High-rate and Long-length IBAD Layers for $GdBa_2Cu_3O_{7-x}$ Superconducting Film

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A large-scale IBAD system with the world's largest ion source was employed to fabricate IBAD-MgO film. We successfully fabricated a 1 km-length IBAD-MgO film at a production rate of 1 km/h. We also studied PLD-CeO_2 films directly on IBAD-MgO films. From an observation by TEM of the interface between MgO and CeO_2 films, it is revealed that CeO_2 film has fine-textured structure on IBAD-MgO though lattice mismatch is large (28.5%). Using the CeO_2/MgO substrate, we fabricated PLD- $GdBa_2Cu_3O_{7-x}$ (GdBCO) film and obtained a high-performance superconducting film whose I_c and J_c were over 300 A and 3 MA/cm^2, respectively, at 77 K, self-field.

1. Introduction

Long-length $REBa_2Cu_3O_{7-X}$ conductors with a high performance have been fabricated by a reel-to-reel system in the world. $REBa_2Cu_3O_{7-X}$ is one of the high-temperature superconductors. Its critical temperature (T_c) is 90 K, which is higher than the temperature of liquid nitrogen (77K). The J_c between grain boundaries of $REBa_2Cu_3O_{7-X}$ are very sensitive to its grain-boundary misorientations[1]. So, if we aim to obtain a high-performance $REBa_2Cu_3O_{7-X}$ tape, we should prepare single-crystal-like substrates. An IBAD process, which was invented at Fujikura in 1991, is one of the effective methods to obtain biaxially textured film like single crystal on flexible polycrystalline metal or alloy tapes. After an IBAD was developed in $REBa_2Cu_3O_{7-X}$ conductors using a material with a fluorite structure[2), 3)], high-performance coated conductors could be obtained. Then, an IBAD phenomenon on a nanometer scale was developed using a material with a rock-salt type structure[4), 5)]. Recently production of long-length IBAD-MgO films at a speed of some hundred meters per hour has been reported by some groups[6)]. In the structures of buffer layers, there are $LaMnO_3$ or CeO_2/$LaMO_3$ layers on an IBAD-MgO layer, because lattice mismatches between MgO and $REBa_2Cu_3O_{7-X}$, and between MgO and CeO_2 are large.

Fujikura has a large-scale IBAD system with the world's largest ion source; it reported the fabrication of IBAD-GZO at a speed of 5 m/h[7)]. We applied this system to the production of IBAD-MgO tapes and studied the deposition of PLD-CeO_2 film directly on IBAD-MgO film. In this paper, we introduce our state of fabrication of IBAD-MgO film and superconductivity of GdBCO on this film.

2. Development of IBAD-MgO tape and RE123 coated conductors

2.1 Fabrication process

On polycrystalline Hastelloy tape (0.1 mm^t × 10 mm^w), Al_2O_3 film and Y_2O_3 film were fabricated by a sputtering method. Roles of Al_2O_3 and Y_2O_3 film are diffusion barrier of metal elements from substrate, and nucleation layer for IBAD-MgO, respectively. Film thicknesses of Al_2O_3 and Y_2O_3 were 100-200 nm and 10-20 nm, respectively. Then IBAD-MgO films were formed on the Y_2O_3/Al_2O_3 substrates at room temperature. The assisting ion was Ar^+ and irradiating direction was 45° from the substrate normal. In the IBAD-MgO process, MgO[110] is aligned to the ion beam direction. MgO(110) is 45° from the substrate normal,

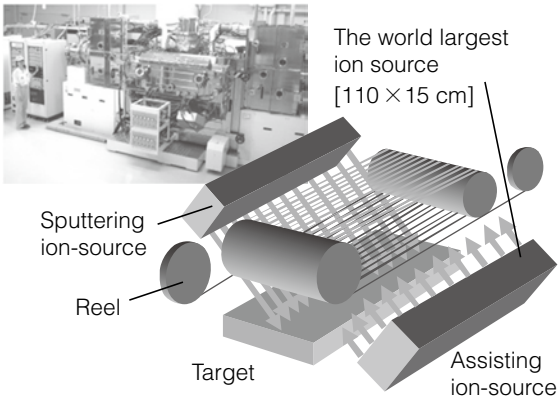

Fig. 1. Appearance of large IBAD system and schematic of the system with the world's largest ion source.

1 Superconducting Research Section

Panel 1. Abbreviations, Acronyms, and Terms.

IBAD—Ion Beam Assisted Deposition
PLD—Pulsed Laser Deposition
RE—Rare Earth
GdBCO—$GdBa_2Cu_3O_{7-x}$
GZO—$Gd_2Zr_2O_7$
I_c—Critical Currents
J_c—Critical Current Density
T_c—Critical Temperature
TEM—Transmission Electron Microscopy

so the ion beam direction is fixed 45°. The IBAD system has a large ion source with the size of 110 cm × 15 cm, and has 15 multiple deposition lanes (Fig. 1). On IBAD-MgO films, PLD-CeO_2 films were deposited directly without $LaMnO_3$ interlayer. Standard thickness of the CeO_2 film was 500 nm. In-plane texture of the CeO_2 film was evaluated from full-width-at-half maximum of X-ray phi-scan of CeO_2 (220) peaks. To analyze atomic structure of CeO_2/MgO interface, a TEM was employed.

To evaluate the long-length PLD-CeO_2/IBAD-MgO film, we fabricated 1-km-length IBAD-MgO tape at 1 km/h and deposited PLD-CeO_2 film on the short samples cut from each 20 m. Further, to verify whether CeO_2/MgO substrate is reliable for superconducting layer, GdBCO film was deposited on CeO_2/MgO/Y_2O_3/Al_2O_3 substrate and its I_c was measured by a 4-probe method at 77K in a self-field. The criterion of I_c was 1 μA/cm.

2.2 Result

IBAD-MgO films were successfully fabricated by the large IBAD system. Besides, PLD-CeO_2 films were also fabricated on the IBAD-MgO films. Figure 2 shows the cross-sectional TEM image of the interface between IBAD-MgO and PLD-CeO_2. This figure reveals that MgO and CeO_2 films aligned on Y_2O_3. CeO_2 film is cube-on-cube on MgO. So, MgO<001> and CeO_2<001> are parallel to the substrate normal, and MgO<100> and CeO_2<100> are horizontal to the substrate normal. Lattice mismatch between MgO and CeO_2 is 28.5% in this orientation relationship. But there are no secondary phases and amorphous layers at the interface, and an in-plane texture of the CeO_2 film (ΔΦ) is about 4°.

Then, we fabricated a 1-km-length IBAD-MgO film at a speed of 1 km/h. To evaluate in-plane texture of IBAD-MgO, PLD-CeO_2 films were fabricated on short samples cut from each 20 m of IBAD-MgO. Figure 3 shows in-plane textures of CeO_2 films and tape positions. It is revealed that IBAD-MgO film at a production rate of 1 km/h has stable properties. An average of in-plane textures is 4.2° and a standard deviation is 0.1°. So we successfully fabricated 1 km IBAD buffer layer at a production rate of 1 km/h. This is very important in terms of commercial aspects such as production cost of superconducting wires and mass of

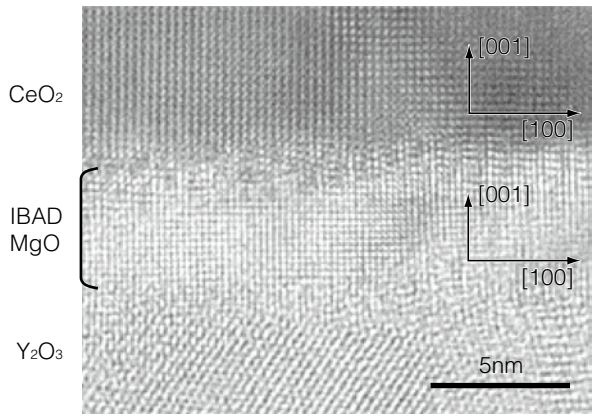

Fig. 2. A cross-sectional TEM image of the interface between IBAD-MgO and PLD-CeO_2.

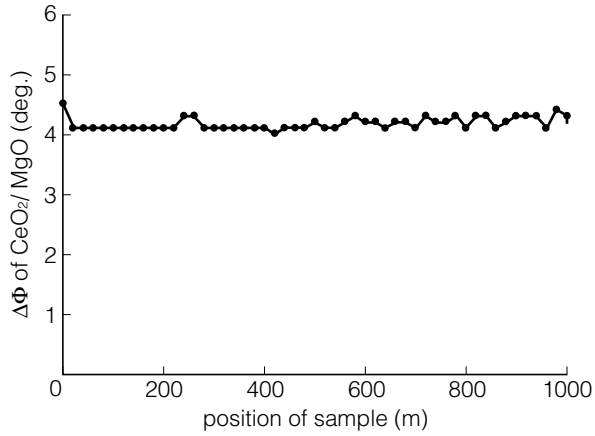

Fig. 3. In-plane texture of 1 km biaxially textured CeO_2 layer on IBAD-MgO. Production rate of IBAD-MgO was 1 km/h.

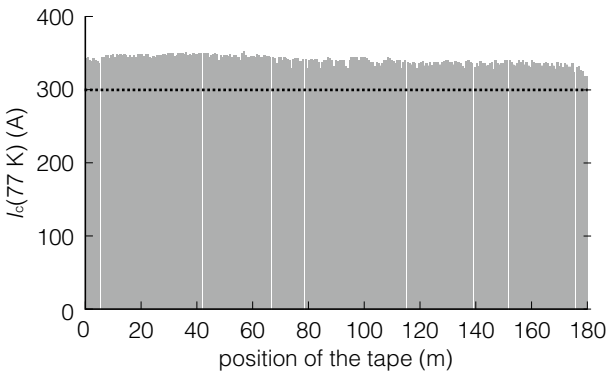

Fig. 4. Profile of critical current of GdBCO on CeO_2/MgO film. Film thickness is 1 μm and critical current density is over 3 MA/cm^2.

production.

To verify the superconductivity on such a buffer layer structure as CeO_2/MgO, $GdBa_2Cu_3O_{7-X}$ film was fabricated on 180 m sample. Figure 4 shows I_c property of the 1.0 μm thick $GdBa_2Cu_3O_{7-X}$ film. It is revealed that $GdBa_2Cu_3O_{7-X}$ film shows high J_c (> 3MA/cm^2) on a long-length PLD-CeO_2/IBAD-MgO tape.

3. Conclusion

IBAD-MgO film was fabricated by the IBAD system with the world's largest ion source on a large deposition area. PLD-CeO_2 films were also successfully fabricated directly on IBAD-MgO films. So we could obtain simple buffer structure for superconducting layer. TEM observation suggested that CeO_2<100> and MgO<100> are horizontal to the substrate. These orientation relationships resulted in 28.5% mismatch between CeO_2 and MgO for lattice constants. But we successfully obtained highly textured CeO_2 films with an in-plane texture (ΔΦ) of 4°.

A 1-km-length IBAD-MgO film was fabricated at a production rate of 1 km/h. In-plane texture of CeO_2 film deposited on IBAD-MgO films cut from 20 m each. An average and a standard deviation of the CeO_2 film at 20 m each were 4.2° and 0.1°, respectively. To evaluate the superconductivity of GdBCO films on CeO_2/MgO substrate, a 180-m-length GdBCO film was fabricated. Its critical current and critical current densities were over 300 A and 3 MA/cm^2, respectively. It is confirmed that long-length IBAD tapes for coated conductors could fabricate actually at 1 km/h.

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