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Shielding and trapped field properties of large MgB_2 bulk

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Abstract

We have studied the magnetic shielding properties of MgB_2 bulk fabricated by a reactive liquid Mg infiltration (Mg-RLI) method. The magnetic shielding profiles indicated partially field-penetrated areas at the bulk periphery with weaker pinning force at 38 K. We discuss about the superconductive inhomogeneity in the bulk by comparing the shielding profiles with trapped field ones by the subsequent zero-field-cooled magnetization (ZFCM) and the pulsed-field magnetization (PFM). The present method is advantageous to detect the inhomogeneity at the periphery of a large superconducting bulk.

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Keywords: MgB_2; bulk superconductor; shielding properties; pulsed field magnetization; magnetic field profiles; pinning force

1. Introduction

A MgB_2 bulk is a metal superconductor with a critical temperature T_c=39 K, in which the problem of intergranular weak links can be ignored even for polycrystalline samples because of their long coherence length ξ, compared with RE-Ba-Cu-O (RE: rare earth element) bulks [1]. Therefore, the polycrystalline MgB_2 bulk can trap the higher magnetic field and is expected as a material replacing conventional superconductors.

To evaluate the superconductive homogeneity of the large bulk without destruction, a magneto-optical imaging (MOI) method [2] and a magnetoscan method [3] are used to visualize the distribution of the magnetic flux penetration and/or the critical current density J_c, both of which have the fundamental limitation for the measurement.

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On the other hand, J_c is directly measured magnetically for a small piece cut from the bulk. A new non-destructive technique is desired to evaluate the superconductive homogeneity of a large MgB_2 bulk. In this study, we measured the magnetic shielding properties of a large MgB_2 bulk just below T_c. The trapped field profiles were also measured by the subsequent zero-field-cooled magnetization (ZFCM) and a pulsed-field magnetization (PFM), both of which were compared with the shielding profiles.

2. Experimental

The MgB_2 bulk (54 mm in diameter and 15 mm thickness), fabricated by a reactive liquid Mg infiltration (Mg-RLI) method and mounted in a stainless steel (SUS) ring using Stycast 2850GT, was set on a cold head of a Gifford-McMahon (GM) cycle helium refrigerator. To measure the shielding and ZFCM profiles, static magnetic field of 28 mT was applied by solenoid-type copper coil after the bulk was cooled to T_s=36, 37, 38 and 39 K. For the shielding experiment, two-dimensional magnetic shielding profiles were mapped 2 mm above the bulk surface using a Hall sensor under the magnetic field. For ZFCM, the trapped field profiles were measured after the applied magnetic field was decreased to zero. The PFM experiments were performed to the bulk cooled to 14 K. A magnetic pulse B_{ex} up to 1.97 T with a rise time of 0.013 s and a duration of 0.15 s was applied to the bulk by flowing the pulsed current from a condenser bank. The trapped field B_T at the center of the bulk surface was monitored by Hall sensor using a digital oscilloscope. Two-dimensional trapped field profiles were mapped on the bulk with 1 mm above the bulk surface. For each experiment, the time dependence of temperature $T(t)$ was also measured at the side of the SUS ring using Cernox thermometer.

3. Results and discussion

Figure 1 shows the magnetic shielding profiles on the bulk 2 mm above the bulk surface at various temperatures. The position of the bulk is shown in each figure. The profile at 38 K indicated that magnetic flux penetrated inhomogeneously from the bulk periphery, especially from the region A. However, the magnetic flux was shielded uniformly at lower temperatures of 36 and 37 K due to the increase of J_c with decreasing temperature. For T_s= 39 K as shown in Fig. 1(d), the magnetic flux penetrated inside of the bulk. Figure 2 shows the cross-sections of the shielding profiles shown in Fig. 1 along the line of Y=0 mm. The flux did not penetrate to the inside of the bulk except for T_s=39 K. It should be noted that the inhomogeneous flux penetration can be observed around region A at 38 K.

Figure 3 presents the trapped field profiles on the bulk surface for ZFCM. The bulk can trap the magnetic flux

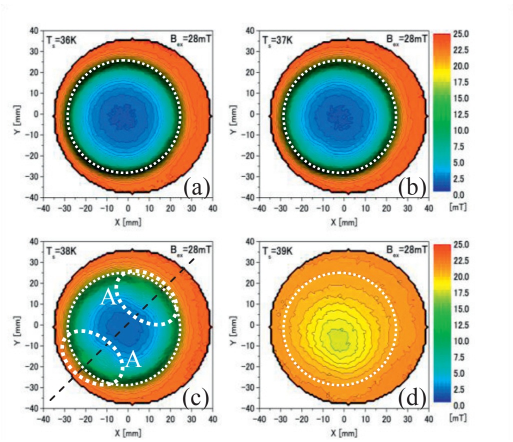

Fig. 1 The magnetic shielding field profiles on the bulk surface at (a)T_s=36 K, (b) 37 K, (c) 38 K and (d) 39 K.

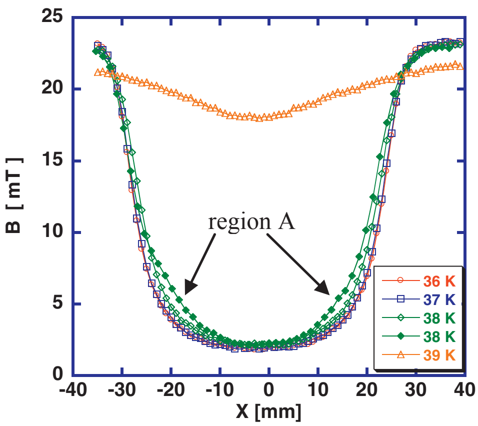

Fig. 2 Cross-section of the shielding profiles. Open symbols were plotted along the line of Y=0 mm and solid symbols were plotted along the diagonal line shown in Fig. 1(c).

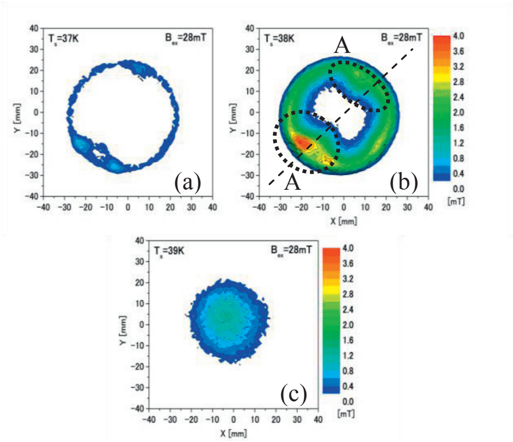

Fig. 3 Trapped field profiles for ZFCM at (a)T_s=37 K, (b) 38 K and (c) 39 K.

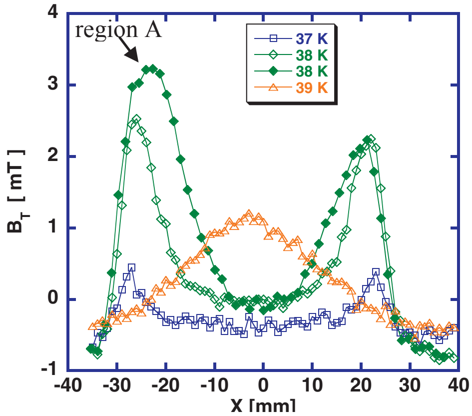

Fig. 4 Cross-sections of the trapped magnetic profiles for ZFCM. Open symbols were plotted along the line of Y=0 mm and solid symbols were plotted along the diagonal line shown in Fig. 3(b).

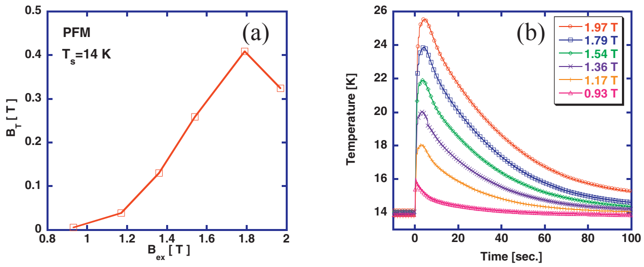

Fig. 5 (a) The applied pulsed field B_{ex} dependence of the trapped field B_T. (b)Time dependence of temperature change for PFM.

only for the bulk periphery below 36 K, which indicated that the applied magnetic field of B_{ex}=28 mT did not exceed the lower critical field H_{c1}, and the bulk shielded the magnetic flux. For T_s=37 K and 38 K as shown in Figs. 3(a) and 3(b), the magnetic flux penetrated in the bulk and was preferentially trapped around region A, at which J_c was considered to be lower from the shielding measurement. For T_s=39 K as shown in Fig. 3(c), the magnetic flux penetrated and trapped at the center of the bulk, in which the trapped field profile was conical and the maximum trapped field was 1.2 mT. Figure 4 shows the cross-sections of the trapped field profiles for ZFCM shown in Fig. 3. For T_s=38 K, it is noticed that the trapped field at region A was relatively higher compared with the cross-section along the line of Y=0 mm.

Figure 5(a) shows the trapped field B_T at the center of the bulk surface, as a function of the applied pulsed field B_{ex} for PFM. B_T increases for $B_{ex} > 1.2$ T, takes a maximum at B_{ex} = 1.79 T and then decreases with increasing B_{ex}. The decrease of B_T for B_{ex}=1.97 T is due to the large temperature rise in the bulk, which was caused by the viscous loss and pinning loss. The maximum B_T was 0.41 T in this study, which was smaller than that on the MgB_2 bulk fabricated by a capsule method (B_T=0.72 T at T_s=17 K) [4]. Figure 5(b) depicts the time dependence of the temperature change at the side of the SUS ring for each applied field B_{ex}. The temperature increases abruptly just after the pulse application and slowly decreases with increasing time. The magnitude of the maximum temperature rise increases with increasing B_{ex}. The sharp temperature change results from the low specific heat and high thermal conductivity of the MgB_2 bulk, compared with those for the REBaCuO bulk at operating temperatures.

Figure 6 shows the trapped field profiles on the bulk 1 mm above the bulk surface for various applied pulsed fields B_{ex}. For lower B_{ex} of 0.93 T as shown in Fig. 6(a), the magnetic flux was preferentially trapped around the region A together with the bulk periphery. It is known that the magnetic flux is trapped at weaker pinning force

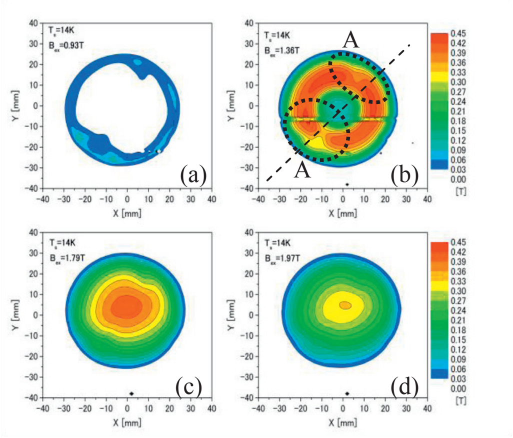

Fig. 6 Trapped field profiles on the bulk for PFM at (a) B_{ex}=0.93 T, (b) 1.36 T, (c) 1.79 T and (d) 1.97

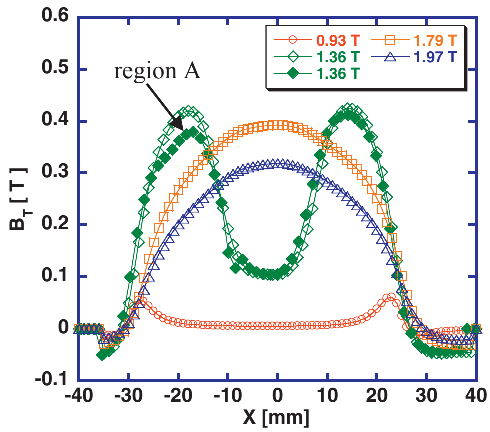

Fig. 7 Cross-sections of the magnetic profiles for PFM. Open symbols were plotted along the line of Y=0 mm and solid symbols were plotted along the diagonal line shown in Fig. 6(b).

region for lower applied pulsed field [5]. Therefore, the critical current density J_c around region A seems to be relatively lower in the bulk, and it is consistent with the results of shielding and ZFCM experiments shown in Figs. 1 and 3. For B_{ex}=1.36 T as shown in Fig. 6(b), the trapped field around the region A was relatively lower because the magnetic flux can be preferentially trapped at strong pinning region for relatively higher B_{ex} [5]. The line-shaped disturbance at Y=-0.6 mm comes from the noise of the apparatus. For B_{ex}=1.79 T and 1.97 T as shown in Figs. 6(c) and 6(d), the tapped field profiles was nearly the cone-shaped ones, but the profile was deformed due to the existence of the region A. Figure 7 presents the cross-sections of the trapped field profiles for PFM shown in Fig. 6. The trapped field profile changes from concave to convex with increasing B_{ex}. For B_{ex}=1.36 T, it is found that the trapped field at region A was relatively lower compared with the cross-section along the line of Y=0 mm. The distribution of the pinning force obtained by PFM was consistent with that obtained from the shielding measurement, despite the time scale of the magnetic flux movement was fairy different. Thus, the shielding measurement is available for non-destructive evaluation technique of superconductive homogeneity at the periphery of the large bulk. However, this technique is not necessarily effective to evaluate the superconductive homogeneity inside of the bulk. In this case, the combination with the trapped field profiles by PFM and/or field cooled magnetization (FCM) is required.

4. Conclusion

We have studied the magnetic shielding profile and the trapped field profiles magnetized by ZFCM and PFM of large MgB_2 bulk fabricated by Mg-RLI method. For the shielding measurement, the magnetic flux penetrated inhomogeneously from the position with low J_c just below T_c. For the subsequent ZFCM, the magnetic flux was trapped at this region. For PFM, at lower applied pulsed field, the magnetic flux was mainly trapped at same position, but at higher applied field, the magnetic flux was not trapped at this position. These results suggest that the shielding profiles can be used for non-destructive evaluation technique of inhomogeneity at periphery of the large bulk.

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