Trapped field and temperature rise in MgB_2 bulks magnetized by pulsed field

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The pulsed field magnetization (PFM) was performed for the MgB_2 bulk 30 mm in diameter by a capsule method, and the applied pulsed-field dependence of the trapped field B_z, temperature rise ΔT and time dependence of the local field $B_L^C(t)$ were measured on the bulk. B_z=0.71 T was achieved at 16 K after applying the magnetic pulsed field of B_{ex}=1.55 T, where ΔT_{max} of about 10 K took place. The results were compared with those by field-cooled magnetization (FCM), and the magnetic flux intrusion and flux trap for the MgB_2 bulk during PFM are discussed.

INTRODUCTION

The superconducting bulk magnet using a REBaCuO (RE: rare earth element or Y) is one of the exemplary models for practical applications such as a sputtering cathode, magnetic separation and drag delivery system [1], which produces tesla-order quasi-permanent magnets. However, the large single-domain bulk over 100 mm in diameter was difficult to fabricate. MgB_2 bulk has also a promising potential as quasi-permanent magnet, which has several attractive natures for bulk superconducting magnet, such as low-cost and light-weight, which are clear contrast with the REBaCuO bulk magnet. The problem of weak-links at the grain boundaries can be ignored in the MgB_2 polycrystalline bulk due to their long coherence length, ξ [2]. The characters enable us to realize the better and larger polycrystalline MgB_2 bulk magnets below the superconducting transition temperature T_c=39 K. Several groups have already reported the trapped field on the MgB_2 bulk by the field-cooled magnetization (FCM), and attained the trapped field over 1.5 T at low temperatures [3-5].

A pulsed-field magnetization (PFM) has also been investigated to magnetize the bulk superconductors because of an inexpensive and mobile experimental set-up with no need for a superconducting magnet. However, for the REBaCuO bulks, the trapped field B_z achievable by PFM is nonetheless lower than that achievable by FCM because of the large temperature rise caused by the dynamical motion of the magnetic flux. Several approaches have been performed and succeeded in enhancing B_z using the multi-pulse techniques [6, 7]. We have experimentally examined the trapped field B_z on the surface of cryocooled REBaCuO bulks during PFM for various starting temperatures T_s and applied fields B_{ex} [8]. To enhance B_z, the reduction in temperature rise and the lowering of T_s are effective. Considering the obtained experimental results, we proposed a new PFM technique named a modified multi-pulse technique with stepwise cooling (MMPSC) and successfully realized a highest field trap of B_z=5.20 T on a GdBaCuO bulk with 45 mm in diameter at 30 K [9], which is a record-high value by PFM to date.

In this paper, we applied the PFM technique to the large MgB_2 bulk fabricated by a capsule method [10]. The PFM experiments for the MgB_2 bulk were performed for the first time and the results were compared with those by FCM.

EXPERIMENTAL PROCEDURE

MgB_2 bulks were fabricated by the *in-situ* capsule method. The detailed procedure of the sample preparation was described elsewhere [10]. Raw powders of Mg (99% in purity) and amorphous B (99% in purity) were weighted with 1.1 : 2.0 in molar ratio, ground and was pressed into pellet 30 mm in diameter and 9 mm in thickness under uni-axial pressure in air. The precursor pellet sealed in the capsule under Ar gas atmosphere was sintered at 800 ℃ for 6 h in a box furnace and cooled to room temperature.

The MgB_2 bulk situated in the stainless steel flange of the capsule was tightly anchored onto the cold stage of a Gifford–McMahon (GM) cycle helium refrigerator. The initial temperature T_s of the bulk was 14 K. The magnetizing solenoid coil (94 mm I.D., 153 mm O.D., and 67 mm height), which was dipped in liquid nitrogen, was placed outside the vacuum chamber. A magnetic pulse B_{ex} up to 1.85 T with a rise time of 0.01 s and a duration of 0.15 s was applied to the bulk by flowing the pulsed current from a condenser bank. The time evolutions of the local field $B_L^C(t)$ and the subsequent trapped field B_z at the center of the bulk surface were monitored by the Hall sensor (BHT 921; F W Bell) using a digital oscilloscope, which was adhered the center of the bulk surface. Two-dimensional trapped field profiles of B_z(1 mm) were mapped on the bulk with 1 mm above the bulk surface, stepwise with a pitch of 1 mm by scanning the axial-type Hall sensor (BHA 921; F W Bell) using an *x–y* stage controller. During PFM, the time dependence of temperature $T(t)$ was also measured at the bulk surface of using the Cernox ™ (Lakeshore Cryotronics, Inc.) thermometer.

FCM was also performed for the MgB_2 bulk using a cryo-cooled superconducting solenoid magnet (JMTD-10T100, JASTEC. Inc.). Under the magnetic field of 5 T, the bulk was cooled to T_s between 16 K to and 30 K, and then the applied field was reduced to zero with a speed of -3 mTs^{-1}. The trapped field B_T^C at the center of the bulk surface was measured by the Hall sensor (BHT 921; F W Bell) adhered at the center of the bulk surface. The trapped field profiles, B_T^{FCM} (4 mm) were measured at T_s=28 K on the vacuum sheath surface at a distance of z=4 mm from the bulk surface.

RESULTS AND DISCUSSION

Figure 1(a) shows the trapped field $B_z=B_T^C$ at the center of the bulk surface, as a function of the strength of the applied pulsed field B_{ex}. B_T^C increases for $B_{ex}>1$ T, takes a maximum at B_{ex}=1.54 T and then decreases with increasing B_{ex}. The maximum B_T^C was 0.71 T. The B_T^C vs B_{ex} curve is a typical one for PFM. Figure 1(b) shows the time dependences of the temperature change on the bulk surface for each applied field B_{ex}. The temperature increases abruptly just after the pulse application and sharply 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 2 presents the trapped field profiles B_z on the MgB_2 bulk 1 mm above the bulk surface for various applied pulsed fields B_{ex}. For B_{ex}=1.04 T as shown in Fig. 2(a), the magnetic flux was trapped at the right lower region of the bulk, where the critical current density J_c seems to be relatively lower in the region. For B_{ex}=1.23 T as shown in Fig. 2(b), the magnetic flux was also trapped at the left upper region of the bulk. For B_{ex}=1.42 T and 1.54 T as shown in Figs. 2(c) and 2(d), the trapped field profiles are nearly the conical one. The trapped field profiles look like nearly homogeneous, compared with those for the REBaCuO bulks [8]. Because the MgB_2 bulk was fabricated by the *in-situ* sintering method. On the other hand, the REBaCuO bulks was fabricated by the melt-growth, in which the four-fold growth sector boundaries (GSBs) existed and the inhomogeneous J_c distribution was shown in the bulk.

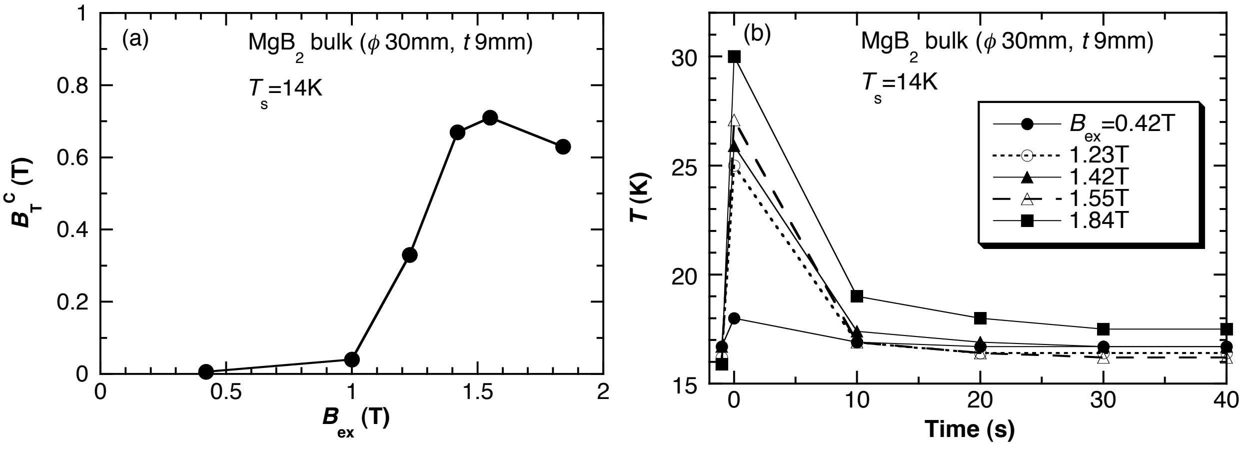

Figure 1 (a) The trapped field B_T^C at the center of the bulk surface as a function of applied pulsed field B_{ex} on the MgB_2 bulk at T_s=14 K. (b) The time dependences of the temperature change on the bulk surface for each applied field B_{ex}

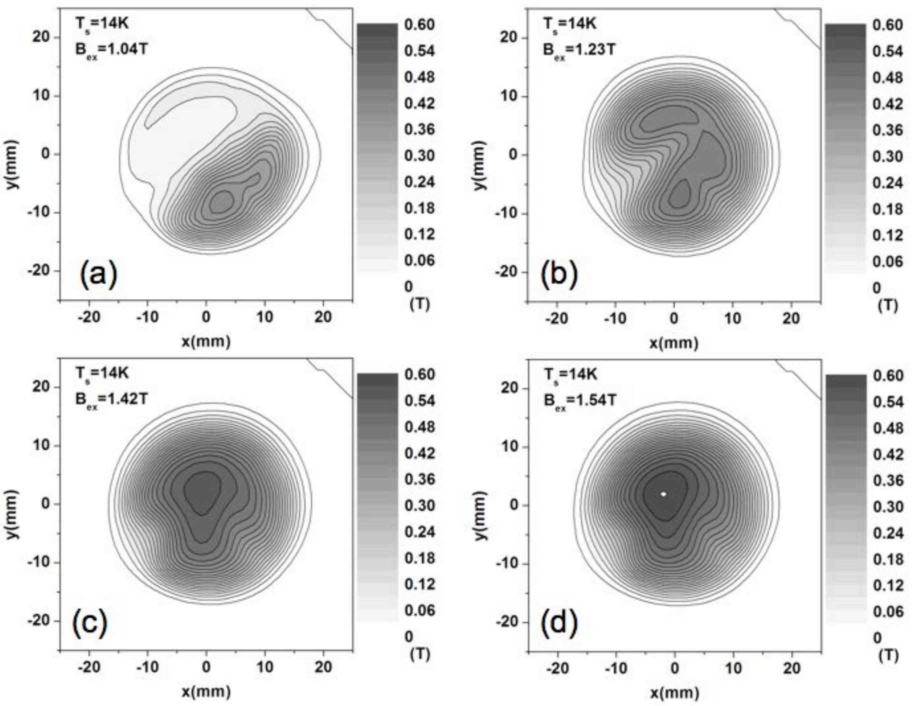

Figure 2 The trapped field profiles B_z on the MgB_2 bulk 1 mm above the bulk surface at (a) B_{ex}=1.04 T, (b) 1.23 T, (c) 1.42 T and (d) 1.54 T.

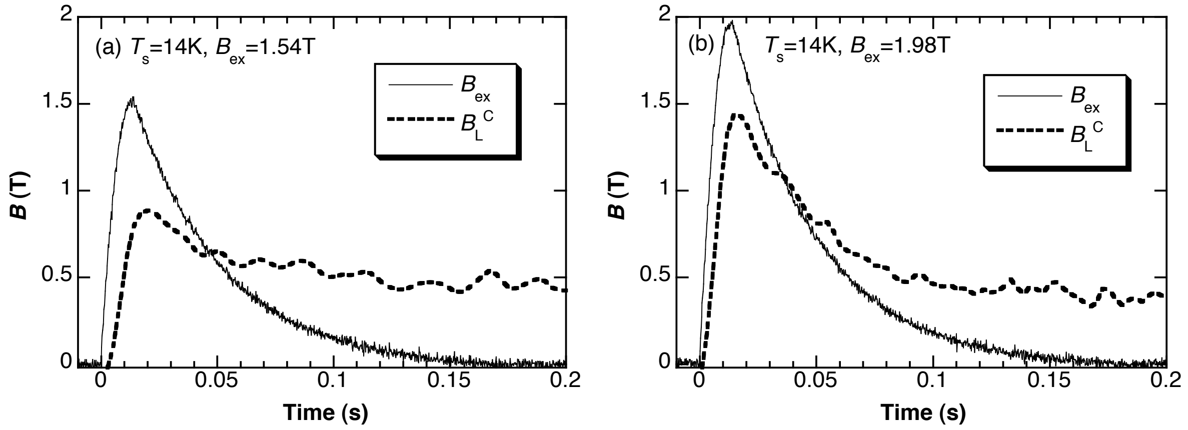

Figure 3 Time dependences of the local field $B_L^C(t)$ and the applied pulsed field $B_{ex}(t)$ for (a) B_{ex}=1.54 T and (b) 1.98 T. The waving in B_L^C comes from the smoothing process.

Figure 3 shows the time dependences of the local field $B_L^C(t)$ after applying the pulsed field of B_{ex}=1.54 T and 1.98 T. Time dependence of pulsed field $B_{ex}(t)$ is also shown. For each B_{ex}, $B_L^C(t)$ starts to increase with a slight time delay, takes a maximum at 0.015 s and then decreases to a final value due to the flux flow. The maximum $B_L^C(t)$ increases with increasing B_{ex} and is smaller than that of $B_{ex}(t)$ because of the shielding effect in the superconductor.

Figure 4(a) depicts the trapped field B_T^C by FCM at the center of the bulk surface as a function of temperature. B_T^C increases with decreasing temperature, which originates from the enhancement of J_c at low temperatures. The highest B_T^C value was 1.50 T at 16 K, which was smaller than that for the reported MgB_2 bulk with 28 mm in diameter fabricated under high pressure [5]. This might come from the fact that the density (approximately 1.3–1.4 g/cm^3) of the present bulk is lower than that of the bulk in Ref. 5.

Figure 4(b) presents the trapped field profile B_T^{FCM} (4 mm) on the bulk magnetized by FCM at T_s=28 K. The maximum B_T^{FCM} (4 mm) was 0.32 T. The trapped field profile is conical, which suggests that the J_c distribution in the bulk is nearly homogeneous from the view point of the profile by FCM. For practical applications, the magnetic field over 0.3 T can be used on the vacuum chamber at present, which is lower than that of the Nd-Fe-B permanent magnet. The MgB_2 bulk magnet over 3 T on the bulk surface and over 1 T on the vacuum sheath can be realized by the enhancements of J_c, the mass density and the connectivity between the grains in the polycristalline MgB_2 bulk.

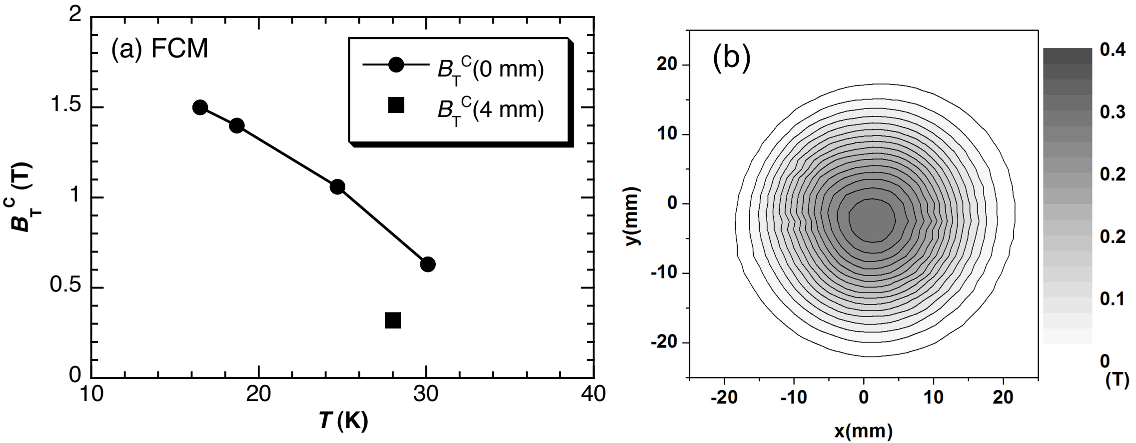

Figure 4 (a) The trapped field B_T^C by FCM at the center of the bulk surface as a function of temperature T_s. (b) The trapped field profile B_T^{FCM} (4 mm) on the bulk magnetized by FCM at T_s=28 K. The maximum B_T^{FCM} (4 mm) was 0.32 T.

SUMMARY

The pulsed-field magnetization (PFM) and the field-cooled magnetization (FCM) were performed for the MgB_2 bulk 30 mm in diameter fabricated by a capsule method, and the applied pulsed field dependence of the trapped field B_z, temperature rise ΔT and time dependence of the local field $B_L^C(t)$ were measured during PFM on the MgB_2 bulk. B_z=0.71 T was trapped by PFM at 14 K after applying the magnetic pulse of B_{ex}=1.55 T, where ΔT_{max} of about 10 K took place. B_T=1.5 T was trapped by FCM at 16 K at the center of the bulk surface with a conical trapped field distribution. PFM is a promising technique to magnetize the MgB_2 bulk besides the FCM.

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REFERENCES

1. Murakami, M., Processing and Applications of Bulk RE-Ba-Cu-O Superconductors, Int. J. Appl. Ceram. Technol. (2007) 4 225-241
2. Kambara, M., Babu, N. H., Sadki, E. S., Cooper, J. R., Minami, H., Cardwell, D. A., Campbell, A. M. and Inoue, I. H., High intergranular critical currents in metallic MgB_2 superconductor, Supercond. Sci. Technol. (2001) 14 L5
3. Viznichenko, R. V., Kordyuk, A. A., Fuchs, G., Nenkov, K., MNuller, K. H., Prikhna, T. A. and Gawalek, W., Temperature dependence of the trapped magnetic field in MgB_2 bulk superconductors, Appl. Phys. Lett. (2003) 83 4360-4362
4. Yamamoto, A., Yumoto, H., Shimoyama, J., Kishio, K., Ishihara, A. and Tomita, M., Development of MgB_2 Bulk Superconducting Magnet, Abstract of 23rd Int. Symp. on Supercond. (2010) 219
5. Perini, E., Giunchi, G., Saglietti, L., Albisetti, A., Matrone, A. and Cavaliere, V., Magnetic Field Trapping in MgB_2 Bulks and Inserts, IEEE Trans. Appl. Supercond. (2011) 21 2690-2693
6. Yanagi, Y., Itoh, Y., Yoshikawa, M., Oka, T., Hosokawa, T., Ishihara, H., Ikuta, H. and Mizutani, U., Trapped field distribution on Sm-Ba-Cu-O bulk superconductor by pulsed-field magnetization, Advances in Superconductivity XII, Springer, Tokyo, Japan (2000) 470-473
7. Sander, M., Sutter, U., Koch, R. and Klaser, M., Pulsed magnetization of HTS bulk parts at T<77 K, Supercond. Sci. Technol. (2000) 13 841-845
8. Fujishiro, H., Hiyama, T., Miura, T., Naito, T., Nariki, S., Sakai, N. and Hirabayashi, I., Pulsed Field Magnetization for GdBaCuO Bulk with Stronger Pinning Characteristics, IEEE Trans. Appl. Supercond. (2009) 19 3545-3548
9. Fujishiro, H., Tateiwa, T., Fujiwara, A., Oka, T. and Hayashi, H., Higher trapped field over 5 T on HTSC bulk by modified pulsed field magnetizing, Physica C (2006) 445–448 334-338
10. Naito, T, T. Sasaki, T and Fujishiro, H., A proposal of new fabricating technique of large MgB_2 bulk by a capsule method, IEEE Trans. Appl. Supercond. (2012) (in print)