Research Article

Electrical Transport Properties of $(\text{Bi}_{1.6}\text{Pb}_{0.4}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10})/\text{Ag}$ Tapes with Different Nanosized MgO

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MgO nanopowders with average size 20 and 40 nm were introduced into $(\text{Bi}_{1.6}\text{Pb}_{0.4}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10})(\text{MgO})_x$ ($x = 0-0.15$ wt.%) in the pellet form. The optimum amounts for the highest transport critical current density J_c were $x = 0.10$ and 0.01 wt.% for 20 and 40 nm MgO, respectively. These results were used to fabricate MgO added (Bi, Pb)-2223/Ag sheathed tapes using the powder-in-tube method. The tapes were sintered at 845°C for 50 h and 100 h. The structure, microstructure, and J_c of the tapes were determined. The temperature and magnetic field dependence of J_c for the MgO added tapes exhibited a significant enhancement compared with the nonadded tapes. J_c of 20 nm MgO added tape was higher compared with the 40 nm MgO added tape. A higher J_c was obtained when the tapes were sintered for 100 h. The increase in J_c can be explained as the increase of the flux pinning strength by nanosized MgO. The nanoparticle with size closer to the coherence length was more effective in enhancing J_c .

1. Introduction

The transport critical current density J_c in $\text{Bi}_{1.6}\text{Pb}_{0.4}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ ((Bi, Pb)-2223) high temperature superconductor is limited by the intergrain weak links, grain alignment, and the weak pinning of flux lines [1–3]. These factors suppressed the J_c and thus prevent the extensive applications of (Bi, Pb)-2223 superconductor. The weak link is also observed in silver-sheathed (Bi, Pb)-2223 tape prepared by powder-in-tube (PIT) technique [4, 5].

Nanoparticles have been used as pinning centers to improve J_c (e.g., [6–9]). Pinning center with size larger than the coherence length ξ was suggested to improve J_c [10]. However, other studies have suggested that the optimum size of pinning centers should be comparable to the penetration depth λ rather than ξ [11]. The ξ of (Bi, Pb)-2223 system is 2.9 nm and λ is 60–1000 nm. It is expected that the interaction between flux line and the nanoparticles will be strong for a particle with size L where $\xi < L < \lambda$ [12].

In previous reports, MgO nanoparticles and nanorods (with average diameter of 30 nm) have been added into (Bi,Pb)-2223/Ag tapes [13, 14]. MgO is chemically inert with (Bi, Pb)-2223, and the transition temperature T_c did not

change considerably with MgO content. In those reports, nanosized MgO additions into (Bi, Pb)-2223/Ag tapes have only been carried out with one average size [13, 14]. It is interesting to investigate the effect of different nanosized MgO on the critical current density of the (Bi, Pb)-2223 system.

Our initial study on samples in pellet form showed that at 77 K, $\text{Bi}_{1.6}\text{Pb}_{0.4}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}(\text{MgO})_x$ ($x = 0-0.15$ wt.%) pellets exhibited the highest J_c at $x = 0.10$ wt.% for 20 nm MgO and $x = 0.01$ wt.% for 40 nm MgO. It is interesting to study the effect of the two different nanosized MgO with those amounts in (Bi, Pb)-2223(MgO) $_x$ /Ag tapes. In this paper, we report on the effect of 20 nm ($x = 0.1$ wt.%) and 40 nm ($x = 0.01$ wt.%) MgO in (Bi, Pb)-2223(MgO) $_x$ /Ag tapes. We also report the influence of sintering time (50 and 100 h) on J_c .

2. Experimental Details

$\text{Bi}_{1.6}\text{Pb}_{0.4}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ superconductor was prepared by the acetate coprecipitation technique. The powders were calcined at 730°C for 12 h. Followed by calcination at 845°C for 24 h.

FIGURE 1: XRD patterns of (Bi, Pb)-2223(MgO) $_x$ /Ag tapes for $x = 0$ wt.%, $x = 0.10$ wt.% of 20 nm MgO, and $x = 0.01$ wt.% of 40 nm MgO heated for 50 h. The Ag peak is indexed to (111).

MgO nanopowders with size 20 and 40 nm (US-nano, 99+% purity) were added to $\text{Bi}_{1.6}\text{Pb}_{0.4}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}(\text{MgO})_x$ ($x = 0-0.15$ wt.%). The mixed powders were ground and then pressed into pellets. The pellets were sintered at 845°C for 48 h. The highest J_c at 77 K for the pellets was found in the $x = 0.10$ and 0.01 wt.% of 20 and 40 nm MgO, respectively. These amounts were used to prepare (Bi, Pb)-2223(MgO) $_x$ /Ag tapes by powder-in-tube (PIT) method. The powders were packed into a 6.35 mm outer diameter and 4.35 mm inner diameter silver tube (99.9% metals basis, Alfa Aesar). The tubes were drawn to a 1 mm wire and then pressed into 0.30 mm thick and 1.53 mm wide tapes. The tapes were sintered for 50 h and 100 h at 845°C.

The structure and microstructure of the tapes were examined by X-ray powder diffraction using a Siemens D 5000 diffractometer with CuK_α radiation and a Philips XL 30 scanning electron microscope (SEM), respectively. The distribution of nano MgO in the tapes was determined by using a Philips energy dispersive X-ray analyzer (EDX) model PV99. The J_c was determined by the four-probe method using the $1\mu\text{V}/\text{cm}$ criterion. Measurements of transport critical current density were done from 30 to 77 K in zero field, and at 77 K under magnetic field from 0 to 0.75 T. The size of the MgO nanopowder was confirmed by a Philips transmission electron microscope (TEM) model CM12.

(a)

(b)

(c)

FIGURE 2: SEM micrographs of (Bi, Pb)-2223(MgO) $_x$ /Ag tapes (a) $x = 0$ wt.%, (b) $x = 0.10$ wt.% of 20 nm MgO, and (c) $x = 0.01$ wt.% of 40 nm MgO. The dots refer to Mg.

3. Results and Discussion

The complete results for $x = 0$ to 0.15 wt.% in pellet form is reported elsewhere [15]. Briefly, at 77 K, the $x = 0.10$ wt.%, 20 nm MgO added pellet showed the highest J_c (1.73 A/cm²). For the 40 nm MgO added pellet, the $x = 0.01$ wt.% sample showed the highest J_c (1.17 A/cm²) as shown in Table 1. The low values of J_c in these polycrystalline samples are similar in

FIGURE 3: J_c of $x = 0$ wt.%, $x = 0.10$ wt.% of 20 nm MgO, and $x = 0.01$ wt.% of 40 nm MgO tapes sintered for (a) 100 h and (b) 50 h as a function of the temperature.

TABLE 1: J_c (at 0 T) of $x = 0$ wt.%, $x = 0.10$ wt.% of 20 nm MgO, and $x = 0.01$ wt.% of 40 nm MgO added pellets and tapes sintered for 50 h and 100 h at 30 and 77 K.

x (wt.%)	J_c (30 K) Pellet (A/cm ²)	J_c (77 K) Pellet (A/cm ²)	J_c (30 K) Tape (50 h) (A/cm ²)	J_c (77 K) Tape (50 h) (A/cm ²)	J_c (30 K) Tape (100 h) (A/cm ²)	J_c (77 K) Tape (100 h) (A/cm ²)
0.00	0.65	0.31	8104	949	10820	1262
0.10 (20 nm)	4.13	1.73	15110	1532	18380	3676
0.01 (40 nm)	2.60	1.17	13120	1312	14060	1875

magnitude to those reported in the Y-based [16] and Bi-based [17] superconductors. A low NiO ($x = 0.002$) addition in (Bi, Pb)-2223 was also reported to elevate the flux pinning in the superconductor [6].

Figure 1 shows the XRD patterns of (Bi, Pb)-2223(MgO) $_x$ /Ag tapes for the nonadded and MgO added samples. Most of the peaks belong mainly to the high- T_c phase (Bi-2223) with a few peaks corresponding to the low- T_c phase (Bi-2212) and a small quantity of Ca₂PbO₄ phase. The Ag peak was also observed. SEM micrographs showed that the nonadded and MgO added tapes consisted of plate-like grains (Figure 2). Figures 2(b) and 2(c) show a homogeneous distribution of MgO (white dots) with additions of 20 and 40 nm MgO, respectively.

Figure 3 shows the J_c of the nonadded and MgO added tapes sintered for 50 and 100 h as a function of temperature. It is clear that J_c of the 20 and 40 nm MgO added tapes samples were higher compared with the nonadded tape. MgO

added tapes sintered for 100 h exhibited a higher J_c than tapes sintered for 50 h (Table 1).

The magnetic field dependence of J_c for the nonadded and MgO added tapes at 77 K with the applied field parallel $B_{||}$ and perpendicular $B_{\perp}$ to the surface of the tape is shown in Figure 4. The J_c of MgO added tapes were higher than the nonadded tape. It can be seen that $J_c(B_{||})$ decreased slower than $J_c(B_{\perp})$ with increasing B . The improvement of J_c under magnetic field can be explained as the strengthening of weak links, grain boundaries and significant improvement of flux pinning centers in MgO added tapes. A high degree of intimate grain connectivity, grain alignment and flux pinning centers enhance J_c of (Bi, Pb)-2223/Ag tape under magnetic field [18, 19].

In Figures 3 and 4 we find that J_c of the 20 nm MgO added tape was higher compared with 40 nm MgO added tape. Particles size (20 nm) which is closer to the coherence length (2.9 nm) is more effective in increasing J_c . Previous reports

FIGURE 4: J_c of $x = 0$ wt.%, $x = 0.10$ wt.% of 20 nm MgO, and $x = 0.01$ wt.% of 40 nm MgO added tapes under magnetic field parallel $B_{||}$ and perpendicular $B_{\perp}$ to the surface of the tape at 77 K.

on nano MgO addition in (Bi, Pb)-2223 pellets and tapes also showed improvement in J_c [13, 14]. In this work we showed that for low MgO content, the size of the nanoparticles also affected the J_c .

In conclusion, the J_c of MgO added tapes exhibited a significant enhancement compared with the nonadded tapes. The J_c of the 20 nm MgO added samples was higher than the 40 nm MgO added pellets and tapes. A higher J_c was obtained when the tape was sintered for 100 h due to improvement in grains connectivity. The enhancement of the J_c could be the result of the increase in the flux pinning ability in (Bi, Pb)-2223(MgO)_x/Ag tapes. Our results showed that in order to enhance J_c , the size of the pinning center should be closer to the coherence length.

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References

- [1] D. Larbalestier, "Superconductor flux pinning and grain boundary control," *Science*, vol. 274, no. 5288, pp. 736–737, 1996.
- [2] D. J. Bishop, P. L. Gammel, D. A. Huse, and C. A. Murray, "Magnetic flux-line lattices and vortices in the copper oxide superconductors," *Science*, vol. 255, no. 5041, pp. 165–172, 1992.
- [3] D. S. Fisher, M. P. A. Fisher, and D. A. Huse, "Thermal fluctuations, quenched disorder, phase transitions, and transport in type-II superconductors," *Physical Review B*, vol. 43, no. 1, pp. 130–159, 1991.
- [4] K. Sato, T. Hikata, H. Mukai et al., "High- J_c silver-sheathed Bi-based superconducting wires," *IEEE Transactions on Magnetics*, vol. 27, no. 2, pp. 1231–1238, 1991.
- [5] J. Tenbrink, M. Wilhelm, K. Heine, and H. Krauth, "Development of high- T_c superconductor wires for magnet applications," *IEEE Transactions on Magnetics*, vol. 27, no. 2, pp. 1239–1246, 1991.
- [6] B. A. Albiss, I. M. Obaidat, M. Gharaibeh, H. Ghamlouche, and S. M. Obeidat, "Impact of addition of magnetic nanoparticles on vortex pinning and microstructure properties of BiSrCaCuO superconductor," *Solid State Communications*, vol. 150, no. 33–34, pp. 1542–1547, 2010.
- [7] V. Bartůňek and O. Smrčková, "Nanoparticles and superconductors," *Ceramics*, vol. 54, no. 2, pp. 133–138, 2010.
- [8] A. I. Abou-Aly, M. M. H. Abdel Gawad, R. Awad, and I. G-Eldeen, "Improving the physical properties of (Bi, Pb)-2223 Phase by SnO₂ Nano-particles addition," *Journal of Superconductivity and Novel Magnetism*, vol. 24, no. 7, pp. 2077–2084, 2011.
- [9] A. Agail and R. Abd-Shukor, "Transport current density of (Bi_{1.6}Pb_{0.4})Sr₂Ca₂Cu₃O₁₀ superconductor added with different nano-sized ZnO," *Applied Physics A*, vol. 112, no. 2, pp. 501–206, 2013.
- [10] U. Al Khawaja, M. Benkraouda, I. M. Obaidat, and S. Alneaimi, "Numerical simulations on the role of the defect size on the

- critical current in high-temperature superconductors,” *Physica C*, vol. 442, no. 1, pp. 1–8, 2006.
- [11] N. Takezawa and K. Fukushima, “Optimal size of an insulating inclusion acting as a pinning center for magnetic flux in superconductors: calculation of pinning force,” *Physica C*, vol. 290, no. 1-2, pp. 31–37, 1997.
- [12] I. F. Lyuksyutov and D. G. Naugle, “Frozen flux superconductors,” *Modern Physics Letters B*, vol. 13, no. 15, pp. 491–497, 1999.
- [13] B. Zhao, X. Wan, W. Song, Y. Sun, and J. Du, “Nano-MgO particle addition in silver-sheathed $(\text{Bi,Pb})_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_x$ tapes,” *Physica C*, vol. 337, no. 1, pp. 138–144, 2000.
- [14] W. D. Huang, W. H. Song, Z. Cui et al., “Enhancement of flux pinning in (Bi, Pb) -2223/Ag tapes doped with MgO nanorods,” *Superconductor Science and Technology*, vol. 13, no. 10, pp. 1499–1504, 2000.
- [15] A. A. Nabil Yahya and R. Abd-Shukor, “Effect of Different Nano-Sized MgO on the Transport Critical Current Density of $\text{Bi}_{1.6}\text{Pb}_{0.4}\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ Superconductor,” *Journal of Superconductivity and Novel Magnetism*, 2013.
- [16] K. E. Oldenburg, W. A. Morrison, and G. C. Brown, “Critical current density of $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$,” *American Journal of Physics*, vol. 61, no. 9, pp. 832–834, 1993.
- [17] M. Anis-ur-Rehman and M. Mubeen, “Synthesis and enhancement of current density in cerium doped Bi(Pb)Sr(Ba) -2223 high T_c superconductor,” *Synthetic Metals*, vol. 162, pp. 1769–1774, 2012.
- [18] S. Dou, Y. Guo, and H. Liu, “Critical current density of the Ag-clad Bi-based superconductors,” in *Proceedings of the MRS Spring Meeting*, vol. 275, 1992.
- [19] M. P. Maley, “Overview of the status of and prospects for high- T_c wire and tape development (invited),” *Journal of Applied Physics*, vol. 70, no. 10, pp. 6189–6193, 1991.