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-CeO2 films directly on IBAD-MgO films. From an observation by TEM of the interface between MgO and CeO2 films, it is revealed that CeO2 film has fine-textured structure on IBAD-MgO though lattice mismatch is large (28.5%). Using the CeO2/MgO substrate, we fabricated PLD-GdBa2Cu3O7-x (GdBCO) film and obtained a high-performance superconducting film whose $I_c$ and $J_c$ were over 300 A and 3 MA/cm², respectively, at 77 K, self-field.

1. Introduction
Long-length REBa2Cu3O7-X conductors with a high performance have been fabricated by a reel-to-reel system in the world. REBa2Cu3O7-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 REBa2Cu3O7-X are very sensitive to its grain-boundary misorientations$.^1$ So, if we aim to obtain a high-performance REBa2Cu3O7-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 REBa2Cu3O7-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 LaMnO3 or CeO2/LaMO3 layers on an IBAD-MgO layer, because lattice mismatches between MgO and REBa2Cu3O7-x, and between MgO and CeO2 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-CeO2 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 $\times$ 10 mm$^2$), Al2O3 film and Y2O3 film were fabricated by a sputtering method. Roles of Al2O3 and Y2O3 film are diffusion barrier of metal elements from substrate, and nucleation layer for IBAD-MgO, respectively. Film thicknesses of Al2O3 and Y2O3 were 100-200 nm and 10-20 nm, respectively. Then IBAD-MgO films were formed on the Y2O3/Al2O3 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,
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-CeO₂ films were deposited directly without LaMnO₃ interlayer. Standard thickness of the CeO₂ film was 500 nm. In-plane texture of the CeO₂ film was evaluated from full-width-at-half maximum of X-ray phi-scan of CeO₂ (220) peaks. To analyze atomic structure of CeO₂/MgO interface, a TEM was employed.

To evaluate the long-length PLD-CeO₂/IBAD-MgO film, we fabricated 1-km-length IBAD-MgO tape at 1 km/h and deposited PLD-CeO₂ film on the short samples cut from each 20 m. Further, to verify whether CeO₂/MgO substrate is reliable for superconducting layer, GdBCO film was deposited on CeO₂/MgO/Y₂O₃/Al₂O₃ substrate and its Ic was measured by a 4-probe method at 77K in a self-field. The criterion of Ic was 1 μA/cm.

2.2 Result

IBAD-MgO films were successfully fabricated by the large IBAD system. Besides, PLD-CeO₂ 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-CeO₂. This figure reveals that MgO and CeO₂ films aligned on Y₂O₃. CeO₂ film is cube-on-cube on MgO. So, MgO<001> and CeO₂<001> are parallel to the substrate normal, and MgO<100> and CeO₂<100> are horizontal to the substrate normal. Lattice mismatch between MgO and CeO₂ 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 CeO₂ film (∆Φ) 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-CeO₂ films were fabricated on short samples cut from each 20 m of IBAD-MgO. Figure 3 shows in-plane textures of CeO₂ 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-CeO₂.

Fig. 3. In-plane texture of 1 km biaxially textured CeO₂ layer on IBAD-MgO. Production rate of IBAD-MgO was 1 km/h.

Fig. 4. Profile of critical current of GdBCO on CeO₂/MgO film. Film thickness is 1 μm and critical current density is over 3 MA/cm².
production.
To verify the superconductivity on such a buffer layer structure as CeO₂/MgO, GdBa₂Cu₃O₇-x film was fabricated on 180 m sample. Figure 4 shows $I_c$ property of the 1.0 μm thick GdBa₂Cu₃O₇-x film. It is revealed that GdBa₂Cu₃O₇-x film shows high $J_c$ (> 3MA/cm²) on a long-length PLD-CeO₂/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-CeO₂ films were also successfully fabricated directly on IBAD-MgO films. So we could obtain simple buffer structure for superconducting layer. TEM observation suggested that CeO₂<100> and MgO<100> are horizontal to the substrate. These orientation relationships resulted in 28.5% mismatch between CeO₂ and MgO for lattice constants. But we successfully obtained highly textured CeO₂ films with an in-plane texture ($\Delta \Phi$) of 4°.

A 1-km-length IBAD-MgO film was fabricated at a production rate of 1 km/h. In-plane texture of CeO₂ film deposited on IBAD-MgO films cut from 20 m each. An average and a standard deviation of the CeO₂ film at 20 m each were 4.2° and 0.1°, respectively. To evaluate the superconductivity of GdBCO films on CeO₂/MgO substrate, a 180-m-length GdBCO film was fabricated. Its critical current and critical current densities were over 300 A and 3 MA/cm², respectively. It is confirmed that long-length IBAD tapes for coated conductors could fabricate actually at 1 km/h.

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