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Angular dependence of critical current of SmBCO coated conductor fabricated by co-evaporation method

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Abstract-- **Angular dependence of critical current density of SmBCO coated conductor fabricated by co-evaporation method was investigated. For comparison, three samples were fabricated by a co-evaporation method and one sample was fabricated by a pulsed laser deposition process. The deposition system, named EDDC (Evaporation using Drum in Dual Chambers), is a batch type co-evaporation system, which is composed of reaction chamber and evaporation chamber. The normalized critical current density ratio (I_c/I_c(H//ab-plane)) of EDDC-SmBCO samples was found to be higher than that of PLD-YBCO sample in the whole range of angle. While the EDDC-SmBCO samples evidently had a peak at the angle of H//c-axis in the plot of the angular dependence of critical current, the normalized critical current of PLD-YBCO sample decreased monotonically without any peak as angle increased. The field dependence of critical current under the magnetic field parallel to the normal direction of those samples showed similar aspect in the range of 0 G ~ 5000 G.**

1. INTRODUCTION

The fabrication technology of High T_c coated conductor (CC) has been approached to the level of commercial scale that high performance CC can be available as long as several hundred meter. Among many fabrication processes having been tried so far, MOCVD, MOD and evaporation methods seem to be promising and suitable for mass production. We adopted evaporation technique and developed EDDC (Evaporation using Drum in Dual Chambers) system [1-2] that is a batch type co-evaporation system. EDDC system has the following advantages: 1) The production rate is fast. In EDDC system, there is a drum on which a hundred meter long tape can be wound up to deposit superconducting materials. The required time for 1.3 micron thick SmBCO film is about 1 hour. The calculated production rate for the deposition of superconducting layer is about 100 m/h. If the EDDC system is scaled up, the production rate will be faster in proportion to the size of drum. 2) EDDC system has the possibility of in-situ deposition processing for the superconducting coated conductor of multi layer structure. When the temperature of the drum is raised to the processing temperature, the composing layers can be deposited in series. Therefore, the total time to get a finished product can be reduced by means of omitting the time of pumping for respective layers, transferring tapes from one chamber to the other chamber, increasing temperature and cooling down temperature etc. 3) EDDC system uses metallic sources that are cheaper and more easily transformed into desired shapes than ceramic target and organic metal. They will result in not only reducing the cost of CC production but also increasing production speed. We successfully fabricated high performance SmBCO coated conductor of length: 30 m, critical current: 185 A/cm (End to End measurement) in EDDC system. For the magnet application, it is very important that the superconducting coated conductor should have high critical current under high magnetic field and have less anisotropic J_c for field direction variation. High critical current under high magnetic field can be accomplished by introducing artificial pinning centers such as irradiation, rare-earth mixing, substrate decoration etc.

In this paper, the detailed structure of EDDC system was described and the angular field dependence of critical current of SmBCO coated conductor was investigated using samples fabricated by EDDC and PLD for comparison, and the field dependences of critical current of those samples with the magnetic field parallel to the normal direction of them were investigated.

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2. EXPERIMENT

The EDDC deposition system is composed of dual chambers that are named as reaction chamber and evaporation chamber. The role of evaporation chamber is to evaporate the metallic materials of Sm, Ba and Cu respectively. The compositional ratio of Sm:Ba:Cu is controlled by three QCM(Quartz Crystal Microbalance)s. Each QCM has SUS tube in front of QCM sensor which is aligned to the metallic sources of Sm, Ba and Cu respectively to sensor the deposition rate of the aligned material. Strictly speaking, the deposition rate of each QCM is influenced by other materials slightly according to

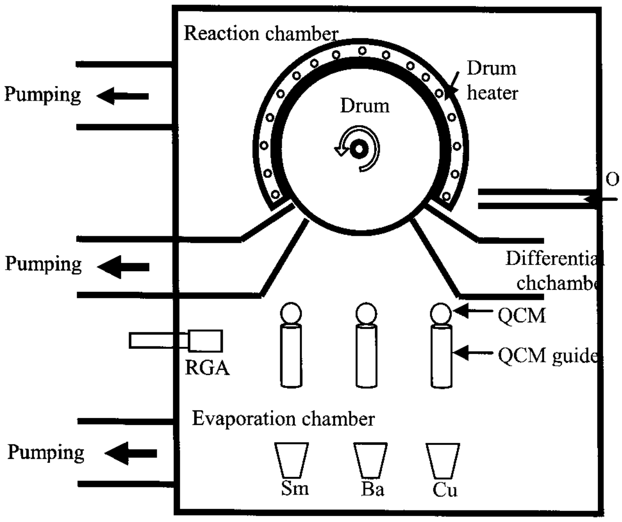

Fig. 1. The schematic diagram of EDDC (Evaporation using Drum in Dual Chambers) deposition system.

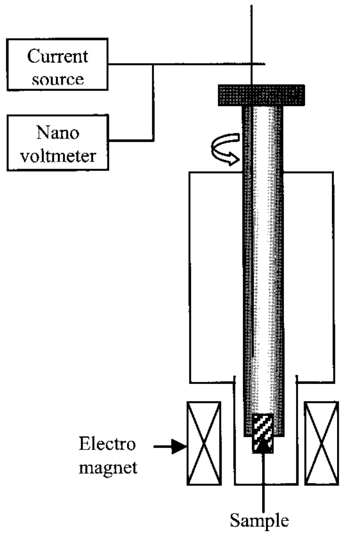

Fig. 2. The apparatus for measuring the field dependency of superconducting coated conductor.

the pressure of evaporation chamber. This is due to the scattering of the atoms of composing materials in ambient atmosphere. Sm and Cu were evaporated using high frequency induction method while Ba was evaporated using the radiation of halogen lamps. The residual gases in evaporation chamber were monitored by RGA (Residual Gas Analyzer)

The drum is exposed to both evaporation chamber and reaction chamber. The substrate on the drum expose to deposition chamber and evaporation chamber by the rotation of the drum. When the substrate is exposed to evaporation chamber, the composing elements of SmBCO are deposited on it in the partially metal state. Subsequently when the tape on drum is exposed to reaction chamber by rotation, the composing elements of Sm, Ba and Cu react with oxygen and form $Sm_1Ba_2Cu_3O_{7-d}$ phase. The drum is heated by the radiation of halogen lamps. The axis of the drum is extended to the outside of the chamber with ferro-sealing and connected with a motor that is capable of rotating the drum with the speed of 90 rpm.

Oxygen gas is fed to the reaction chamber through the tube that surrounds the drum. The tube has many uniformly spaced pinholes with closed to make it possible for the tape on drum to experience uniform oxygen partial pressure. While the partial pressure of oxygen in reaction chamber is kept 15 mTorr, in evaporation chamber it remained $2x10^{-4}$ Torr by means of differential pumping technique before evaporation. But the total pressure in evaporation chamber is lowered to $5x10^{-5}$ Torr during evaporation of elements from three sources by virtue of oxygen absorbing reaction with Sm and Ba.

3. RESULTS AND DISCUSSION

We prepared four samples with the size of 5 mm x 20 mm that are severed from long CC for measuring physical properties.

First sample (a) was fabricated by PLD (Pulsed Laser Deposition) method with the YBCO thickness of 2 μm, the critical current of 200 A/cm, the corresponding critical current density of 1 MA/cm^2 and the cross-sectional structure of Ag (protecting layer)/YBCO (superconducting layer)/CeO_2 (capping layer)/YSZ (diffusion barrier layer)/Y_2O_3 (seed layer)/Ni-5%W (textured metallic substrate) for the purpose of comparison with EDDC - Sm BCO samples.

Second sample (b) was fabricated using EDDC method with the SmBCO thickness of 1.1 μm, the critical current of 73 A/cm, the critical current density of 0.7 MA /cm^2 and thecross-sectional structure of Ag/SmBCO/CeO_2/YSZ/Y_2O_3/RABiTS.

Third sample (c) was fabricated using EDDC method with the SmBCO thickness of 1.1 μm, the critical current of 238 A/cm, the critical current density of 2.2 MA/cm^2 and the cross-sectional structure of Ag/SmBCO/CeO_2/YSZ/Y_2O_3/RABiTS.

Fourth sample (d) was fabricated using EDDC method with the SmBCO thickness of 1.1 μm, the critical current of 160 A/cm, the corresponding critical current density of 1.5 MA/cm^2 and the cross-sectional structure of Ag/SmBCO/LMO/MgO-IBAD.

Fig. 2 is the schematic diagram for measurement apparatus of angular dependence of I_c and field dependence with the maximum magnetic field of 5000 G. The critical currents were measured by the conventional four probe method in the liquid nitrogen and determined by the criterion of 1 μv/cm. The current lead was soldered by Pb-Sn solder and the contact area was 5 mm x 5 mm. For angular dependence of I_c measurement, the sample holder was rotated with the constant interval of angle under a magnetic field of 5000 G. For field dependence of critical current measurement, we adjusted the sample holder angle so that the c axis of superconducting layer was parallel to the magnetic field direction. Then the magnetic field was

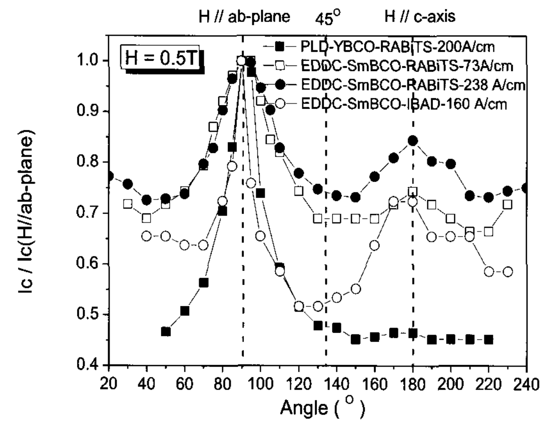

Fig. 3. The normalized critical current ratio (I_c/I_c(H//ab-plane))as the function of angle between the normal direction of the sample and the magnetic field.

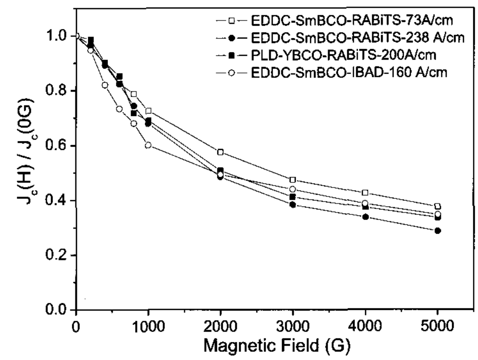

Fig. 4. The normalized critical current density ratio (J_c(H)/J_c(0)) as the function of the magnetic field parallel to the normal direction of the sample.

increased from 0 to 5000 G, the limit of our electro magnet, with constant interval of magnetic field.

Fig. 3 shows the normalized critical current (I_c/I_c(H//ab-plane)) as the function of angle between the normal direction of sample and the magnetic field direction. The normalized critical currents of EDDC-SmBCO samples were higher than that of PLD-YBCO sample almost over the whole angular range. For EDDC-SmBCO-RABiTS-238 A/cm sample shown in Fig. 4 (c), the value of I_c/I_c(H//ab-plane) at 180^0 was 0.85 and the lowest value of it over whole angular range was 0.72. On the other hand, for PLD-YBCO-RABiTS-200A/cm, the value of I_c/I_c(H//ab-plane) at 180^0 was 0.45 and the lowest value of it was 0.44. While the EDDC-SmBCO samples evidently had a peak of normalized critical current at the angle of H//c-axis, the normalized critical current of PLD-YBCO sample decreased monotonically as angle increased. In the SmBCO film on IBAD-MgO template and RABiTS template in EDDC-SmBCO samples, we could not confirm difference in I_c/I_c(H//ab-plane) measurement. We could conclude that the c-axis corelated pinning centers were formed during EDDC processing. It is well known that the peak at the angle of H//c-axis can be observed in those samples with self aligned nano-dots and nano-rods of $BaZrO_3$ [3], or growth on ISD(Inclined Substrate Deposited) template [4] or ion irradiation [5]. Though artificial pinning centers were not added into EDDC-SmBCO samples, they had the peak of c-axis corelated pinning centers. We have not identified the pinning centers yet. We can guess that 1) they may be a kind of self assembled nano-rods nucleated by the slightly deviated compositional ratios from Sm:Ba:Cu=1:2:3 during deposition, 2) grain boundary and 3) nano-sized nucleations on the substrate formed by scattered particles before deposition processing. We are still working on confirming the identity of pinning centers by TEM.

Fig. 4 shows the field dependence of critical current with the magnetic field parallel to the normal direction of the sample. The values of critical current density ratio were similar in the range of 0 G ~ 5000 G. Our samples have little difference from the LTG-SmBCO/IBAD samples fabricated in Yoshida group in the in-field dependence of critical current density [6,7].

4. SUMMARY

Angular dependence of critical current of SmBCO coated conductor fabricated by co-evaporation method was investigated. The results indicate that EDDC-SmBCO samples have less anisotropic J_c compared with YBCO-PLD sample under the magnetic field of 5000 G, and EDDC fabrication method have a potential of self c-axis corelated pinning center formation without any additional process such as adding impurity in the film, using ISD template, ion irradiation, etc.

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