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Improvement of film thickness uniformity in TFA-MOD coated conductors

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Abstract

TFA-MOD process is expected to be promising for future applications since it can produce high performance YBCO coated conductors with low cost. The dip-coating is adopted as the coating process because of its simplicity and controllability of the overall film thickness. Dip-coated films have uniform thickness along longitudinal direction, but not necessary in transverse direction. In the case of thicker films, the more cracks form during processing at the thicker region near the edges generate and propagate mainly due to tensile and bending strain. So we have to suppress the thickness distribution in transverse direction for thicker films for high \( I_C \) values. In this study, we found that the thickness distribution was firstly given by meniscus shape and then the solution flew down till it’s dried. The solution in the center region drops more since it is slowly dried compared with the edge region. Then, we developed a drying process, which accelerates the drying by blowing hot gas to prevent the coated solutions from dropping. As a result, the thickness uniformity was improved; the thickness ratio of the thick region (edge) to the flat one (center) was improved from 1.35 to 1.07. Furthermore, we successfully produced ~1.5\( \mu \)m thick films with high critical current density values (> 2MA/cm\(^2\)) by the new coating process including the force drying step.

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Keywords: YBCO; TFA-MOD; Coating; Thickness distribution

1. Introduction

YBCO coated conductors with high critical current density (\( I_C \)) under the self-fields as well as the external magnetic fields would be expected for applications of electric power devices such as power cables, Superconducting Magnetic Energy Storage (SMES) and transformers. The metal-organic deposition (MOD) method using the starting solution containing trifluoroacetate (TFA) salts is one of the most promising methods for fabrication of long YBCO tapes cost-effectively with high superconducting property[1,2]. High \( I_C \) characteristics are desired for practical applications. Thickening films is a simple approach to improve \( I_C \) values. However, dip-coated MOD films have thickness distribution along transverse direction. In particular, the thicker regions are generated at both ends of the tape as shown in inset of Fig.2(b). And the thicker regions lead to formation of cracks.

In this work, we investigated the mechanism of the film thickness distribution in transverse direction and developed new process to obtain uniform thickness for crack-free thick film.

2. Experimental

The starting solution was prepared by dissolving TFA salts of Y and Ba and Cu-2-ethylhexanoate with a cationic ratio of Y : Ba : Cu = 1 : 1.5 : 3 into the organic solvent[3]. The starting solution was dip-coated on the buffered metal...
substrates with the architecture of CeO$_2$/LaMnO$_3$/IBAD-MgO/GZO/Hastelloy™ using the single-turn Reel-to-Reel (RTR) system as schematic drawn in Fig.1[4]. The dip-coating process was performed under various drying conditions. The tapes were calcinated to form precursor films by increase the temperature to 440 °C in a dry oxygen atmosphere. The dip-coated/decomposed process was repeated to obtain desired thickness. These decomposed samples were heated to 750 °C in a mixed humid gas of argon and oxygen for formation of superconducting layer.

The film thickness was measured by the optical microscopy. $I_c$ values of these YBCO films were measured by the conventional four-probe DC transport method with a criterion of 1 $\mu$V/cm.

3. Results and discussion

As an investigation of the drying behavior of the coated solution, the time dependence of the coated films held vertically on the thickness distribution was studied. Fig.2(a) shows the schematic drawing of experimental condition. We adjusted the time in the vertical state by changing the traveling speed. Fig.2(b) shows the dependence of the thickness ratio of the thick region ($t_2$) to the flat region ($t_1$) on the time in the vertical state. We defined $t_2$ as maximum thickness and $t_1$ as average thickness of center region (6mm width) of tape. The film thickness distribution in transverse direction became uniform by shortening the time spent under the vertical state.

This indicates that the gravity influences the film thickness distribution. We inferred the formation mechanism of the film thickness distribution as follows; the initial film thickness distribution in the coating process was given by meniscus shape and then the solution flew down along the tape surface until drying is finished. The solution in the center region flows down more since it is slowly dried compared with that in the edge region. As a result, the film thickness distribution becomes non-uniform as schematic drawn in Fig.3.
To realize make uniform drying situation, the force drying process was adopted by blowing hot gas to the coated solution. The temperature, flow velocity and flow rate of the hot gas were 100°C, 4m/s and 15L/min, respectively. The hot gas was blown almost vertically against the tape. This new approach made the drying time significantly shorter in whole width area.

Fig. 4 shows the thickness distribution in transverse direction of fired films prepared with and without the force drying step in the dip-coated process. The dip-coated/decomposed process was repeated four times and the traveling speed was 2.1m/h.

The film thickness uniformity was evaluated by the thickness ratio (t2/t1). The ratios of conventional and force dried films were 1.35 and 1.07, respectively. Furthermore, the uniformity was also evaluated by the film amount ratio at the edge region, which is defined as the ratio of the thickness distribution to the rectangular distribution. The area of rectangular distribution is the area surrounded by t2 and the position in transverse direction of t2 as shown in Fig.5(a). The film amount ratio (S2/S1) at the edge region was also improved by adopting the force drying from 59% to 73% (Fig.5(b)). It was confirmed that the force dried sample showed enough high critical current density values ( >2MA/cm²). The improved film thickness distribution are expected to improve $I_c$ distribution in transverse direction. Uniform $I_c$ distribution should help narrowing the filament width for AC loss reduction. Furthermore, the
uniform ~1.5μm thick films with uniform thicker distribution in transverse direction were successfully produced by the new process including the force drying step. The hot gas and traveling speed were same conditions as described above. Fig.6 shows the thickness distribution in transverse direction of ~1.5μm thick films prepared with the force drying step.

![Graph showing thickness distribution](image)

**Fig. 6.** Thickness distribution in transverse direction of ~1.5μm thick films prepared with the force drying step

4. Conclusion

We investigated the mechanism forming the film thickness distribution in transverse direction for dip-coated MOD films. That distribution became uniform by shortening the time spent under the vertical state. From this result, we thought that the gravity and the difference of drying speed between the edge region and the center one caused the film thickness distribution.

So we modified the drying process to prevent the solution from flowing down. We successfully improved the film thickness distribution by adopting the new process including the force drying step. And the uniform ~1.5μm thick films were successfully produced by the new process. This could improve \( I_c/J_c \) distribution and help narrowing the filament width for AC loss reduction.

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References