ANL/ET/CP-97046

ENHANCEMENT OF CRITICAL CURRENTS IN $(Bi,Pb)_2Sr_2Ca_2Cu_3O_y$ (Bi-2223) SUPERCONDUCTING TAPES*

U. Balachandran and M. Lelovic
Argonne National Laboratory, Argonne, IL 60439, U.S.A.

N. G. Eror
University of Pittsburgh, Pittsburgh, PA 15261, U.S.A.

J. Talvacchio and R. Young
Science & Technology Center, Northrop Grumman, Pittsburgh, PA 15235, USA

V. Selvamanickam and P. Haldar
Intermagnetics General Corporation, Latham, NY 12110, U.S.A.

November 1998

Manuscript to be submitted for publication in Proceedings of 1998 International Symposium on Superconductivity, Fukuoka, Japan, Nov. 16-19, 1998.

*Work supported by the U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy, as part of a DOE program to develop electric power technology, under Contract W-31-109-Eng-38.

DISCLAIMER

Enhancement of Critical Currents in $(Bi,Pb)_2Sr_2Ca_2Cu_3O_y$ (Bi-2223) Superconducting Tapes

U. Balachandran[1], M. Lelovic[1], N. G. Eror[2], J. Talvacchio[3], R. Young[3], V. Selvamanickam[4], and P. Haldar[4]

[1]Energy Technology Division, Argonne National Laboratory, Argonne, IL 60439, USA
[2]Department of Materials Science, University of Pittsburgh, Pittsburgh, PA 15261, USA
[3]Science & Technology Center, Northrop Grumman, Pittsburgh, PA 15235, USA
[4]Intermagnetics General Corporation, Latham, NY 12110, U.S.A

Abstract: The performance of $(Bi,Pb)_2Sr_2Ca_2Cu_3O_y$ (Bi-2223) superconducting tapes in magnetic fields at 77 K is critical for winding this material into high-field magnets. We have recently enhanced the transport current (I_c) of multifilament Ag-clad Bi-2223 tapes in a self-field at 77 K by increasing the packing density of the precursor powder, improving the mechanical deformation, optimizing the conductor design, and adjusting the cooling rate. I_c values of >40 A were obtained repeatedly. However, a transport current of 42 A in a self-field declined to 4 A in a 0.2 T magnetic field applied parallel to the c-axis at 77 K. A new composite tape was then fabricated in which a $YBa_2Cu_3O_{7-\delta}$ (Y-123) film was deposited on the top of the Ag-sheathed Bi-2223 tape to shield the applied magnetic field and protect the central Bi-2223 filaments. Magnetization measurements showed that the critical current densities of the Y-123-coated, Ag-sheathed Bi-2223 tapes were higher than those of an uncoated tape. These preliminary results may provide the basis for further improving the processing of long-length Bi-2223 tapes for high-field applications.

Key words: Powder-in-tube (PIT) technique, Bi-2223 superconducting tapes, Y-123 thin film, magnetic shielding

INTRODUCTION

Material processing still remains the key factor in realizing the application potential of high-temperature superconductors. Three different approaches have been taken for processing high-temperature superconductors: powder-in-tube (PIT) process, which yields a highly textured $Bi_2Sr_2CaCu_2O_x$ (Bi-2212) and $(Bi,Pb)_2Sr_2Ca_2Cu_3O_y$ (Bi-2223) superconductors [1,2]; the melt-textured growth of bulk $YBa_2Cu_3O_{7-\delta}$ (Y-123) [3-5]; and the growth of oriented thin films on flexible substrates [6-9]. At this time, only the PIT process is used as industrial technique for fabricating long-length superconductors. High critical current density (J_c) in superconducting wires and tapes is essential for many practical applications. Significant progress has been made over the past several years in improving J_c values in wires and tapes to acceptable levels for some commercial applications.

EXPERIMENTAL PROCEDURE AND RESULTS

As in our previous study [10], multifilament Ag-clad Bi-2223 tapes were made by the PIT technique with precursor powder having the overall stoichiometry of Bi-2223. The precursor powder contained Pb-added 2212, Ca_2PbO_4, alkaline-earth cuprate, and CuO phases. Three density levels in the Ag tubes were achieved by using precursor powder, at $\approx$2.3 g/cm^3 and prepressed billets at 3.5 g/cm^3 (low packing density) and 4.5 g/cm^3 (high packing density). The powder and prepressed-billet Ag tubes were swaged, drawn through a series of dies, and then rolled to a final thickness of $\approx$200 µm. The standard mechanical processing consisting of >10% reduction per pass was used in fabricating these tapes. Samples measuring 1.5 m in length were cut from the three tapes and heat treated in 8% oxygen atmosphere. Transport critical current (I_c) was measured at 77 K, and self-field with 1 µV/cm criterion. The higher packing density resulted in higher I_c values after heat treatment at 820°C, and these values were maintained uniformly over the entire length [10].

In another set of experiments, we varied the mechanical deformation schedule. The Ag tubes were drawn and rolled according to various reduction ratios per pass. Improved mechanical processing of the high-density billet produced a pronounced effect on the uniformity of the Ag/superconductor interface. Scanning electron microscopy (SEM) images showed that the smoothness of the interface had improved [10]. This effect is significant because the interface is important in controlling the grain morphology and texture of 2223 grains. The more coherent Bi-2223/Ag interface for the light-reduction specimens resulted in higher I_c values.

Figure 1a shows the current-voltagwe (I-V) characteristics of the superconducting tape that carried 42 A in zero applied magnetic field. Magnetic fields up to 0.4 T were applied along the c-axis. A field of $\approx$ 0.2 T (2000 Oe) lowers the I_c value from 42 A to 4 A and changes the slope around the I_c value [11]. These results strongly suggest that $\approx$0.2 T is the "irreversibility field" (H^*) at 77 K. Figure 1b shows the exponential decline of I_c with applied field H_{app} at 77 K (H_{app} <0.2 T). These results are consistent with the observation that $I_c(0)$ and $I_c(H_{app})$ in Bi-2223 tapes are controlled by different mechanisms: while $I_c(0)$ is controlled by the transfer of current between grains, $I_c(H_{app})$ is controlled by both "intragranular" and "intergranular" effects of flux pinning.

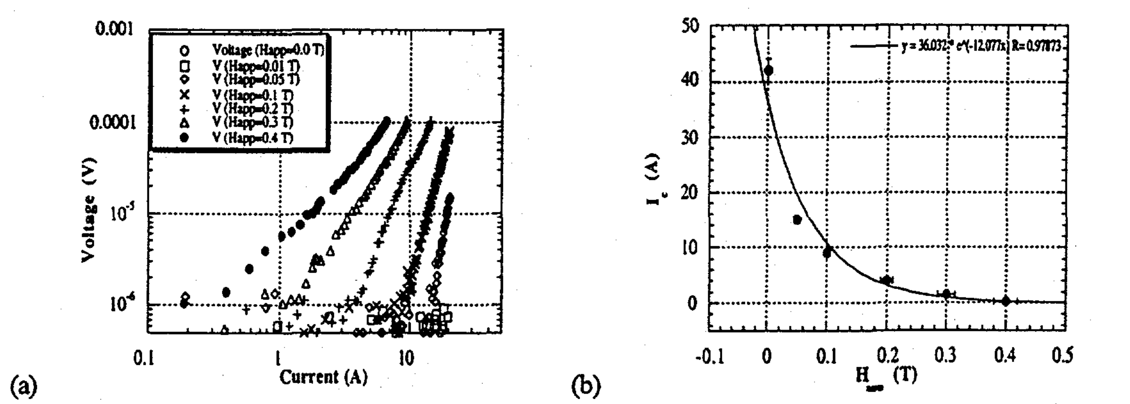

Fig. 1. (a) Voltage-current characteristics of multifilament tape at 77 K and magnetic field along the c-axis; (b) exponential dependence of I_c as a function of applied field at 77 K.

A new composite multifilament tape was fabricated so that its central portion contained Bi-2223 filaments [12], which were surrounded by a Y-123 thin film to shield the applied magnetic field and protect the Bi-2223 filaments. The as-rolled tape was cut into 4-cm lengths, and Y-123 thin films were grown on the segments by off-axis magnetron sputter deposition [13]. A 100-nm-thick layer of $SrTiO_3$ (STO) was deposited as a buffer. Y-123 was sputtered in a 200-mtorr gas mixture of argon and oxygen. The substrates were held at ≈700°C. Figure 2a shows the schematic arrangement.

Coated and uncoated tapes were heat treated according to the Bi-2223 schedule. Magnetic measurements as a function of temperature for Y-123 thin film in the as-coated tape at H_{app} = 100 Oe parallel to the c-axis showed the transition temperature T_c ≈72 K along with the broad transition region. This T_c was lower than other reported values [14], possibly due to the surface structure of the thin film grown on the Ag-sheathed Bi-2223 tape. Also, it is possible that the oxygen deficiency in the as-coated state caused the lower T_C.

Figure 2b shows the J_c dependence on H_{app} and T of a heat-treated Bi-2223 tape coated with Y-123 thin film; the reference tape in the figure was uncoated but heat treated under the same conditions. A magnetic field was applied parallel to the c-axis for all measurements performed at 20, 40, and 60 K. The increase in J_C is more pronounced at lower temperatures because of the critical temperature of the Y-123 thin film. Also, the magnitude of the increase is affected by the misorientation of the Y-123 grains. However, the results of our work show that this approach can be used to enhance J_c response of Bi-2223 phase at higher temperatures and in higher magnetic fields.

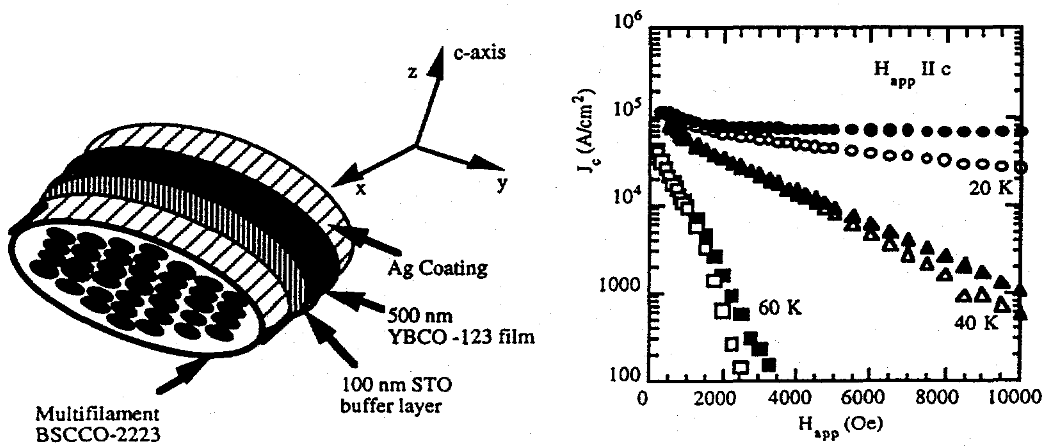

Fig. 2. (a) Schematic diagram of Y-123-shielded Bi-2223 multifilament tape; (b) magnetization J_C vs. magnetic field applied parallel to c-axis at 20, 40, and 60 K: solid triangles represent Bi-2223 tape coated with Y-123 thin film and heat treated; open squares represent uncoated and heat-treated reference tape.

CONCLUSIONS

Transport current properties in multifilament Ag-clad Bi-2223 superconducting tapes were improved by varying the mechanical and thermal parameters during tape processing. Packing density of the precursor powder, improved mechanical deformation, and cooling rate all had a pronounced effect on the critical current of the superconducting tapes. Dependence of the critical current density on magnetic field and temperature for the optimally processed tapes was measured. J_C was $>10^4$ A/cm^2 at 20 K in magnetic fields up to 3 T and parallel to the c-axis, which is of interest for use in refrigerator-cooled magnets. A new composite multifilament tape was fabricated such that its central part contained Bi-2223 filaments, with the primary function of conducting the transport current. The central Bi-2223 filaments were surrounded by a Y-123 thin film to shield the applied magnetic field and protect the Bi-2223 filaments. The increase in J_c is attributed to the magnetic contribution of the Y-123 thin film to the Bi-2223 grains.

ACKNOWLEDGMENTS

Work supported by the U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy, as part of a DOE program to develop electric power technology, under Contract W-31-109-Eng-38.

REFERENCES

1. Balachandran U, Iyer AN, Haldar P, Motowidlo LR, (1993) J Metals 9: 54
2. Flukiger R, Hensel B, Jeremie A, Perin A, Grivel JC, (1993) Appl Supercon 1: 709
3. Jin S, Tiefel TH, Davis ME, Kammlott GW, Fastnacht RA, (1988) Phys Rev B 37: 7850
4. Salama K, Selvamanickam V, Gao L, Sun K, (1989) Appl Phys Lett 54: 2352
5. Murakami M, Morita M, Doi K, Miyamoto K, (1989) Jpn J Appl Phys 28: 1189
6. Iijima Y, Tanabe N, Kohno O, Ikeno Y, (1992) Appl Phys Lett 60: 769
7. Knierim A, Auer R, Geerk J, Reiner H, Schneider R, (1992) Appl Phys Lett 70: 661
8. Wu XD, Foltyn SR, Arendt PN, Blumenthal WR, Campbell IH, Cotton JD, Coulter JY, Hults WL, Maley MP, Safar HF, Smith JL, (1995) Appl Phys Lett 67: 2397
9. Norton DP, Goyal A, Budai JD, Christen DK, Kroeger DM, Specht ED, He Q, Saffian B, Paranhaman M, Klabunde CE, Lee DF, Sales BC, List FA, Science (1996) 274: 755
10. Balachandran U, Selvamanickam V, Haldar P, Lelovic M, Eror NG, (1998) Supercon Sci Technol 11: 978
11. Li Q, Weismann HJ, Suenaga M, Motowidlo L, Haldar P, (1995) App Phys Let 66: 637
12. Lelovic M, Eror NG, Prorok BC, Balachandran U, Selvamanickam V, Haldar P, Talvacchio J, Young R, (1998) Supercon Sci Technol 11: in press
13. Talvacchio J, Forrester MG, Hunt BD, McCambridge JD, Young RM, Zhang XF, Miller D, (1997) IEEE Trans Appl Supercon 7: 2051
14. Budai JD, Young RT, Chao BS, (1993) App Phys Lett 62: 1836