layer. There are two main approaches to obtain biaxially textured metal template. One is the biaxially aligned metal type process, known as RABiTS (Rolling Assisted Biaxially Textured Substrate) [1], and the other is the biaxially aligned buffer layer type process, known as the IBAD (Ion Beam Assisted Deposition) [2,3] and ISD (Inclined Substrate Deposition) [4] process.

The buffer layer functions as a template for the growth of the YBCO superconducting layer and as a barrier to lattice-mismatched stress and chemical diffusion between the YBCO and metal substrate. Many deposition methods including both physical methods such as pulsed laser deposition (PLD), sputtering and evaporation, and chemical methods such as metal organic decomposition (MOD), metal organic chemical vapor deposition (MOCVD), sol-gel etc., have been used to fabricate buffer layers and also been used to improve buffer structure [5].

Multiple approaches are used to make texture template, buffer layers, and superconducting layer, respectively. Many different combinations of methods to make textured template and superconducting layer (IBAD-PLD [6-9], IBAD-MOCVD [9], IBAD-MOD_TFA [10], RABiTS-Evaporation [11,12], RABiTS-MOD [13], RABiTS-MOCVD [14] and ISD-PLD [15]) are used to fabricate long length coated conductor.

RABiTS process which is a simple and low cost process, is based on the deposition of an epitaxial oxide buffer layer on a deformation textured metal substrate made by cold rolling and annealing. PLD technique is one of the most popular and versatile process for the deposition of oxide superconducting films. Despite the high cost of the process compared to others, PLD is particularly attractive with the relatively low number of control parameters, small stoichiometry variation during the deposition, wide range of processing atmosphere, high deposition rate compared to other physical vapor deposition (PVD) methods and high energy of depositing species. And so, RABiTS-PLD method for textured template and superconducting layer can be a promising combination of manufacturing process for long length coated conductor with affordable template and high performance. In this paper, we present progress in fabrication of meter-long coated conductor using the continuous PVD method including PLD, evaporation, and sputtering, on RABiTS template.

2. EXPERIMENTAL

Meter-long YBCO coated conductor was made using three film deposition systems (PLD, evaporation, and sputtering), with reel-to-reel (R2R) metal tape moving apparatus from the seed layer through the Ag stabilization layer deposition. Table. I shows the architecture and thickness of the YBCO coated conductor using the RABiTS for the textured template and PVD methods for the deposition of oxide buffer layers and the superconducting layer.

2.1. Textured metal tape

The long length textured metal tape fabricated by thermo-mechanical treatment used in this work was

TABLE I
THICKNESS, AND DEPOSITION METHODS OF EACH COMPONENT OF THE COATED CONDUCTOR.

Structure	Thickness	Deposition Method
Ag	4-5μm	Sputtering
YBCO	0.6-1μm	PLD
CeO_2	25-200nm	PLD or thermal evaporation
YSZ	300nm	DC reactive sputtering
Y_2O_3	200nm	DC reactive sputtering
Ni-3%W	50 μm	

manufactured and supplied by Oxford Superconducting Technology (OST). The metal alloy (Ni 3% at.W) tape had a thickness of 50 μm and a width of 10 mm. Percentage cube texture value was 99.2 % and full width at half maximum (FWHM) values for in-plane and out-of-plane texture were 6.0~8.3° and 3.5 ~5.0° respectively from the XRD analysis performed using the D8 Discover with area detector from Bruker.

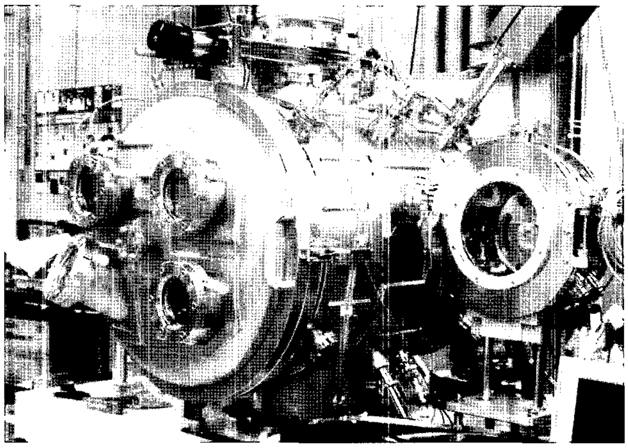

Fig. 1. Photograph of R2R sputter-evaporation system used for the fabrication of long length coated conductor.

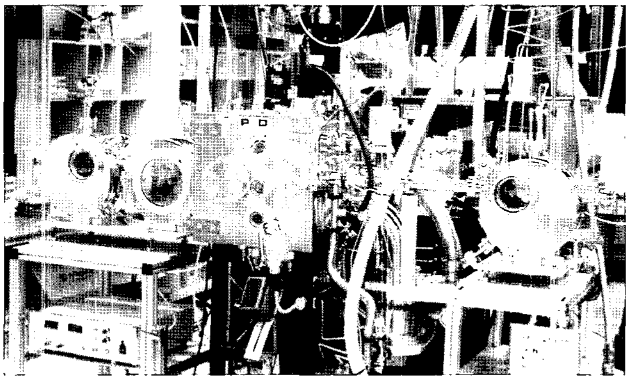

Fig. 2. Photograph of R2R PLD system used for the fabrication of long length coated conductor.

2.2. Y_2O_3 seed and YSZ diffusion barrier layers

We used a R2R sputter-evaporation system consisting of a specially designed chamber equipped with two sputtering guns, one crucible for evaporation and R2R apparatus to make buffered metal tape by continuous deposition of oxide materials on textured metal tape, shown in Fig. 1. The deposition rate is monitored by quartz crystal microbalance. Epitaxial buffer layers of Y_2O_3/YSZ were deposited on NiW using R2R DC reactive sputtering.

Y_2O_3 film was deposited at 800 °C in 4 mTorr 4% H_2/Ar gas and 0.5 mTorr water vapor atmosphere by DC reactive sputtering using metallic yttrium target. During the reaction of H_2O and yttrium, water is consumed and hydrogen is produced, which results in the formation of Y_2O_3 and H_2 which prevents the formation of NiO [16]. After the deposition of the 200 nm thick Y_2O_3 seed layer, the 300 nm thick YSZ diffusion barrier layer was also deposited by DC reactive sputtering using the same conditions as was used for Y_2O_3 layer using metallic yttrium and zirconium target.

2.3. CeO_2 cap and YBCO HTS layers

The CeO_2 cap layer (25-200 nm thick) was deposited on the NiW/Y_2O_3/YSZ buffered tape at 700 °C by thermal evaporation in $1\text{-}3\times10^{-5}$ Torr water vapor atmosphere or by PLD under oxygen pressure of 10 mTorr.

For the YBCO superconducting layer deposition, R2R PLD system, shown in Fig. 2 has been installed with R2R tape transport apparatus and DC sputtering system for *in-situ* Ag deposition to prevent direct exposure of YBCO films to air. A quartz-lamp heater is used for heating of tape and a 80 W KrF excimer laser, LPX220i with a wavelength of 248 nm from Lambda Physik,is used for the PLD process.

In this work, immediately after the CeO_2 capping layer was deposited by PLD, the YBCO layer was continuously pulsed laser deposited under the oxygen pressure of 200 mTorr. The buffered metal tape passed the deposition zone twice. The deposition temperatures of 810 °C and 835 °C and the moving speed 54 cm/hr and 72 cm/hr were used for the first and the second pass, respectively._The laser pulse energy was 100 mJ with the pulsed repetition rate of 200 Hz. Right after the YBCO deposition, a thin Ag layer was deposited *in-situ* by DC sputtering in the same chamber before the deposition of additional 4-5 μm Ag in a separate sputtering chamber. The coated conductor was post-annealed at 450-550 °C for 2-4 hours in flowing pure oxygen atmosphere.

3. RESULTS AND DISCUSSION

3.1. Characterization of texture and surface morphology

(*l*00)-oriented buffer layers have been deposited on the textured metal reproducibly using DC reactive sputtering in Ar gas and a water vapor atmosphere. Fig. 3 (a) shows a typical θ-2θ scan XRD pattern for YSZ/Y_2O_3 films grown on textured metal tape and no evidence of the formation of Ni oxide phases from YSZ/Y_2O_3/NiW film. Fig. 3 (b) shows θ-2θ scan and φ scan XRD pattern of YBCO films deposited on CeO_2/YSZ/Y_2O_3 /NiW architecture in R2R

PLD system. Except for the substrate and buffer layer reflections, only (00*l*) reflections from YBCO films were observed, indicating that the films was preferentially aligned with the c-axis perpendicular to the buffer surface. The FWHM values of the φ scans for Ni(111), Y_2O_3(111), YSZ(111), CeO_2(111) and YBCO (103) were 7.9°, 7.1°, 7.8°, 7.3° and 8.5°, respectively, indicating that all the buffer and HTS layers closely replicate the in-plane texture of textured metal tape.

As shown in the SEM micrograph (Fig. 4), the surface of the YSZ layer was quite smooth without any cracks, and the surface of the meter length YBCO was dense and had a very uniform microstructure.

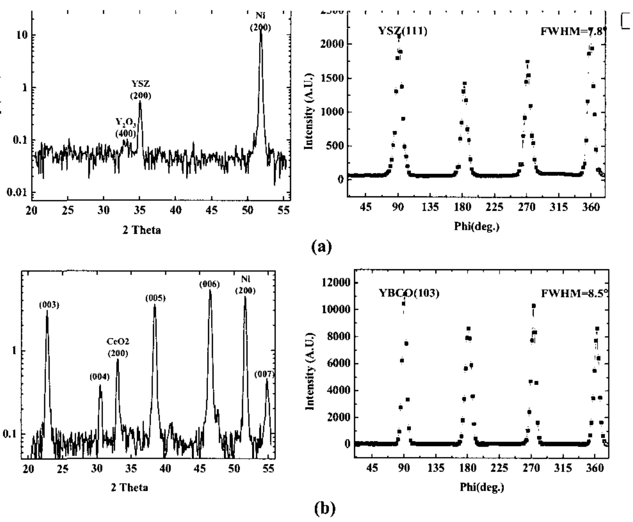

Fig. 3. (a) θ-2θ scan and φ scan XRD pattern of YSZ / Y_2O_3 deposited on textured NiW tape. (b) θ-2θ scan and φ scan XRD pattern of YBCO coated conductor deposited on CeO_2/YSZ/Y_2O_3/ NiW in R2R PLD system.

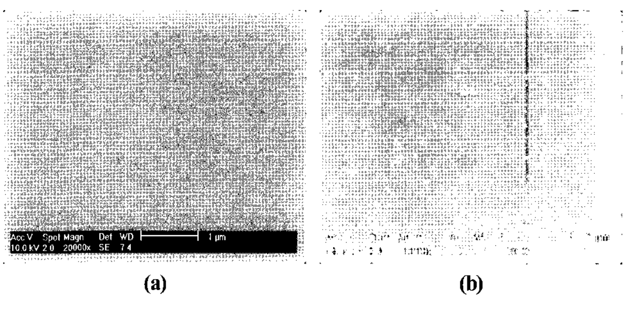

Fig. 4. SEM plane view images of (a) YSZ deposited on Y_2O_3 /NiW and (b) YBCO deposited on CeO_2 /YSZ/Y_2O_3 / NiW.

3.2. Characterization of electrical transport properties

Electrical properties were measured at 77 K, in self field by DC four-probe method using a 1 μV/cm criterion. Fig. 5 shows the critical current distribution over a meter-long YBCO coated conductor made by PVD method on RABiTS template and inset is *I-V* curve for a meter end-to-end. Average I_c of 104 A/cm-width and standard deviation of 8.7 % were obtained from the data measured in 11 cm intervals over the length of YBCO coated conductor. The Ic value of the tape measured in each section was 88 - 110 A/cm-width.

As shown in Fig.5, I_c distribution was not uniform because the deposition during the second pass was not carried out completely. End-to-end critical current (I_c) at 77 K of 107 A/cm-width has been achieved in 1 meter length. The critical current densities (J_c) at 77 K in section B (1 μm thick) and A (0.6 μm thick) of Fig. 5 were 1.1 MA cm^{-2} and 1.5 MA/cm^{-2}, respectively.

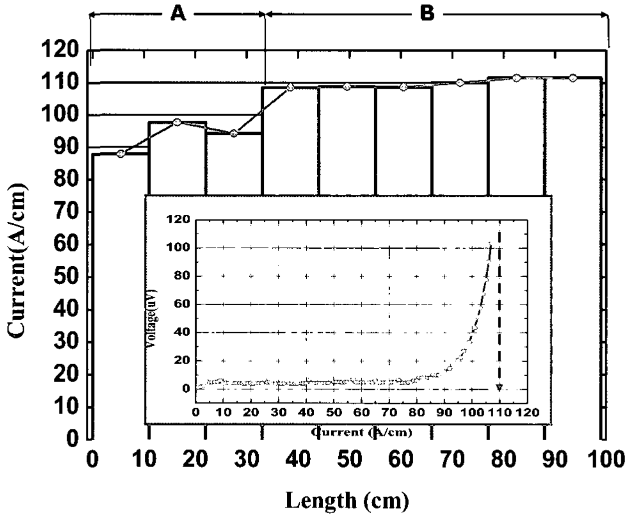

Fig. 5. Critical current distribution of a meter-long YBCO coated conductor made by RABiTS-PVD processing. Inset: An end-to-end critical current of 107 A was achieved over 1m at 77 K.

4. CONCLUSION

High-Ic meter-long YBCO coated conductor with the structure of YBCO/CeO_2/YSZ/Y_2O_3 has been fabricated by continuous deposition of multi-layer oxide film using pulsed laser deposition (YBCO and CeO_2) and DC reactive sputtering (YSZ and Y_2O_3). End-to-end critical current (I_c) at 77 K of 107 A/cm-width has been achieved in 1 meter length. The critical current densities (J_c) at 77 K were 1.1 - 1.5 MA/cm^{-2}. RABiTS-PLD method for textured template and superconducting layer can be a promising combination of manufacturing process for long length coated conductor with affordable template and high performance.

ACKNOWLEDGMENT

This research was supported by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea. The authors express their appreciation to Dr. K. R. Marken of Oxford Superconducting Technology for providing textured Ni and NiW tapes.

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