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# Long Length YBCO Coated Conductors Prepared by an MOD Process on Buffered Metallic Tapes

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*Abstract*-- **YBCO coated conductors have been fabricated by the reel-to-reel processing using TFA-MOD method. In this work, the fluorine-free Y & Cu precursor solution was synthesized to shorten the calcining time by reducing the evolution of HF gas, thus the meter-long YBCO precursor films can be made within few hours by the continuous slot-die coating & calcination step using the F-free Y & Cu precursor solution. The annealing step was followed to make the YBCO films by the reel-to-reel method with the vertical gas flow system onto the moving tape. To increase the growth rate of the YBCO films by enhancing the removal of HF gas, the low total pressure was adopted in the annealing processing. And the water partial pressure and the oxygen partial pressure were varied to optimize the growth conditions of the MOD-YBCO films on the buffered metal tape. FE-SEM and XRD were used to investigate the surface morphologies and the texture of the meter-long YBCO films. The end-to-end critical current ($I_c$) of 63A/cm-width and the critical current density ($J_c$) of 0.9MA/cm$^2$ with the thickness of 0.7μm were obtained in the 0.42m long coated conductor.**

## 1. INTRODUCTION

The significant efforts have been focused on the development and the applications of the high $T_c$ superconducting coated conductors worldwide [1-2]. The high critical current ($I_c$) and the critical current density ($J_c$) at 77K and self-field were obtained not only on the short samples but also on the longer ones. The metal organic deposition (MOD) method is one of the promising candidate to fabricate coated conductors in long-length, since the processing cost is low, the precise control of precursor stoichiometry is possible, the fabrication system is easily scaled up to long length, and the expensive vacuum system is not required. In addition, the high performance of coated conductors using the MOD method was confirmed with the critical current density over MA/cm$^2$ and long-length over several tens of meters [1-3].

However, when the TFA for all metal elements was used in the conventional TFA-MOD process, the calcining time was about ten hours for a single coating of precursor solution. To shorten the calcining process, the fluorine-free Y & Cu organic salts and Ba-TFA salts was selected as starting materials for TFT-MOD method. The continuous slot-die coating & calcination step was performed to form the YBCO precursor films on the buffered metal tape using the F-free Y & Cu precursor solution. And followed was next step of reel-to-reel annealing process to fabricate the superconducting YBCO films on buffered metal tape with the vertical gas flow system onto the moving tape. The above two step process was adopted to fabricate the long YBCO coated conductors.

In this paper, the results for the continuous slot-die coating & calcination step on the meter-long buffered metal tape using the F-free Y & Cu precursor solution and the reel-to-reel annealing step of YBCO films are reported. Also, the surface morphology and the texture of the meter-long YBCO films fabricated in two step process are investigated.

## 2. EXPERIMENTAL

The buffered metal tape used in this experiment was the biaxially alligned Ni-5at%W alloy tape buffered with $CeO_2$/ YSZ/$CeO_2$ layer. The seed layer $CeO_2$ films was formed by the thermal evaporation using Ce metal. The YSZ layer on top of it was coated by D.C. sputtering method using metal target composed of Y and Zr. Then, as the capping layer for the MOD-YBCO layer, $CeO_2$ was deposited by the reel-to-reel pulsed laser deposition [4].
The fluorine-free Y & Cu precursor solution doped with Sm was coated on the buffered metal tape using the continuous slot-die coating & calcination step. The coated films were heated up to 400°C in the humid oxygen atmosphere in the continuous reel-to-reel method. To obtain the thicker films by one single coating, the viscosities of the YBCO precursor solution, die gap, and the moving speed of the buffered metal tape were varied appropriately. The YBCO precursor films were successively annealed in reel-to-reel method using the vertical gas flow system. The YBCO precursor films are moved through the long tube furnace held at 780°C with the humid Ar/$O_2$ gas mixture flowed vertically down. In the reel-to-reel annealing step, the low oxygen partial pressure of about 500ppm and the water partial pressure of 6.3% were used.

The evaluation of YBCO films on the buffered metal tape was conducted using the x-ray diffraction (XRD) for the phase identification and the field emission-scanning electron microscope (FE-SEM) for the surface and cross section microstructures. The critical current measurement was done using the four-probe method and the distribution of critical current was analyzed for the homogeneity of the long coated conductors.

## 3. RESULTS AND DISCUSSION

Fig. 1 shows the typical θ-2θ scans of the buffered metal tape used in this experiment. The FWHM values of the φ-scans was 7.4°, 7.2°, and 7.3° for Ni-5at%W(111), YSZ(111), and $CeO_2$(111) respectively, which indicate a well textured in-plane structure on the bi-axially aligned metal substrates [4]. And the thickness of the buffer layer was controlled to be 20nm for the $CeO_2$ seed layer grown on top of the Ni-5%W metal tape. To prevent the diffusion of the metal element from the substrate, the YSZ layer of the thickness 100nm was deposited by the D. C. magnetron sputtering method. And the 200nm thickness of $CeO_2$ layer was deposited by the PLD method as the capping layer for the MOD-YBCO films.

The YBCO precursor films on the buffered metal tape formed by the continuous slot-die coating & calcination step using the F-free Y & Cu precursor solution doped with Samarium were smooth and crack-free. To obtain the thicker YBCO precursor films from the single coating, the viscosities of the YBCO precursor solution were controlled from 60cP to 200cP. About the 2.5μm thick YBCO precursor films was recognized with the viscosity of 200cP. In this study, the moving speed of the buffered metal tape was varied according to the full coverage of the width of the buffered metal tape.

The next reel-to-reel annealing step was followed to form the YBCO films from the YBCO precursor films on the buffered metal tape. The YBCO precursor films on the buffered metal tape were moved through the tube furnace with predetermined heating profile and moving speed of the tape. To increase the growth rate, low total pressure was adopted to enhance the removal of HF gas from the surface of the YBCO precursor films [5].

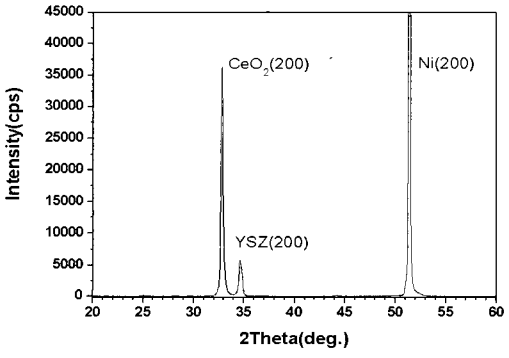


Fig. 1. Typical θ-2 θ patterns of the buffered metal tape.

In Fig. 2, the preliminary test results of 1m-long coated conductors was shown using two step processes. The fist step of slot-die coating & calcination start from the left to the right. After the second step of reel-to-reel annealing, the left part of YBCO films showed high resistance where the slot-die coating began and also moved through the annealing furnace ahead. The surface and cross section morphology of the coated conductors are also different between the two regions. The un-reacted phase and $BaF_2$ phase were found in the left part of the YBCO films and thickness of the YBCO films was about 0.6μm, which was two times higher than the right part of the 0.3μm thick YBCO films. The typical surface morphologies in TFA-MOD process characterized with the c-axis oriented micro -structure was obtained only in the right part as shown in Fig. 2 [6-7].

And the annealed films exhibited high phase purity YBCO (00L) peaks in the right part of the films whereas the un-reacted phase like $BaF_2$ was identified in the left, as shown in Fig. 3.

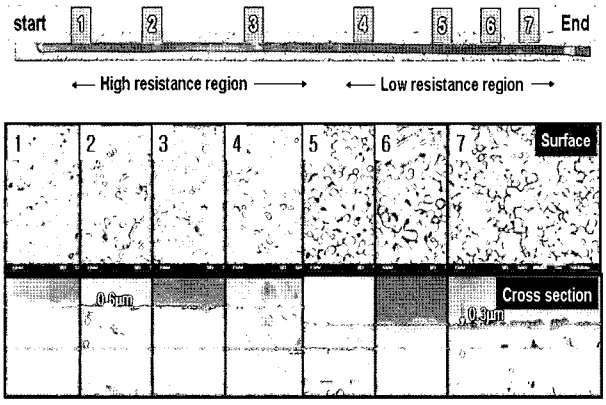


Fig. 2. Preliminary test of the 1m-long coated conductor. The slot-die coating starts from the left to the right. Also, shown are the surface and the cross section micrograph of the annealed MOD-YBCO coated conductor.

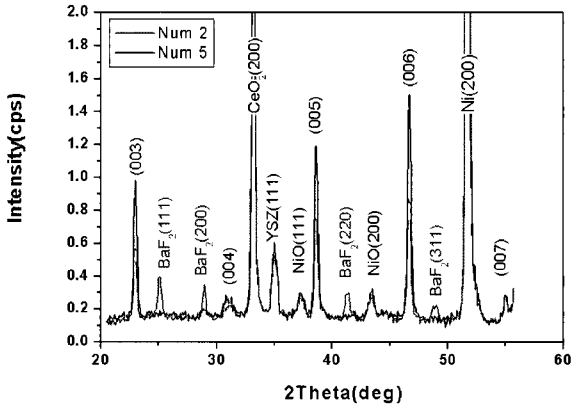


Fig. 3. XRD patterns of the preliminary test of the 1m-long length coated conductor. The left part of YBCO films showed un-reacted phase like $BaF_2$.

From the preliminary test results of the 1m-long coated conductors, the thickness of YBCO precursor films formed by the continuous slot-die coating & calcination step was not uniform throughout the long length and the thicker part of the YBCO precursor films are not converted to YBCO films completely.

After the careful control of the thickness of the slot-die coating of the fluorine-free Y & Cu precursor solution doped with Sm, YBCO precursor films formed by the continuous slot-die coating & calcination step was uniform throughout the films with the thickness of about 1.4μm. And the YBCO films formed by the reel-to-reel annealing step followed showed the end-to-end critical current ($I_c$) of 63A/cm-width in 0.42m-long coated conductor as shown in Fig. 4 The critical current density ($J_c$) of 0.9MA/cm$^2$ with the thickness of 0.7μm was obtained. To increase the critical current of YBCO coated conductor, the optimization of process variables in the reel-to-reel annealing step is going on, especially with the annealing heating profile.

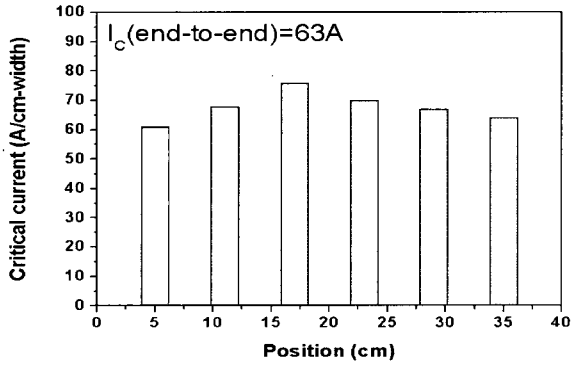


Fig. 4. The critical current distribution of 0.42m-long YBCO coated conductor fabricated using the continuous slot-die coating & calcination and following reel-to-reel annealing.

## 4. CONCLUSIONS

The reel-to-reel processing was done to fabricate long length YBCO coated conductors. By using the fluorine-free Y & Cu precursor solution, the calcining time was significantly reduced, thus smooth and crack-free precursor YBCO films on meter-long buffered metal tape was obtained by the continuous slot-die coating & calcination step. The YBCO films annealed by reel-to-reel method showed the end-to-end critical current of 63A/cm-width and the critical current density of 0.9MA/cm$^2$ with the thickness of 0.7μm in the 0.42m-long coated conductor.

## ACKNOWLEDGMENT

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