WBP2-1

REBCO superconductor with ultimately dispersed PrBCO for pinning centers fabricated by TFA-MOD

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Metal Organic Deposition using Trifluoroacetates deposition (TFA-MOD) is a low-cost non-vacuum approach that offers high reproducibility, making it one of the best candidates for preparing uniform long tape of rare-earth barium copper oxide (REBCO). Although many groups have improved critical current density (J_c) for REBCO superconductors in a magnetic field by introducing artificial pinning centers (APCs) such as $BaMO_3$ fabricated by Pulsed Laser Deposition or Metal Organic Chemical Vapor Deposition, these films have less uniformity and degraded critical temperature (T_c) values. Furthermore, it is difficult to introduce APCs by TFA-MOD. We therefore attempted to establish a new perovskite structure in which non-superconducting PrBCO co-exists with superconducting REBCO. Here, PrBCO serves as an atom replaced pin (ARP). We prepared a purified coating solution and obtained REBCO superconductor dispersed with PrBCO. TEM observation of the film in which the YBCO matrix was substituted with 10 mol% PrBCO revealed a completely uniform structure as shown in Fig. (a). XRD results for the film showed a single REBCO(00n) phase. The above two results suggest that ultimately dispersed PrBCO unit cells co-exist with YBCO unit cells. Figure (b) shows the relationship between substituted Pr concentration at Y sites and T_c. At concentrations of up to 8 mol% Pr, T_c values were kept around 90.7 K. ARPs appeared not to degrade the T_c value because they do not withdraw oxygen from neighboring YBCO unit cells as reported for $BaMO_3$ pins. To improve J_c-B properties, dispersed PrBCO needs to be accumulated at one site. We added 2 mol% Pr, 2 mol% Sm (as large unit cells) and 4 mol% Tm (as small unit cells) to YBCO and were able to improve J_c-B properties as shown Fig. (c).

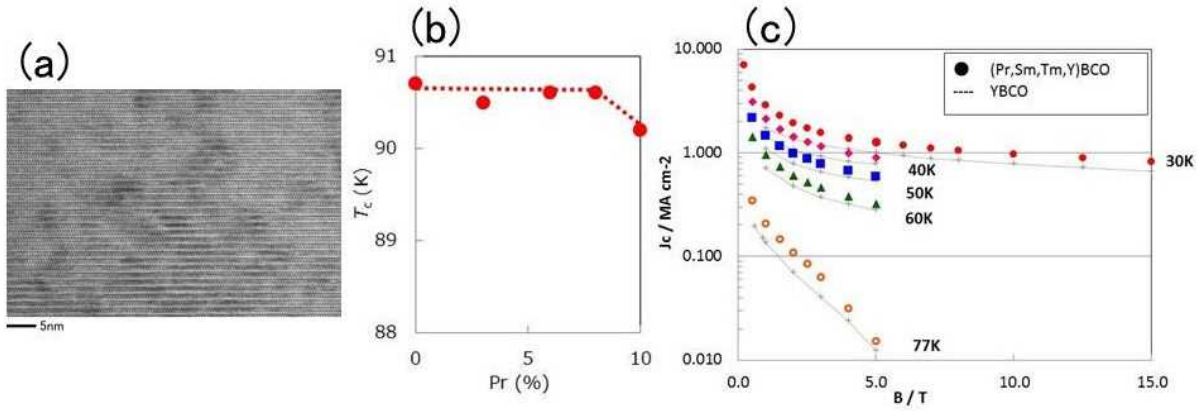

Fig. (a) Cross-sectional TEM observation of $(Pr_{0.1},Y_{0.9})BCO$. (b) Dependence of T_c on Pr concentration. (c) J_c-B properties of $(Pr_{0.02},Sm_{0.02},Tm_{0.04},Y_{0.92})BCO$.

Keywords: TFA-MOD, Atom Replaced Pin, PrBCO, Critical temperature

WBP2-2

Co-doping effects on the fabrication of fluorine-free MOD-GdBCO films

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It is essential to develop REBCO coated conductors of a low cost and excellent mass productivity with high J_c-B performances for the application of the REBCO superconducting films to high current-carrying superconducting wires. In order to accomplish the purpose, we have been studied the fabrication of REBCO films by a fluorine-free metal organic deposition (FF-MOD) method. In our previous study, we studied the effect of Ho or Zr addition on the fabrication of fluorine-free MOD-GdBCO films, and found that the J_c-B performance of the films are improved by Ho or Zr oxides formed in the film. Furthermore, we have investigated the effect of La addition on the fabrication of fluorine-free FF-MOD GdBCO films. The GdBCO film with La addition showed the improved J_c at the self-magnetic field and the decrease in the number density of holes on the film surface. The J_c at the self-magnetic field for the La-added GdBCO film was 1.7 times as high as that of the pure GdBCO film, however, the J_c-B performance has not improved yet. In the present study, we have studied the co-doping effects of La and Zr, or La and Ho to improve the J_c-B performance by investigating the superconductivity properties and crystal growth of FF-MOD GdBCO films. La and Zr co-doped GdBCO films up to the amount of 3.0 mol% Zr showed the enhancement of the c-axis orientation compared to the pure GdBCO film. The increase of the average size and density of the hole were observed on the film surface with the increase of the Zr doping amount. The La-doped GdBCO film with Zr co-doing of over 5.0 mol% suppressed the crystal growth of the superconductive phase. The 1.0-mol%-La-doped GdBCO film showed a J_c of 2.32 MA/cm^2. On the other hand, 1.0mol%-La and 1.0mol%-Zr co-doped films showed the improved a value, though the decrease of the J_c at the self-magnetic field compared to La-doped film. These results indicate that the La and Zr co-doping into the GdBCO film has an effect on the improvement of the J_c-B performance of the film.

Keywords: Thin film, MOD, La, Zr, Ho, Fluorine-free

WBP2-3

Flux pinning properties of hafnium doped Gd123 films fabricated by fluorine-free MOD method with multistage heat treatment

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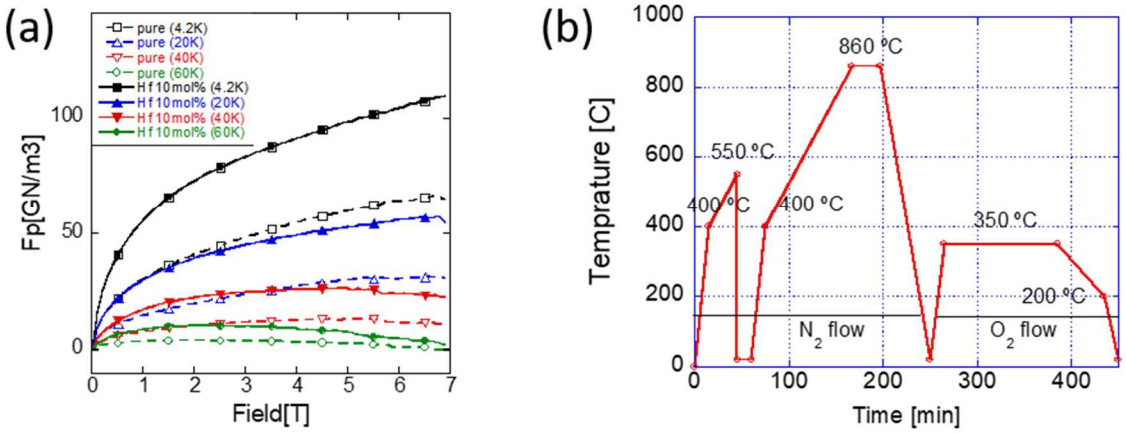
We have fabricated Hf doped FF-MOD $GdBa_2Cu_3O_y$ (Gd123) thin films on $LaAlO_3$ substrates and investigated their flux pinning properties. Temperature dependence of J_c in magnetic fields parallel to the c-axis orientation up to 7 T was estimated from the width of the magnetization curves using the modified critical state model. Critical temperature for Gd123 thin films indicated around 92 K, and T_c varied little by Hf doping. Hf 10 mol% doped film achieved high critical current densities of 2.72 MA cm^{-2} at 77.3 K under 0 T, and 0.27 MA cm^{-2} at 77.3 K under 1 T. With increasing Hf doping amount, F_p gradually increased, and the peak of F_p shifted to the high magnetic field side. The elementary pinning force and the effective pinning center density also increased. We believe that effective APCs, probably $BaHfO_3$ are introduced into FF-MOD Gd123 thin films by Hf doping. Furthermore, it has been studied that the size of APCs can be miniaturized by multistage heat treatment to obtain more efficient flux pinning.



Keywords: artificial pinning centers, fluorine-free metal organic deposition, GdBa2Cu3Oy, Hf doping

WBP2-4

Fabrication of coated conductor with artificial pinning center by MOD method using new calcination process

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High temperature superconductor (HTS) is nearing practical use in some devices such as MRI, NMR and cable. Among them, especially high field applications, it is expected that HTS exhibiting high critical current even in magnetic field at liquid nitrogen temperature is going to be developed. In these days, coated conductor (CC) with an artificial pinning center (APC) is becoming possible to manufacture, however, the performance and the cost have not achieved to market requirements.

We manufacture CC by Metal Organic Deposition (MOD) method. It is known that the thickness of each coating and calcination step is repeated to the characteristics in magnetic field, and Izumi et. al. reported that 30 nm of d_{once} is an appropriate thickness to obtain high critical current density (J_c) value in magnetic field.[(1), (2)]

We have manufactured 120 m-long YGdBaCuO with BaZrO APC which had d_{once} was 150 nm and obtained the J_c value of 2.2 MA/cm^2 (77 K, Self field). In the case, the d_{once} reduced to 30 nm the J_c of the tape reached 4.6 MA/cm^2 (77 K, Self field) even in using a production scale batch furnace. Major factors of improving characteristics are miniaturization the particle size of APC and the dispensability thereof. In addition, we prepared a 20 m-long calcined film by a new method, and evaluated its characteristics. The results will be reported in the session.

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Keywords: Coated conductor, MOD method, Artificial pinning center, Properties in magnetic field

WBP2-5

Enhancement of Flux Pinning in $BaZrO_3$-doped TFA-MOD (Y,Gd)$Ba_2Cu_3O_y$ CCs with Intermediate Heat Treatment

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Trifluoroacetate metal organic deposition (TFA-MOD) derived $REBa_2Cu_3O_y$ coated conductors (CCs) are one of the good candidates for magnet applications due to the low-cost and high superconducting properties. However, further improvement of the in-field critical current density (J_c) is necessary to reach the level of the applications. So far, we have succeeded in introducing a high density of $BaZrO_3$ nanoparticles (BZO NPs) into (Y,Gd)$Ba_2Cu_3O_y$ ((Y,Gd)BCO) CCs with no degradation of the critical temperature (T_c) [1]. The in-field J_c for (Y,Gd)BCO CCs with BZO NPs increases with increasing density of BZO NPs. For further enhancement of in-field J_c, controlling the size and density of the BZO NPs without affecting the matrix is one of the key factors. Recently another approach to control the size and density of BZO NPs by an introducing intermediate heat treatment (IHT) before the conversion process has been reported by AIST [2]. However, the influence of an IHT on the in-field J_c for highly BZO NP doped (Y,Gd)BCO CCs is not clear.
In this work, in order to investigate the effect of IHT on the superconducting properties, we fabricated highly BZO doped (Y,Gd)BCO CCs. The 12 vol. % BZO doped CC (12BZO CC) with an IHT shows the highest in-field J_c in this experiment. The minimum J_c as a function of angle at 77 K, 3 T in 12BZO CC is 0.31 MA/cm^2, which is 1.2 times higher than those without IHT. From microstructural measurements, the BZO NPs in BZO CC with an IHT have smaller size and higher density of compared to a CC without an IHT, which is consistent with in-field J_c properties. Our results demonstrate that the introduction of an IHT is an important way for controlling the size and density of BZO NPs even for highly BZO doped TFA-MOD (Y,Gd)BCO CCs.
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Reference: [1] M. Miura et al., Scientific Reports **6** (2016) 20436. [2] K. Nakaoka et al., IEEE Trans. Appl. Supercond. **30** (2017) 055008.

Keywords: nanoparticles, Flux Pinning, MOD, Coated Conductor

WBP2-6

Influence of Carrier Density on the In-field J_c in $BaZrO_3$ Doped TFA-MOD-$(Y_{0.77}Gd_{0.23})Ba_2Cu_3O_y$ CCs

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$(Y_{0.77}Gd_{0.23})Ba_2Cu_3O_y$ coated conductors ((Y,Gd)BCO CCs) derived from trifluoroacetate-metal organic deposition (TFA-MOD) are expected to be valuable for magnet applications because of the low cost and high superconducting performance. However, in-field critical current density (J_c) in the TFA-MOD-(Y,Gd)BCO CCs needs to be further improved for applications. To achieve this, the introduction of $BaMO_3$ (M=Zr, Nb, Sn) nanoparticles (NPs) and the control of carrier density through oxygen annealing conditions are effective. So far, we have succeeded in obtaining high in-field J_c by introducing $BaZrO_3$(BZO) NPs into the TFA-MOD-(Y,Gd)BCO CCs and controlling the oxygen annealing conditions on CCs [1,2]. However, the influence of the oxygen annealing conditions on the in-field J_c of the BZO doped TFA-MOD-(Y,Gd)BCO ((Y,Gd)BCO+BZO) CCs was not clear.
In this work, we fabricated TFA-MOD-(Y,Gd)BCO+BZO CCs with various oxygen annealing temperatures (T_A) in order to investigate the effect of oxygen annealing temperature on carrier density and superconducting properties. The TFA-MOD-(Y,Gd)BCO+BZO CC with T_A=450°C (BZO(450°C) CC) shows higher critical temperature (T_c) (=91.9 K) compared with that of the CC with T_A=350°C (BZO(350°C) CC). Although the T_c of the BZO(350°C) CC is lower than that of the BZO(450°C) CC, the self-field J_c ($J_c^{s.f.}$) of the BZO(350°C) CC is 1.24 times higher $J_c^{s.f.}$ (=5.13 MA/cm^2) than that of BZO(450°C) CC . From Hall effect measurements, the BZO(350°C) CC has a higher carrier density compared with the BZO(450°C) CC, indicating that BZO(350°C) CC is in the overdoped state. This trend is similar to that of TFA-MOD-(Y,Gd)BCO wires. Our results indicate that controlling of the carrier density has an important role in the improvement of J_c in BZO-doped TFA-MOD-(Y,Gd)BCO CCs.

Acknowledgements: This work is supported by JSPS KAKENHI (17H03239 and 17K18888). A part of this work was supported by a research grant from the Japan Power Academy.
Reference: [1] K. Agatsuma *et al*, *29th International Superconductivity Symposium* 2016. [2] M. Miura et al., Scientific Reports **6** (2016) 20436.

Keywords: Critical Current, Carrier Density, MOD, Coated Conductor, nanoparticles

WBP2-7

The Influence of $BaZrO_3$ Nanoparticles on the J_c in Longitudinal Magnetic Field for TFA-MOD $(Y_{0.77}Gd_{0.23})Ba_2Cu_3O_y$ CCs

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T. Matsushita *et al.* proposed that a superconducting DC cable using a longitudinal magnetic field (i.e, a Lorenz force-free cable) can achieve higher current-carrying capacity compared with a conventional superconducting cable [1]. The trifluoroacetate metal organic deposition (TFA-MOD) process derived $REBa_2Cu_3O_y$ coated conductor (REBCO CC) is one of the valuable candidates for a Lorenz force-free cable because of its high superconducting performance. However, for a practical force-free cable using the TFA-MOD REBCO CCs, it is necessary to further enhance the critical current density (J_c) in a longitudinal magnetic field. So far, we have succeeded in obtaining high J_c in a transverse magnetic field for $(Y_{0.77}Gd_{0.23})Ba_2Cu_3O_y$ ((Y,Gd)BCO) CCs by introducing $BaZrO_3$ (BZO) nanoparticles (NPs) ((Y,Gd)BCO+BZO)) [2]. However, the effect of BZO NPs on the superconducting properties of (Y,Gd)BCO CC in a longitudinal magnetic field is not clear.
In this work, in order to investigate the effect of BZO NPs on the superconducting properties in a longitudinal magnetic field, we fabricated TFA-MOD (Y,Gd)BCO+BZO CCs. The critical temperature of (Y,Gd)BCO+BZO CCs is almost the same as that of standard (Y,Gd)BCO CC, indicating that even with the introduction of BZO nanoparticles, the crystallinity and the composition of the matrix hardly change. The J_c in longitudinal magnetic field at 77 K for (Y,Gd)BCO+BZO CC is 3.2 MA/cm^2 at 1.0 T, which is 1.23 times higher than that of standard (Y,Gd)BCO CC. From this result, we then calculate that the current-carrying capacity of a Lorenz force-free cable using (Y,Gd)BCO+BZO CC is also higher than that of similar cable using standard (Y,Gd)BCO CC. These results suggest that introduction of the BZO NPs into (Y,Gd)BCO CC grown by TFA-MOD process plays an important role in the enhancement of the critical current in a longitudinal magnetic field and thus in Lorenz force-free cable applications.

Acknowledgements: This work was supported by a research grant from the Japan Power Academy. A part of this work is supported by JSPS KAKENHI (17H03239 and 17K18888).
Reference: [1] T. Matsushita *et al*, *AIP Conf. Proc.* **1574** (2014) 225. [2] M. Miura *et al*, *Scientific Reports* **6** (2016) 20436.

Keywords: Critical Current, Longitudinal Magnetic Field, MOD,Coated Conductor, DC Cable

WBP2-8

Annealing Treatment of CeO_2 Buffered R-Al_2O_3 for the Improvement of the Critical Current Density of TFA-MOD $(Y_{0.77}Gd_{0.23})Ba_2Cu_3O_y$ Films

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For high sensitivity nuclear magnetic resonance (NMR) pick-up coils made from $REBa_2Cu_3O_y$ (REBCO) [1], lower surface resistance (R_s) in magnetic field is required. To reduce the R_s, increasing the critical current density (J_c) is needed because the R_s is strongly correlated with J_c ($R_s \propto 1/J_c$) [2], and the improvement of the crystallinity of the buffer layer is one key factor [3]. The annealing treatment before deposition of the superconducting layer is an effective way to improve the crystallinity and decrease the surface roughness of the buffer layer [4]. However, the influence of the annealing treatment of CeO_2-buffered R-Al_2O_3 substrates for trifluoroacetate metal organic deposition (TFA-MOD)-derived $(Y_{0.77}Gd_{0.23})Ba_2Cu_3O_y$ (YGdBCO) films is not clear.

In order to investigate the effect of the annealing treatment of the CeO_2-buffered R-Al_2O_3 substrates on the crystallinity and J_c of the TFA-MOD films, we fabricated TFA-MOD YGdBCO films on as-grown and annealed CeO_2/R-Al_2O_3 substrates (annealing temperature = 600-1000°C). The crystallinity and J_c of TFA-MOD YGdBCO films improve with increasing the annealing temperature. The TFA-MOD YGdBCO films with the optimum annealling treatment show higher self-field J_c and in-field J_c. The mechanism of the improvement of the crystallinity and surface roughness of CeO_2 buffer layer by the annealing treatment will be discussed.

Acknowledgements: MM is supported by JSPS KAKENHI (17H03239 and 17K18888).

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Keywords: Pick-up Coil, Surface Resistance, TFA-MOD, YBCO films