Rectangular (1 cm × 12 cm) YBCO films prepared by MOD using spin-coating and wire-bar coating

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Abstract. 1 cm × 12 cm rectangular YBCO films for fault current limiter devices were prepared by MOD. Usually, solution coating in MOD is carried out by spin coating. However, there are some problems associated with spin coating of large-size rectangular substrates. Namely, the maximum substrate dimension is limited by cup size and motor torque of the apparatus. It was found that wire-bar coating is a promising alternative; this method is more easily scaled up to a large size at lower cost. By both methods, YBCO films with high $J_c$'s around 2 MA/cm² were obtained on CeO₂-buffered sapphire. So far, the uniformity of $J_c$ in the YBCO films prepared by spin coating was better than those by wire-bar coating.

1. Introduction
Superconducting thin film fault-current limiters (FCL) are one of the most promising applications of high-temperature superconductor films. Large-size rectangular YBa₂Cu₃O₇ (YBCO) films are necessary for fabricating FCL devices, such as 1 cm × 12 cm [1] or 3 cm × 10 cm size [2].

Large-size YBCO films have successfully been prepared by various methods, such as vacuum evaporation [3], pulsed laser deposition and metal organic deposition (MOD) [4]. Among these processes, MOD enables the lowest production cost and non-vacuum process, which is suitable for mass production of YBCO films. Usually, MOD employs spin coating for application of a coating solution on the substrates. However, there are some problems associated with spin coating on rectangular substrates. Thus, we have tried another coating method, namely, wire-bar coating, in this study.

2. Solution coating methods on rectangular substrates for MOD process
The spin coating method is one of the most mature methods not only for MOD but also for depositing photo resist films onto wafers in semiconductor manufacturing. Figure 1(a) shows schematic drawings of spin coating. An excessive amount of solution is dropped through a nozzle onto a substrate. Next, the substrate is rotated and accelerated to the final spin speed (w), where the excess solution is flung off the substrate. The maximum substrate dimension for spin coating is limited by the cup size and motor torque of the apparatus. Thus, the price of the coater rises as the size increases

Alternative coating method is schematically shown in figures 1(b), namely, the wire-bar coating process. In this process, the solution is fed through gaps between spiral-wound wires and coated onto a substrate by moving of either wire or the substrate at a constant speed. The film thickness is mainly controlled with the diameter of wire (r). This process require no high-torque motors for spinning
substrates, and is a simpler and the lower-cost apparatus for 10-50 cm long works, which is the target size of superconducting FCL elements.

3. Preparation of 1 cm ×12 cm YBCO films by MOD using spin-coating

Rectangular (1 cm ×12 cm) YBCO films were prepared on CeO₂-buffered sapphire (CbS) by MOD using spin-coating method. The apparatus used was model ASS-502 of ABLE Co., Ltd., the maximum work size being 33 cm-φ. From the preliminary experiments, uniform spin-coating of a rectangular (1 cm ×12 cm) substrate with the solution is far more difficult than of substrates with lower aspect ratios, i.e., discs or squares. The thickness of the coated film is apparently fluctuated at the leading edge of the substrates due to the Bernoulli effect [5]. The use of a recessed chuck was found to be essential for obtaining homogeneous coating on the rectangular substrates with such a high aspect ratio. A metal acetylacetonate-based solution with a molar ratio Y:Ba:Cu = 1:2:3 was spin-coated onto the substrates in a recessed chuck at 2000 rev./min and heated at 500°C in air to remove most of the organic component. This coating-pyrolysis procedure was repeated twice to increase film thickness. The prefired films were annealed at 750°C for crystallization of YBCO. The detailed procedure of annealing was reported in the previous article [4]. The thickness of the product films was approximately 0.2 μm.

Spatial distribution of critical current density \(J_c\) of the films was investigated by mapping analysis of inductive-\(J_c\) measurement (THEVA Cryoscan; probe coil diameter: 5 mm) in liquid nitrogen. Figure 2 shows a typical bar chart of \(J_c\) distribution along the centerline parallel to the long side of a 1 cm ×12 cm-rectangular YBCO film on CeO₂-buffered sapphire by spin-coating method with a recessed chuck.

![Figure 2. \(J_c\)-distribution along the centreline for a 1 cm ×12 cm-rectangular YBCO film on CeO₂-buffered sapphire by spin-coating method with a recessed chuck.](image)

4. Preparation of 1 cm ×12 cm YBCO films by MOD using wire-bar coating

Spatial distribution of critical current density \(J_c\) of the films was investigated by mapping analysis of inductive-\(J_c\) measurement (THEVA Cryoscan; probe coil diameter: 5 mm) in liquid nitrogen. Figure 2 shows a typical bar chart of \(J_c\) distribution along the centerline parallel to the long side of a 1 cm ×12 cm-rectangular YBCO film by spin-coating. Average \(J_c\) of 2.1 MA/cm² along the centerline was obtained. The uniformity of \(J_c\) is fairly good; the standard deviation (σ) of \(J_c\) for the film was 0.32, which is comparable to those of the films with low aspect ratios such as 10 cm ×30 cm by spin-coating [4]. However, it is still larger than commercially available YBCO films by evaporation [3].
Rectangular (1 cm ×12 cm) YBCO films were also prepared by MOD using the wire-bar coating method. The apparatus was model PM-9050MC of SMT Co., Ltd., the maximum work size was 33 cm stroke ×28 cm wide. The solution was applied on CbS substrates using the spiral-wound wires with a 0.3 mm diameter, and the shaft was moved at a constant speed of 40 cm/min. The coated films were similarly pyrolyzed at 500°C in air and annealed at 750°C. The thickness of the product films was approximately 0.1 μm.

Figure 3 shows a typical bar chart of $J_c$ distribution along the centerline parallel to the long side of a 1 cm ×12 cm-rectangular YBCO film on CeO$_2$-buffered sapphire by wire-bar coating method. The wire bar had been moved from the right-hand side to the left hand side.

Figure 3 shows a typical bar chart of $J_c$ distribution along the centerline parallel to the long side of a 1 cm ×12 cm-rectangular YBCO film by wire-bar coating. In case of wire-bar coating, the solution is supplied only once; a pool of solution is formed and spread by the wire bar; its thickness is controlled by the gap between wires and substrate. Therefore, in the wire-bar coating, the solution is liable to be depleted in the downstream side. However, $J_c$ was recognized at all measured points of the film surface, and an average $J_c$ of 1.9 MA/cm$^2$ along the centerline was obtained. So far as we know, this is the first report on the application of wire-bar coating to MOD process for YBCO film preparation. At present, the standard deviation ($\sigma$) of $J_c$ for the films was 0.47, which is slightly larger than that for the above spin-coated film. Wire-bar coating is a promising alternative of spin-coating, because the former being more easily scaled up to a large size at lower cost. Further investigation is required to prepare wider- and longer-size YBCO films with more uniform $J_c$ distribution, and to fabricate thicker films by multi-coating.

5. Summary
Rectangular (1 cm ×12 cm) YBCO films were prepared by MOD using both spin-coating and wire-bar coating methods. By these methods, YBCO films with high $J_c$’s around 2 MA/cm$^2$ were obtained on CeO$_2$-buffered sapphire. So far, $J_c$-distribution in the spin-coated films is more uniform than the wire-bar coated ones. However, wire-bar coating can be a promising low-cost alternative.

References
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