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AC loss properties of laser-scribed multi-filamentary GdBCO coated conductors with artificial pinning centres

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Abstract

$RE_1Ba_2Cu_3O_{7-\partial}$ (RE: Rare Earth, Gd, Y and so on) coated conductors have a large aspect ratio and also anisotropy in critical current density. For practical application of REBCO tapes, we evaluated J_c and ac loss properties in a wide range of temperature and magnetic field. The induced ac losses due to the perpendicular magnetic field to a tape face are considerably huge. Therefore, in case that REBCO coated conductors are applied electric power machines and devices, ac loss induced in the windings should amount to a great part of the total heat load. We proposed an ac loss reduction method, which is combined with a laser scribing technique and a special winding process into a multi-filamentary structure. Additionally, we are trying to enhance critical current density J_C, by doping artificial pinning centre. In this study we investigated the ac loss properties of multi-filament structural GdBCO tapes with BZO nano-lods as artificial pinning centers. We measured ac losses of 5, 10, 20-filament GdBCO tapes by using a saddle-shaped pickup coil. Consequently we confirmed the ac loss decreased in inverse proportion to the number of filaments even in the GdBCO tapes with enhanced J_C by introducing artificial pinning centers.

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1. Introduction

REBCO coated conductors have higher J_C-B property than Bi2223 superconducting tapes at liquid nitrogen temperature. However it is necessary to enhance further J_C for practical use. To enhance J_C, the introduction of artificial pinning centers has been studied aggressively [1]. On the other hand, we have evaluated ac losses various types of YBCO superconducting tapes in perpendicular field [2]. We have found out that the ac loss due to the perpendicular field to the tape face is so huge that it is a great part of the heat load of a superconducting system. Recently we proposed an ac loss reduction method, which is a combination of laser scribing techniques[3] and a special winding process into a multi-filamentary structure. The ac loss should be reduced in inverse proportion to the number of filaments theoretically. In this study, we investigated the ac loss and J_C-B properties of a multi-filament structural GdBCO tapes with BZO nano-lods as artificial pinning center using a saddle-shaped pickup coil.

2. Samples and measurements

2.1. Parameters of samples

The parameters of the sample REBCO superconducting tapes are listed in table 1. The tape structure of samples A, B and C is schematically illustrated in figure 1. These samples have the same structure except the number of filaments. The buffer layer of $Ga_2Zr_2O_7$ was deposited on a Hastelloy tape by the Ion-Beam-Assisted-Deposition (IBAD) method. The cap layer of CeO_2 was deposited on the $Ga_2Zr_2O_7$ layer by PLD method. The GdBCO+$BaZrO_3$ superconducting layer was deposited by the Pulsed-Laser-Deposition (PLD) method. A stabilizing layer of silver was sputtered. The superconducting, buffer and cap layers were scribed to 5, 10 and 20 filaments by a YAG laser respectively. Each filament was electrically isolated since the buffer layer was non-conductive. Sample D had no artificial pinning centers and were not scribed. It was prepared for comparison.

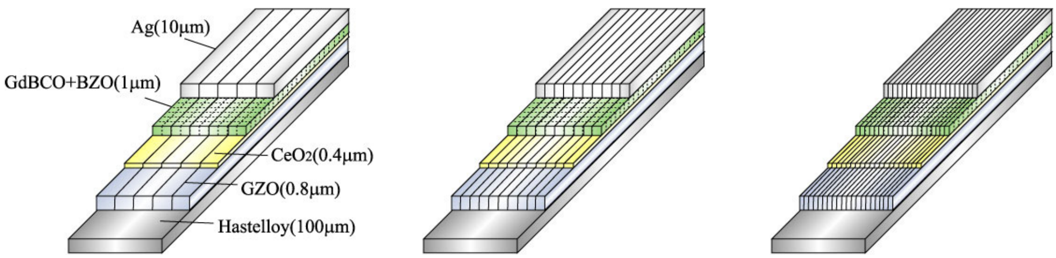

Fig. 1. Schematic illustrations of a REBCO superconducting tape (a) Sample A; (b) Sample B; (c) Sample C

Table 1. Parameters of REBCO superconducting samples.

	Sample A	Sample B	Sample C	Sample D
Production process	IBAD-PLD	IBAD-PLD	IBAD-PLD	IBAD-PLD
Width	10mm	10mm	10mm	10mm
Stabilizer	Ag (10μm)	Ag (10μm)	Ag (10μm)	Ag (10μm)
Superconductor	GdBCO+$BaZrO_3$ (1.0μm)	GdBCO+$BaZrO_3$ (1.0μm)	GdBCO+$BaZrO_3$ (1.0μm)	GdBCO (1.2μm)
Cap and	CeO2 (0.4μm)	CeO2 (0.4μm)	CeO2 (0.4μm)	CeO2 (0.4μm)
buffer layers	$Gd_2Zr_2O_7$ (0.8μm)	$Gd_2Zr_2O_7$ (0.8μm)	$Gd_2Zr_2O_7$ (0.8μm)	$Gd_2Zr_2O_7$ (0.8μm)
Substrate	Hastelloy (100μm)	Hastelloy (100μm)	Hastelloy (100μm)	Hastelloy (100μm)
Number of filaments	5	10	20	1

2.2. Measurements

The magnetization loops of these samples were measured by a pickup coil method with a saddle-shaped coil [4]. The ac loss is equivalent to the area of the magnetization loop. The dependence of J_C on magnetic field, B, of REBCO superconducting tapes was estimated from the observed magnetization loops by assuming the uniformity in J_C over the tapes. Here we used the following equations. The magnetization of a superconducting tape is expressed as

$$M(B, T) = \frac{I_C(B, T)}{4h} \quad (1)$$

where $I_C(B, T)$ is the critical current, h is the thickness of a superconducting layer, and $M(B, T)$ is the magnetization of superconductor. $I_C(B, T)$ and $M(B, T)$ are a function of magnetic field B and temperature T [5]. Therefore we can estimate the critical current from the observed magnetization as

$$I_C(B, T) = 4hM(B, T) \quad (2)$$

The samples were conduction-cooled by a GM cryocooler. Temperature ranged from 35K to 77K.

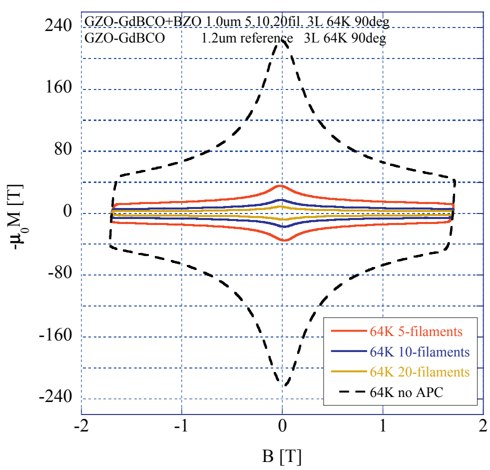

Fig. 2. Observed magnetization curve of sample A, B, C and D at 64K

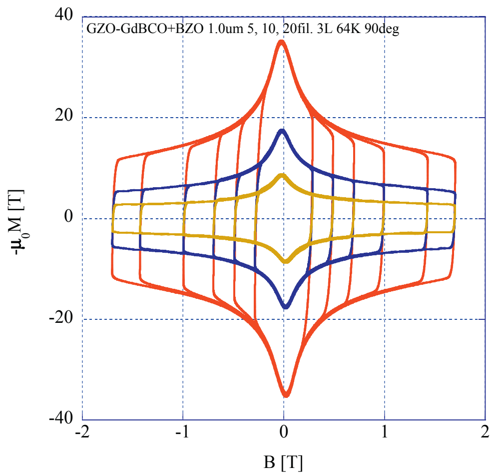

Fig. 3. Magnetization curve observed for sample A, B, and C at 64K, B_m = 0.41, 0.70, 1.00, 1.43 and 1.70T

3. Result and discussion

3.1. Magnetization loops

Fig.2 shows the observed magnetization loops of sample A, B, C, and D at 64K for magnetic field amplitude, B_m, of 1.7T. As shown in Fig.2, the observed M became smaller in inverse proportion to the number of filaments. Fig.3 shows the magnetization curve of sample A, B and C at 64K varying B_m from 0.4T to 1.7T. The ac loss is generally expressed as

$$W = -\oint M\, dB \qquad (3)$$

We obtained an I_C-B curve according to equation (2) and ac loss according to equation (3) by measuring magnetization curves.

3.2. I_C-B properties

Fig.4 shows the estimated I_C-B characteristics of sample tapes at 64K from the observed magnetization curves. We can see that I_C of sample D, which has no artificial pinning centers, decreased rapidly with increasing B. Fig.5 shows the temperature dependences of the pinning parameter, γ , of sample A, B, C and D, where the $I_C(B)$ curves are fitted by using the Irie-Yamafuji model [6] expressed as

$$J_c = \alpha B^{\gamma-1} \qquad (\alpha, \gamma : const., 0 \le \gamma \le 1) \qquad (4)$$

where α is also a pinning parameter. As the pinning parameter, γ , is higher, the decrease of J_C due to the increment of B is smaller. γ of samples A, B, and C ranged from 0.6 to 0.7 and was higher than that of sample D. It was shown that the additional of artificial pinning centers of $BaZrO_3$ were very effective to improve the I_C-B properties of GdBCO tapes.

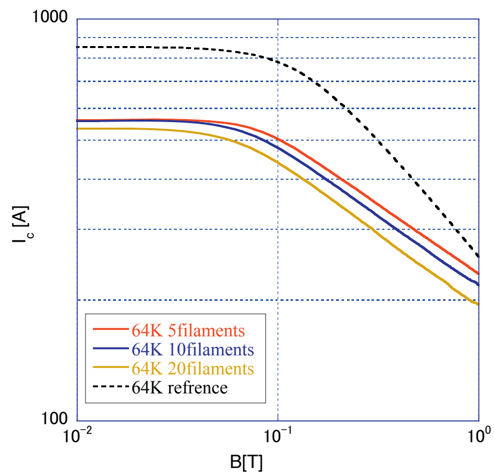

Fig. 4. Estimated I_C-B characteristic of sample A, B, C and D at 64K

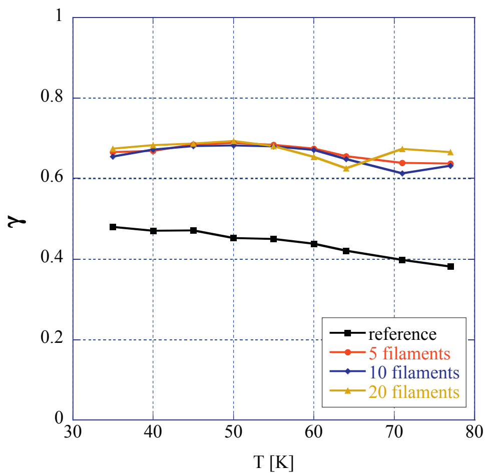

Fig. 5. Temperature dependences of pinning parameter γ of sample A, B, C and D for 35K to 77K

3.3. ac loss properties

Fig.6 shows the observed dependences of the ac loss on the magnetic field amplitude, B_m, for sample A, B, and C at 64K. It was calculated from magnetization curves, Fig. 3. The observed ac losses for B_m = 1[T] are listed in Table 2. We can see that ac losses were actually reduced in inverse proportional to the number of filaments.

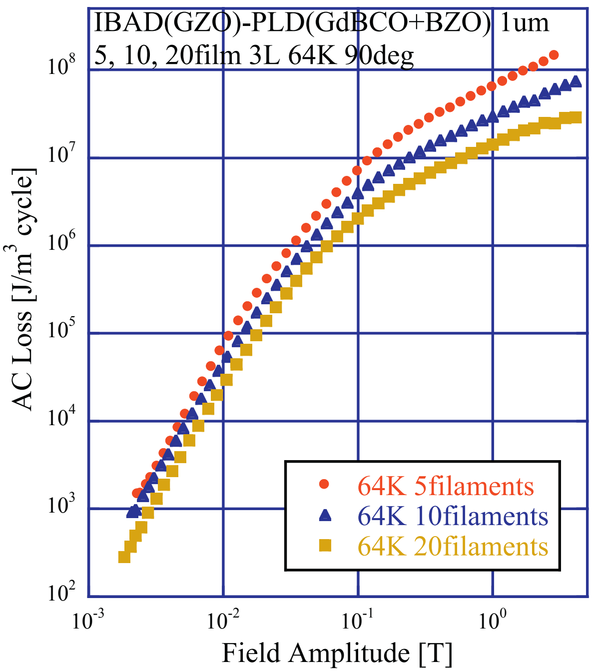

Fig. 6. Observed field amplitude dependence of ac losses of sample A, B and C

Table 2. Comparison of the ac losses at B_m = 1T for sample A, B and C

	Ac loss at 64K, B_m = 1[T]	The ratio of ac loss to Sample A
Sample A (5 filaments)	6.29 x 10^7 [J/m^3 cycle]	1.00
Sample B (10 filaments)	2.94 x 10^7 [J/m^3 cycle]	0.47
Sample C (20 filaments)	1.41 x 10^7 [J/m^3 cycle]	0.23

4. Concluding remarks

The I_C-B properties of GdBCO superconducting tapes were improved by doping artificial pinning centers of $GdZrO_3$. In addition, the ac losses of GdBCO tapes were successfully reduced by laser scribing in inverse proportion to the width of filaments. It was shown that the ac loss reduction by scribing was effective even for the tapes with higher I_C properties owing to the introduction of artificial pinning centers. The result suggests that we successfully developed the technology to produce GdBCO superconducting tapes with not only high J_C property but also low ac loss property.

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