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Critical current properties in longitudinal magnetic field of YBCO superconductor with APC

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Abstract

The critical current density (J_c) properties of the Artificial Pinning Center (APC) introduced $YBa_2Cu_3O_7$ (YBCO) films in the longitudinal magnetic field were measured. Y_2O_3 or Y_2BaCuO_5 (Y211) was introduced as APCs to YBCO, and YBCO films with APC were fabricated on $SrTiO_3$ single crystal substrate. The sizes of Y_2O_3 and Y211 were 5—10 nm and 10—20 nm, respectively. As a result, J_c enhancement in the longitudinal magnetic field was observed in Y_2O_3 introduced YBCO films. However, it was not observed in Y211 introduced YBCO films. Therefore, it was considered that J_c properties in the longitudinal magnetic field were affected by introducing of small size APC, and it was necessary that APC does not disturb the current pathway in the superconductor.

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Keywords: REBCO; longitudinal magnetic field; artificial pinning center; critical current density

1. Introduction

The $REBa_2Cu_3O_y$ (REBCO; RE = Rare Earth) coated superconductors have the large critical current density (J_c) up to the high magnetic fields, and also have the high critical temperature (T_c). Since REBCO coated superconductors have high T_c, applications using them can be operated in the liquid nitrogen. The running cost of the device which uses the liquid nitrogen is cheaper than that of the device which uses the liquid helium. Therefore, the REBCO

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coated superconductors are expected to be applied to the various superconducting applications such as the electric power transmission cable, the current limiting device, and so on [1, 2, 3].

In the longitudinal magnetic field in which the magnetic field is parallel to the current flow, Lorentz force does not work to the magnetic flux lines. Thus, J_c in the longitudinal magnetic field is larger than that in the perpendicular magnetic field [4]. There are some reports of J_c in the longitudinal magnetic field for the metallic superconductors [5, 6]. Cullen et al reported that J_c properties in the longitudinal magnetic field of Nb_3Sn superconductor film is 10 times larger than that in self-magnetic field, and the enhancement of J_c is largely depended on the pinning force by different kinds of dose of the neutron irradiation [6].

Recently, Tsuruta et al reported that J_c enhancement in the longitudinal magnetic field from J_c in the self-magnetic field in $SmBa_2Cu_3O_y$ superconducting film with the Artificial Pinning Center (APC) below 0.6 T. The enhancement of J_c was observed only APC introduced specimen [7]. It is concluded that the introduction of APC is effective for the enhancement of J_c properties in the longitudinal magnetic field. Therefore, it is necessary to investigate the effect of the enhancement of J_c in the longitudinal magnetic field by the APCs properties such as the size, the shape and so on. In this paper, J_c properties of REBCO specimens with the different size and amount of APC are measured, and the relationship between the properties of APCs and J_c in the longitudinal magnetic field is discussed.

2. Experimental procedure

The $YBa_2Cu_3O_y$ (YBCO) films that used in the present work were fabricated on $SrTiO_3$ single crystal substrate by the pulsed laser deposition (PLD) method. Y_2O_3 or Y_2BaCuO_5 (Y211) was introduced as APCs to YBCO by the target-modified method [8]. In this method, the target with a small piece of APC seeds was used. The quantity of Y_2O_3 is 3 area% and 4 area%, respectively. And the quantity of Y211 is 2 area% and 4 area%, respectively. The shape of Y_2O_3 and Y211 were the particle, and the size were 5—10 nm and 10—20 nm, respectively. Hence the size of Y_2O_3 is smaller than that of Y211. The ratio of pinning center in the superconducting layer of Y211 is larger than that of Y_2O_3, since the size of Y211 is larger than that of Y_2O_3 as shown in Table 1. The thicknesses of the APC doped YBCO layer of Y_2O_3 and Y211 were 170 nm and 300 nm, respectively. Since it is difficult to control the thickness, samples thickness varies. Micro bridge of 80 μm width and 1 mm length was fabricated in the YBCO layer with the APC of each specimen. *E-J* properties of each specimen were measured by the four-probe method. The value of J_c of each specimen was evaluated by using the electric field criteria: $E_c = 1.0 \times 10^{-4}$ V/m. J_c properties were measured under the longitudinal or the perpendicular magnetic field, in the range from 0 T (self-field: s. f.) to 0.5 T. The arrangement of current J and external magnetic field B is shown in Fig. 1. All experiments were performed in liquid nitrogen. Specifications of specimens are listed in Table 1.

Table 1: Specifications of specimens

	shape of APCs	size of APCs[nm]	thickness [nm]	J_c(s.f.) [GA/m^2]
YBCO +4 area% Y_2O_3	particle	5—10	170	49.0
YBCO +3 area% Y_2O_3	particle	5—10	170	40.1
YBCO +4 area% Y211	particle	10—20	300	19.9
YBCO +2 area% Y211	particle	10—20	300	16.2

3. Results and discussion

Fig. 2 shows the magnetic field dependence of J_c properties of each specimen in the longitudinal magnetic field and the perpendicular magnetic field. The enhancement of J_c in the longitudinal magnetic field from that in self-

magnetic field was observed for the specimens with Y_2O_3. The maximum J_c in the longitudinal magnetic field was observed below B = 0.3 T and about 20% larger than that in self-magnetic field of the specimen. On the other hands, the enhancement of J_c in the longitudinal magnetic field was not observed in the specimens with Y211. In addition, J_c in the longitudinal magnetic field of the specimen which contains larger amounts of APCs was higher for each APC. Fig. 3 shows the magnetic field dependence of J_c normalized by J_c in self-magnetic field (J_c(s.f.)). The enhancement of J_c (J_c /J_c(s.f.))in the longitudinal magnetic field was more remarkable in the specimen which contains large amount of APCs. From these results, it is found that introducing APCs to superconducting layer is effective to increase J_c in longitudinal magnetic field, and the enhancement of J_c from self-magnetic field in longitudinal magnetic field was observed in the specimen with small APCs (Y_2O_3). Although, it is effective to introduce APCs to superconductor to improve J_c in longitudinal magnetic field, it is also necessary that the current should be parallel to the external magnetic field. The large APCs may obstruct the current flow. As a result, it seems that external magnetic field and current flow deviates from parallel, and the enhancement of J_c in the longitudinal magnetic field is not observed in the large APCs (Y211). In addition, the thickness of the specimens with Y211 was larger than that of specimens with Y_2O_3. If the thickness of superconducting layer increases, the homogeneous of specimen seems to decrease. However, it is reported that decrease of J_c is only 15 % as increasing thickness of superconducting layer from 170 nm to 300 nm in YBCO+Y211 [9]. Hence, the reason for decrease of J_c in Y211 is ascribed to the larger size of APC.

Fig. 4 shows the magnetic field dependence of n-value of each specimen in the longitudinal magnetic field, where n-value is determined from E-J characteristics from the electric filed region of 10^{-4}—10^{-3} V/m. The n-values of specimen with Y_2O_3 tend to increase as increasing J_c, and take the maximum value at the maximum value of J_c. Although the n-value increases with increasing J_c in the perpendicular magnetic field, similar results are observed in the longitudinal magnetic field. On the other hands, the n-values of the specimen with Y211 tend to decrease in the longitudinal magnetic field. Since the n-values tend to increase only for the case of J_c enhancement, it is considered that the n-value relates with enhancement of J_c in the longitudinal magnetic field. If the superconductor is highly homogeneous, distribution of J_c is small in the superconductor, and the n-value is high. The homogeneousness of superconductor is important for the higher J_c in the longitudinal magnetic field as discussed above. Therefore, it is considered that the current flow and the external magnetic field becomes parallel in the superconductor which has high n-value, and the enhancement of J_c in longitudinal magnetic field was observed.

From these results, we should discuss the possibility to have higher J_c in the longitudinal magnetic field. Since the enhancement of J_c was observed in the specimen with 4 area% Y_2O_3, more enhancement of J_c might be observed in the specimen with 5 area% Y_2O_3 or 6 area% Y_2O_3 which size is smaller than 10 nm. In addition, since it is considered that the thickness of specimen affects J_c of specimen with Y211 in the longitudinal magnetic field, the enhancement of J_c might be observed in the thinner specimen with high homogeneous superconducting layer.

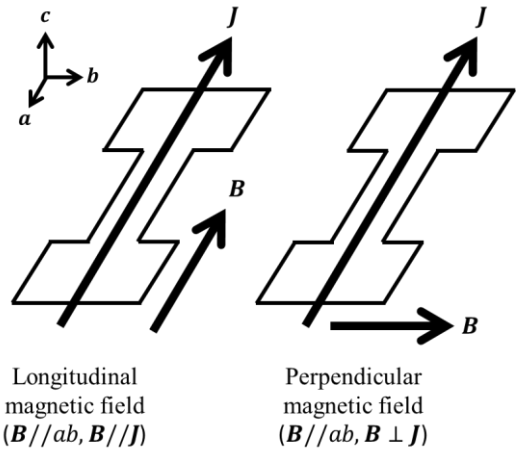

Fig. 1. Arrangement of current J and magnetic field B for the measurement of J_c

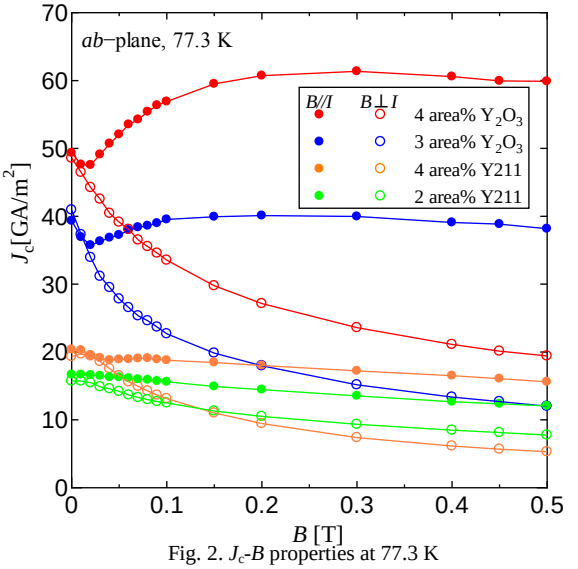

Fig. 2. J_c-B properties at 77.3 K

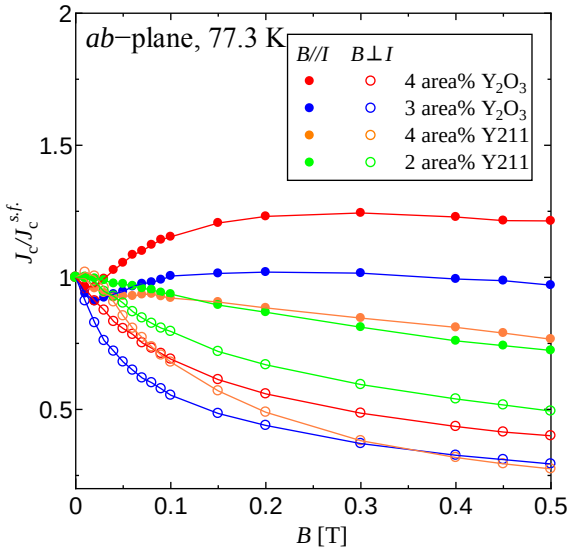

Fig. 3. J_c/J_c(s.f.)-B properties at 77.3 K

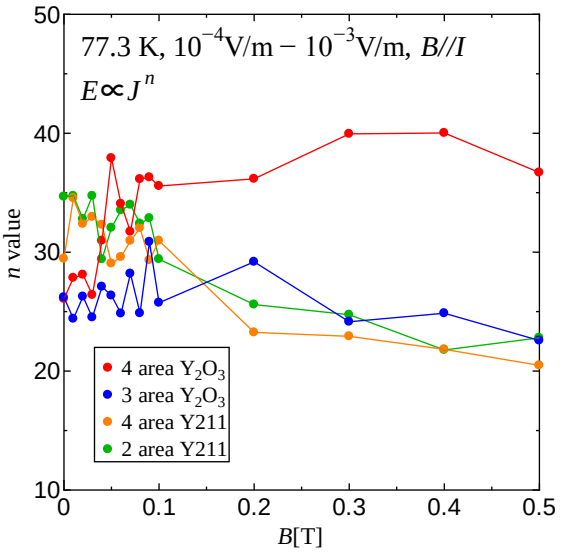

Fig. 4. Magnetic field dependence of n-values in longitudinal field at 77.3 K

4. Conclusion

The J_c properties of the APC introduced YBCO films were measured. The enhancement of J_c in the longitudinal magnetic field from that in the self-magnetic field was observed in the specimen with smaller APCs (Y_2O_3), and not observed in the specimen with larger APCs (Y211). The maximum J_c of the specimen with Y_2O_3 in the longitudinal magnetic field was observed below B=0.3 T and is about 20% larger than that in self-magnetic field of the specimen. The n-values in the longitudinal magnetic field tended to increase when the J_c increases in the longitudinal magnetic field. It is considered that the size of the APC or the thickness of the specimen affected J_c in the longitudinal magnetic field, and it is expected that more enhancement of J_c was observed in the specimen with more amount of Y_2O_3 or the thinner specimen with Y211.

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