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Position dependence of irreversibility line on thin plate Gd-Ba-Cu-O bulk superconductor

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Abstract

We measured the profiles of the trapped field, B_T, on a thin Gd-Ba-Cu-O superconducting bulk plate with 45 mm in diameter and 2 mm in thickness magnetized by the pulsed field, where Gd-Ba-Cu-O consists of a superconducting matrix phase of $GdBa_2Cu_3O_{7-\delta}$ and a nonsuperconducting secondary phase of Gd_2BaCuO_5. The vortices were mainly trapped at the periphery in the growth sector regions (GSRs) for low applied fields, and around the growth sector boundaries (GSBs) and under the seed crystal (SC) position for high applied fields. The irreversibility line, which was determined from the resistivity measurements, of the sample cut from the GSR was rather lower than those of the samples cut from the GSBs and the SC position. This result revealed the weak vortex pinning strength in the GSRs and was consistent with the B_T profiles by PFM. The obtained results suggest that the resistivity can also probe the distribution of the vortex pinning strength.

Keywords: Gd-Ba-Cu-O bulk; pulsed field magnetization; trapped field; irreversibility line; resistivity

1. Introduction

RE-Ba-Cu-O superconducting bulks (RE:rare earth elements), which consists of a superconducting $REBa_2Cu_3O_{7-\delta}$ and a nonsuperconducting RE_2BaCuO_5 phases, can realize strong quasi-permanent magnets by trapping a large amount of vortices. A field-cooled magnetization (FCM) is a preferable technique to maximize the trapped field, B_T, on the superconducting bulk, although a large and expensive superconducting solenoid coil magnet is needed. Pulsed field magnetization (PFM) has been intensively studied, because the apparatus is compact and mobile. However, the magnitude of the B_T by PFM is rather small and inhomogeneous in comparison with that by FCM, which is caused by the large temperature rise due to the dynamic motion of vortices [1]. Yanagi *et al.* reported that in the Sm-Ba-Cu-O bulk the vortices were trapped mainly around the growth sector regions (GSRs) and the growth sector boundaries (GSBs), respectively, by applying low and high pulsed field [2]. These results indicate that the B_T by PFM depends

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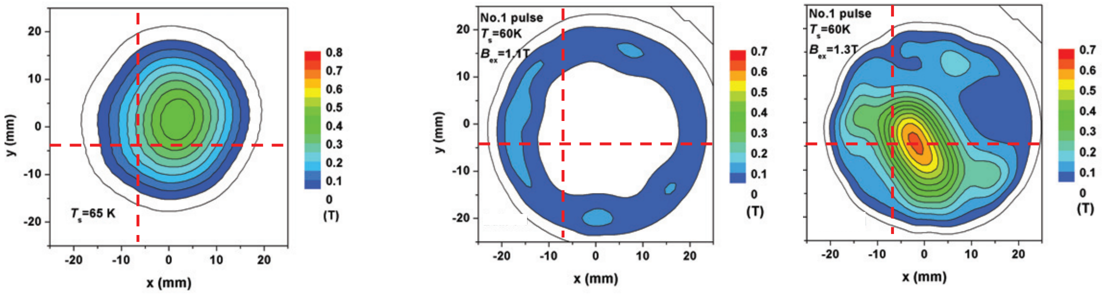

(a) FCM (b) PFM (B_{ex}=1.1 T) (c) PFM (B_{ex}=1.3 T)

Fig. 1. (a) Trapped field profile magnetized by FCM at 65 K. Trapped field profiles magnetized by PFM at 60 K for (b)B_{ex}=1.1 T and (c)B_{ex}=1.3 T. The broken lines represent the growth sector boundaries (GSBs) and the crossing point is the seed crystal (SC) position.

sensitively on both the critical current density, J_c, distribution and the magnitude of the pulsed field. The relationship between the B_T profile by FCM and the relative J_c distribution was successfully explained by Eisterer *et al.* using the magnetoscan method [3], where the absolute value of J_c was not reported. Recently, Fujishiro *et al.* showed that the B_T profiles of the Gd-Ba-Cu-O thin bulk plate magnetized by PFM depended mainly on the J_c distribution which was directly evaluated by the magnetization measurement using the small pieces cut from the thin bulk plate [4].

In this paper, we examine the irreversibility lines determined from the resistivity measurements using the identical samples cut from the thin Gd-Ba-Cu-O plate and discuss a possibility of the resistivity as a probe for the vortex pinning strength.

2. Experimental procedure

Thin plate of Gd-Ba-Cu-O bulk with 45 mm in diameter and 2 mm in thickness was sliced from the top surface of the 15 mm thick bulk [5] grown by a top-seeded melt-texture technique using a Nd-Ba-Cu-O seed at Superconductivity Research Laboratory, ISTEC, Japan. The thin plate was mounted tightly on the cold head of a Gifford-McMahon (G-M) type helium refrigerator with a 1 mm stainless steel cap for both PFM and FCM measurements. In the PFM, the copper solenoid coil was set outside the vacuum chamber and was cooled using the liquid nitrogen. The thin plate was cooled down to a target temperature by zero-field cooling and then a pulsed field was applied with a rise time of 12 ms and duration of 100 ms. Two dimensional (2-D) B_T profile was taken at a distance of 1 mm from the plate surface by scanning a cryogenic axial-type Hall probe (BHA-921, F.W. Bell Inc.). In the FCM, the plate was cooled down to the target temperature in the magnetic field of 1.5 T generalized by a cryo-cooled superconducting solenoid magnet (JMTD-10T100, JASTEC Inc.), kept for 10 min, and finally the applied field was decreased to zero at a rate of 3 mT/s. 2-D B_T profile for the FCM was measured on the vacuum chamber at a distance of 4 mm from the plate surface. For the resistivity measurements, the thin plate was cut into small pieces with a typical size of $1 \times 1 \times 2\text{mm}^3$ after the PFM and FCM measurements. We measured two pieces cut from the GSBs (GSB-#1 and #2), one piece from the SC position (SC-#1) and another from the GSR (GSR-#1). Resistivity was measured by a conventional dc four probe method with a typical current density of 5 A/cm^2 in magnetic fields parallel to the *c*-axis up to 10 T.

3. Results and Discussion

Fig. 1(a) shows the B_T profile by FCM at 65 K 4 mm above the bulk surface. The profile is nearly homogeneous and whose maximum appears around the center of the thin plate. The broken lines represent the GSBs and the crossing point corresponds to the SC position at the crystal growth. Figs. 1(b) and 1(c)

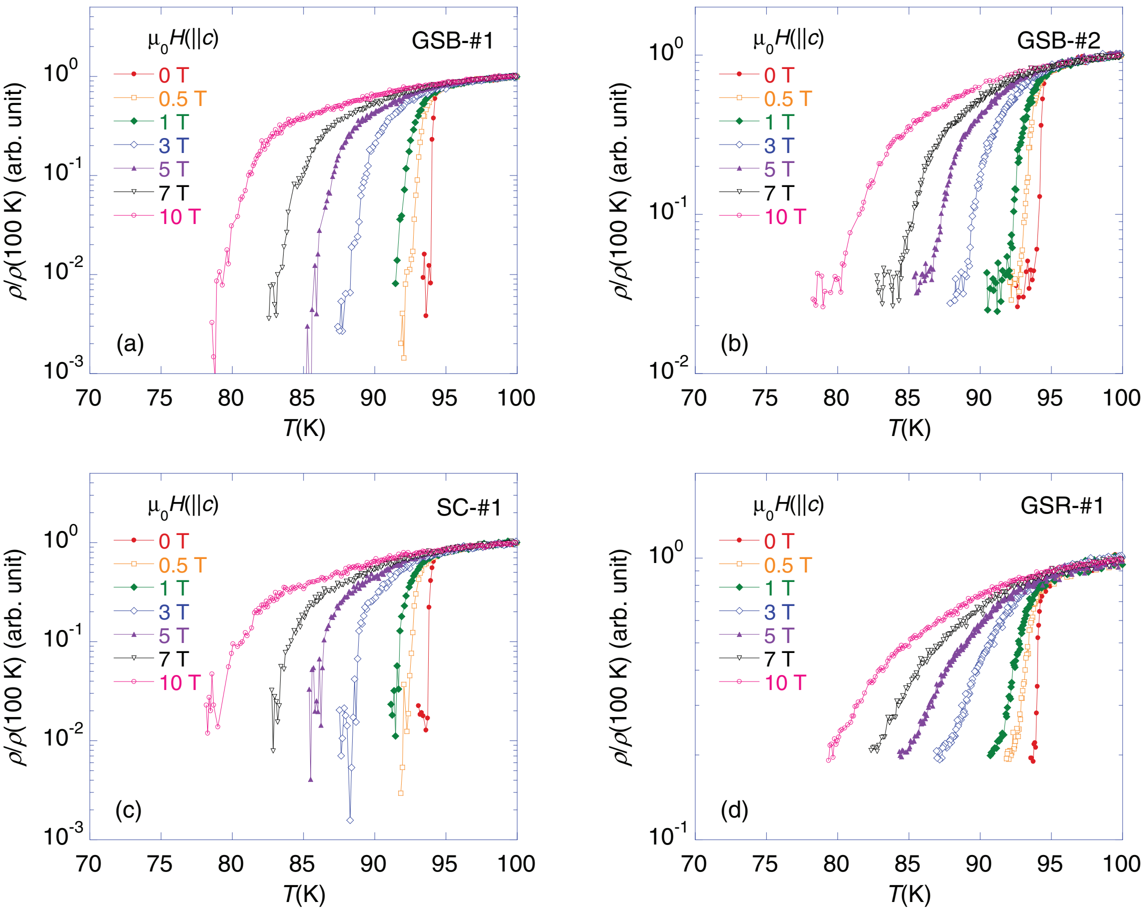

Fig. 2. Temperature dependence of the reduced resistivity , $\rho(T)/\rho(100\text{ K})$, of the small pieces samples in magnetic fields parallel to the c-axis up to 10 T, where $\rho(100\text{ K})$ is the resistivity at 100 K.

show the B_T profiles at 60 K by PFM 1 mm above the bulk surface after applying pulsed field, B_{ex}, of 1.1 T and 1.3 T, respectively. For B_{ex}=1.1 T, the vortices are trapped mainly around the periphery in the GSRs and do not intrude into the center. On the other hand, the vortices penetrate into the center and are trapped mainly around the GSBs and SC position for B_{ex}=1.3 T. The inclined elliptic B_T profile indicates the inhomogeneous distribution of the vortex pinning strength and the temperature rise.

Fig. 2 presents the temperature dependence of the reduced resistivity, $\rho(T)/\rho(100\text{ K})$, of the small pieces in magnetic fields parallel to the c-axis up to 10 T, where $\rho(100\text{ K})$ is the resistivity at 100 K. The critical temperature, T_c, is about 94 K for all the samples, demonstrating high quality and homogeneous superconductivity. The transition temperature in the magnetic field decreases with increasing magnetic field and the resistive broadening of GSR-#1 is somewhat larger than those of other samples. The irreversibility temperature, T_{irr}, is defined at the temperature in $\rho(T)/\rho(100\text{ K})=0.2$. Fig. 3 shows the magnetic-field vs. temperature diagram. The irreversibility line, $H_{irr}(T)$, of GSR-#1 is located obviously at lower temperature and magnetic-field, in comparison with those of GSB and SC samples, which suggests that the vortex pinning in GSR is weaker than those of GSBs and SC and is consistent with the B_T profiles by PFM. The H_{irr} line of the SC-#1 is slightly lower than those of GSB samples, which might originate from the fact that the amount of pinning centers such as Gd_2BaCuO_5 (Gd211) particles decreases at the position far from the SC because of the pushing effect. Since the current density using the resistivity measurement corresponds to the critical current density, J_c, the $H_{irr}(T)$ line represents the isothermal J_c=5 A/cm^2 one in this study. Although

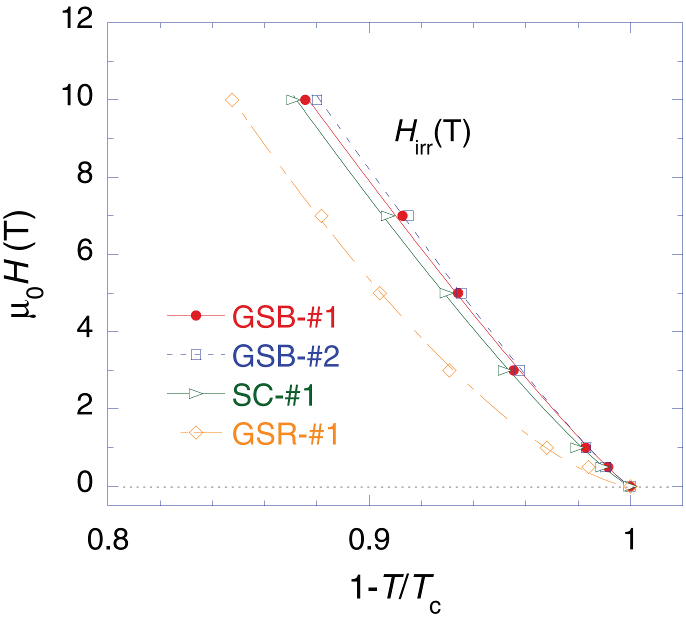

Fig. 3. The phase diagram of magnetic-field vs. reduced temperature. The irreversibility lines determined from the resistivity measurements are shown.

this J_c value is about four orders of magnitude smaller than that determined from the magnetization loop [4], the relationship between the B_T profiles by PFM and the $H_{irr}(T)$ lines suggests that we can use the resistivity measurement as a probe to estimate the distribution of vortex pinning strength.

4. Summary

We measured the trapped field, B_T, profiles on a ϕ45 mm Gd-Ba-Cu-O superconducting bulk plate with 2 mm in thickness magnetized by PFM and examined the relationship between the B_T profiles and the irreversibility lines determined from the resistivity measurements. The B_T profiles suggested that the vortices were trapped mainly the periphery in the GSRs for lower applied magnetic pulse and around the GSBs and SC for higher applied field. The irreversibility line of the sample cut from the GSR was lower than those in the GSBs and SC. This is consistent with the B_T profiles by PFM, although the J_c in the resistivity measurement is generally about three to four orders of magnitude smaller than that determined by the magnetic hysteresis loop. The results suggest that we can probe the vortex pinning properties by the resistivity measurements.

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References

[1] Fujishiro H, Hiyama T, Miura T, Naito T, Nariki S, Sakai N, Hirabayashi I 2009 *IEEE Trans. Appl. Supercond.* 2009;**19**;3545
[2] Yanagi Y, Itoh Y, Oka T, Ikuta H, Mizutani U *Supercond. Sci. Technol.* 2005;**18**;839
[3] Eisterer M, Haindl S, Wojcik T, Weber H W *Supercond. Sci. Technol.* 2003;**16**;1282
[4] Fujishiro H, Naito T, Furuta D, Arayashiki T, Yanagi Y, Itoh Y *Supercond. Sci. Technol.* 2011;**24**;105003
[5] Nariki S, Sakai N, Murakami M *Supercond. Sci.Technol.* 2005;**18**;S126