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Bi2212 High Temperature Superconductors Prepared by the Diffusion Process for Current Lead Application

by

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Abstract

Bi2212 High temperature superconducting (HTS) conical tubular conductors have been prepared by the diffusion process for current lead. The Bi2212 HTS layers are synthesized through the diffusion reaction between a Sr-Ca-Cu oxide substrate and a Bi-Cu oxide coating with Ag addition. The HTS diffusion layers about 150 μm in thickness are formed around both outside and inside of the conical tubes 34/29 mm in outside/inside diameter at the larger end, 24/19 mm in outside/inside diameter at the smaller end, and 100 mm in length. The Ag added to the coating enhances the diffusion reaction, and precipitates on the surface of the specimen decreasing its contact resistance. The transport current properties were evaluated by measuring system using two cryocoolers at Railway Technical Research Institute. The critical temperature of transport current of 1000 A at 0.5 T for the specimen is 57.4 K, which corresponds to the current density of 33 A/mm^2 for the Bi2212 layers. The transport current decreases with increasing temperature at the warm end of the conical specimen, and is about 800 A at 60.2 K and 600 A at 62.5 K. The joint voltage of 20 μV at cold end was generated at 50 K and 0.5 T with transport current of 1000 A, which corresponds to the small heat load of 20 mW resulted from the Joule heating. Present Bi2212 conical tubes seem to be promising as current leads with small heat loads for superconducting magnets.

Keywords: Bi2212 superconductor, Diffusion process, Current lead, Critical current, Heat leakage

1. Introduction

High temperature superconductors (HTS) can be synthesized through the diffusion process between the two components in an appreciably shorter reaction time than that of the HTS prepared by the conventional sintering process. In the Bi-Sr-Ca-Cu-O system, a thick and homogeneous HTS layer of $Bi_2Sr_2Ca_1Cu_2O_8$ (Bi2212) is easily synthesized by the diffusion reaction between Sr-Ca-Cu oxide substrate and Bi-Cu oxide coating [1], [2]. The Bi2212 HTS cylindrical tubes prepared by the diffusion process were found to be promising for current leads with large transport current and small heat leakage [3]-[6]. In the present study, the transport current performance and the structures of Bi2212 HTS conical tubular bulk conductor prepared by the diffusion process will be reported. The conical shaped tube may be expected to yield larger transport current due to the larger cross-sectional area at warm end and smaller heat leakage due to the smaller cross-sectional area at cold end in comparison with the cylindrical tubes previously reported [5], [6]. The Bi2212 HTS conical tubes synthesized by the diffusion process are attractive for a current lead to be used in superconducting magnet system.

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2. Experimental

The preparation procedure of Bi2212 HTS conical tubular bulk specimen through the diffusion process is schematically shown in Fig. 1. The substrate is composed of Sr-Ca-Cu oxide with the composition ratio of Sr:Ca:Cu=2:1:2 (referred to as “0212”). The calcined 0212 oxide powder was formed into conical tubes 34/29 mm in outside/inside diameter at the larger end, 24/19 mm in outside/inside diameter at the smaller end, and 100 mm in length by cold

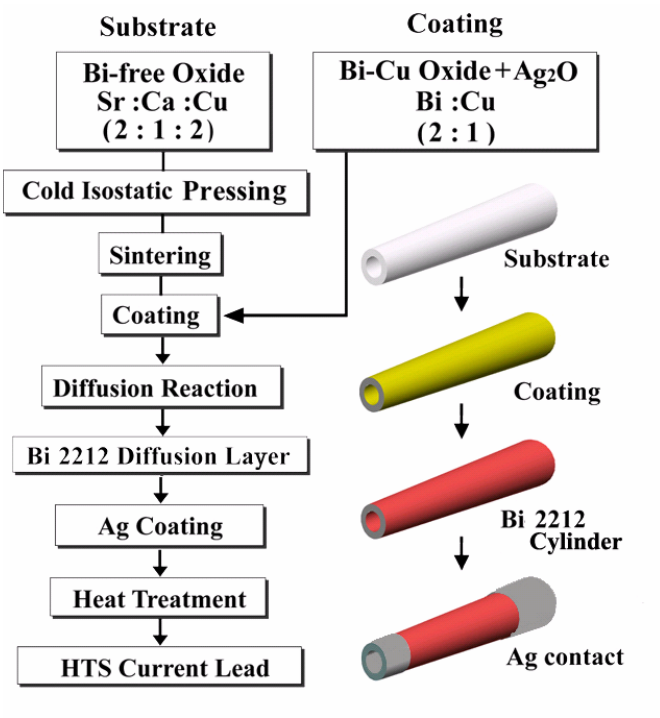

Fig. 1. Preparation procedure of the Bi2212 conical tubular specimen by the diffusion process.

isostatic pressing (CIP). It was then sintered at 1000°C in open air. The coating is composed of Bi-Cu oxide with the composition ratio of Bi:Cu=2:1(referred to as 2001). The calcined 2001 oxide powder with 30wt%Ag_2O addition was mixed with wax to form slurry, and was coated around the conical tubular substrate. The diffusion reaction was performed at 850°C for 20 h to produce the Bi2212 HTS layer. Ag added to the coating precipitates on the surface of the specimen after the heat treatment. The Ag paste was coated around both ends of the diffusion specimen, and was sintered at 800°C in air to form the Ag contacts. One of the advantages in diffusion process enables to form HTS diffusion layer on substrates in any shape.

The structural properties of the prepared specimens were studied by an optical microscope (OM), scanning electron microscope (SEM), and X-ray diffractometry (XRD). The transport current of the specimens were measured resistively by a dc four-probe method. The transport current density was obtained by dividing transport current by the cross-sectional area of both HTS diffusion layers. The transport currents were measured in the facilities of Railway Technical Research Institute.

3. Results and discussion

3.1 Structural properties of Bi2212 HTS conductor

Fig. 2 demonstrates the HTS conical tube specimen 34/29 mm in outside/inside diameter at the larger end, 24/19 mm in outside/inside diameter at the smaller end and 100 mm in length. (a) is as diffused specimen with Ag contacts of 20 mm in length on both ends. The specimen shown in (b) is soldered to both Cu end caps using commercial Sn-Pb solder. Four voltage taps were attached on the both Cu end caps (V1 and V4) and to the HTS (40 mm between V2 and V3). Five cernox resistance thermo sensors were attached on the both Cu end caps (T1 and T5) and to the HTS (distance of every 20 mm between T2, T3 and T4). A pair of stainless steel (SUS304) boards serves as a shunt, and relieves thermal stress in the specimen.

SEM micrograph taken on the fractured outside cross-section of the specimen is shown in Fig. 3. The Bi-2212 HTS diffusion layer of about 150 μm is synthesized around the substrate. The diffusion layer is composed of thin

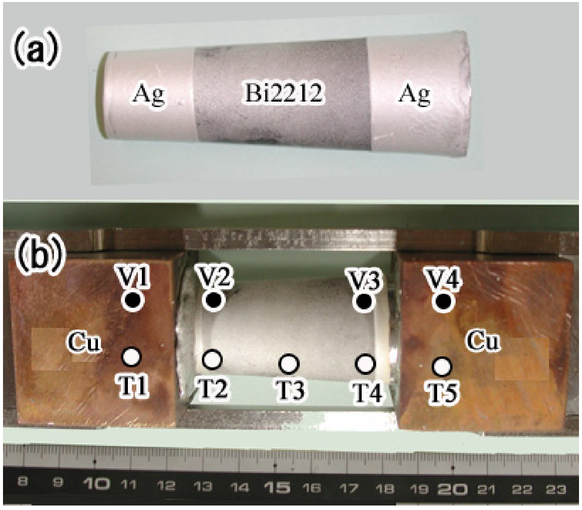

Fig. 2. Bi2212 conical tubular specimen. (a) as diffused, (b)connected to Cu end cap. Totally four voltage taps and five cernox resistance thermo sensors were attached on the surface of HTS and Cu caps.

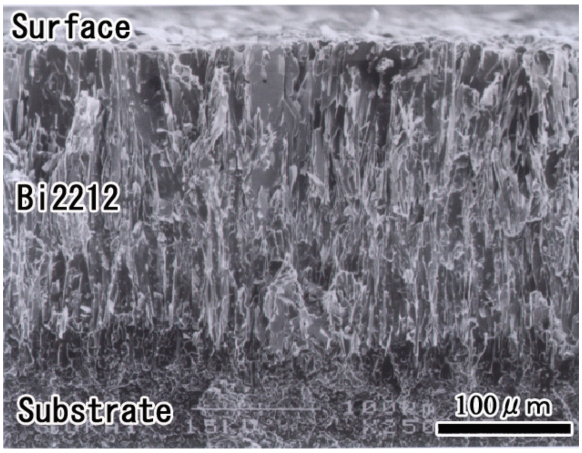

Fig. 3. SEM micrograph taken on the fractured outside cross-section of the specimen.

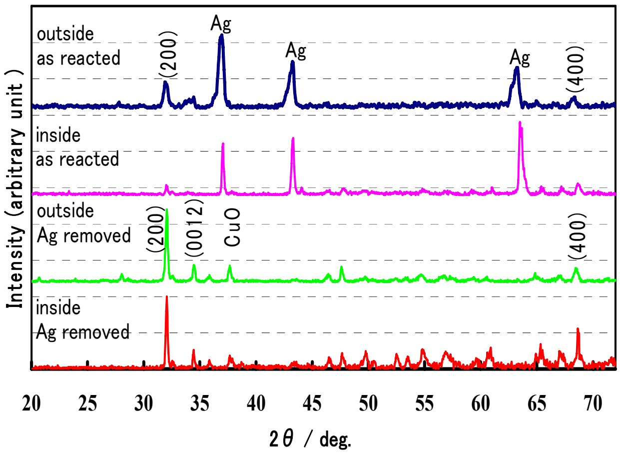

Fig. 4 X-ray diffraction patters taken on the outside and inside surfaces of the specimen.

plate-like grains grown along the diffusion direction, that is to say, the radial direction of the conical tube. The characteristic structure of the diffusion layer results from the preferred grain growth along a-axis and b-axis direction in Bi2212 HTS crystallization process.

Fig. 4 indicates the XRD patterns taken on the outside and inside surfaces of the conical tube specimen. A peak of the Ag is seen on the outside and inside surface after diffusion reaction. The XRD pattern indicates strong (200) peak in comparison with that of conventionally sintered Bi2212 bulk surface after removing the Ag precipitation by an etching solution. Some CuO particles unsolved by the etching solution remain on the surface. Therefore, the diffusion layer is found to be composed of a-axis textured grains. The transport current longitudinally passes through the conical specimen along the a-b planes of the grains grown in the radial direction.

3.2 Transport performance of Bi2212 HTS conductor

Fig. 5 shows the schematic illustration of measuring system [7] for transport current using two cryocoolers. The larger end (warm joint) for the specimen and Cu current leads were cooled by a 1-Stage Gifford-McMahon (GM) cryocooler. The smaller end (cold joint) for the specimen was cooled by a 2-Stage GM cryocooler. Resistive heaters were installed on the Cu leads and the cooling stage of cryocoolers to adjust the temperature of the conical specimen. The capacity of transport current is 1,000 A for the power source. Magnetic field of 0.5 T is always applied perpendicular to the specimen current using a pair of Nd-B-Fe permanent magnets. Then, the specimen was installed into a cryostat, and cooled in a vacuum to be about 10 K at cold joint and 40 K at warm joint for 20 h.

Transport current and current density versus temperatures at warm joint under 0.5 T for the Bi2212 conical specimen is shown in Fig. 6. The transport current was supplied at a ramp rate of 20 A/s. Arrows in the figure indicate that the transport current exceeds the capacity limit of 1,000 A. The critical temperature of transport current of 1000 A at 0.5 T for the specimen is 57.4 K, which corresponds to the current density of 33 A/mm^2 for the Bi2212 layers at warm end. The transport current decreases with increasing temperature at the warm joint of the conical specimen, and is about 800 A at 60.2 K, 600 A at 62.5 K and 200 A at 70 K, respectively.

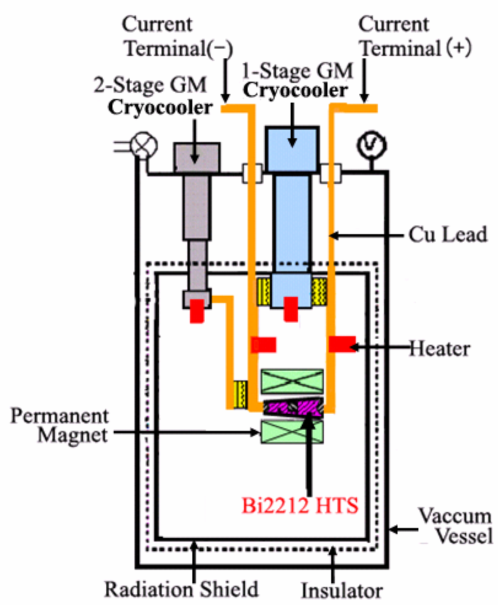

Fig. 5 Schematic illustration of measuring system for transport current using two cryocoolers.

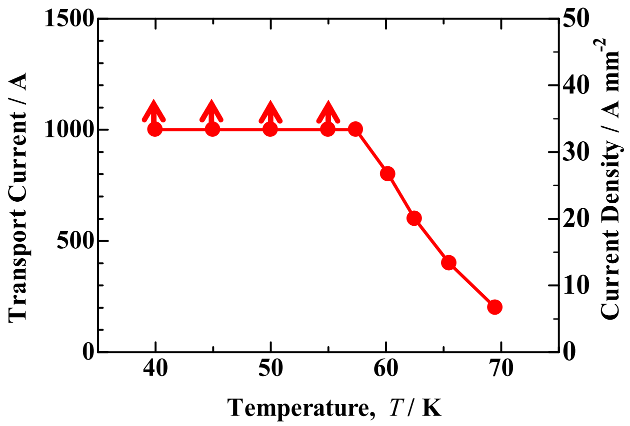

Fig. 6 Transport current and current density versus temperatures at warm joint under 0.5 T for the Bi2212 conical specimen.

Fig. 7 shows the transport current performance of 1,000 A for the Bi2212 specimen at 50 K and 0.5 T. The transport current of 1000 A at 50 K was stably run for 600 s with almost no voltage on the HTS part (between V2 and V3). The voltages of both joints increased with increasing transport current, and were 280 μV at the warm joint and 21 μV at the cold joint after reaching 1,000 A. Then, the voltages of warm and cold joints rose to 380 μV and 34 μV after holding the current for 600 s. Therefore, the heat load at cold joint is as small as about 30 mW due to the small Joule heat. The small heat load, that is, low voltage at cold joint results from low contact resistance between Bi2212 grains and Ag precipitated through the diffusion reaction.

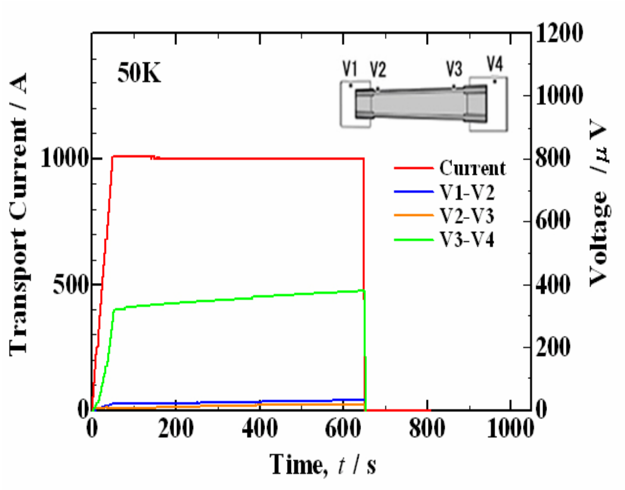

Fig. 7 Transport current performance of 1000A for the Bi2212 specimen at 50K and 0.5T.

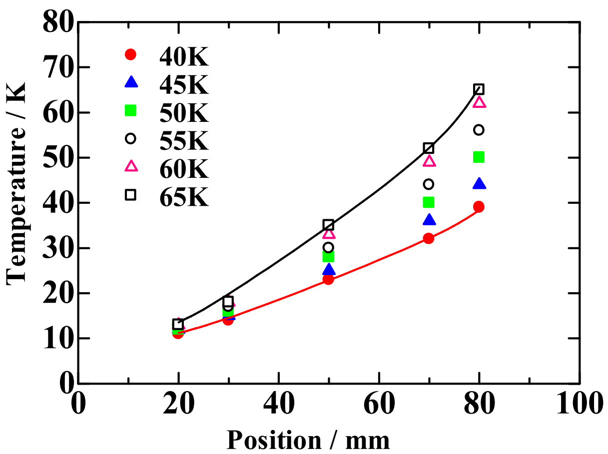

Fig. 8 Temperature distribution curves along the Bi2212 conical tubular specimen.

Fig. 8 shows the longitudinal temperature distribution curves along the Bi2212 conical tubular specimen. Although the temperature at warm joint rose from 40 K to 65 K by resistive heater installed near the joint, the temperature at cold end varied from 10 K to 12 K by only 2 K. The temperature difference between warm and cold ends is larger than 50 K for the conical tube specimen with effective 60 mm in length. The sharp gradient of the temperature results from low thermal conductivity of the Bi2212 HTS conductor as well as low heat load at cold joint. According to a previous study [8], the temperature difference between warm and cold ends is about 50 K for the similar conical specimen with effective 150 mm in length. The low temperature gradient is due to cooling by evaporated helium gas. Therefore, it is important to evaluate the heat load of HTS conductors without a gas-cooling for current lead application using the measuring system shown in Fig. 5. Thus, Bi2212 HTS conical tubular conductor with a large transport current and a small heat load are attractive for current lead in superconducting magnets.

4. Conclusions

Bi2212 HTS conical tubular conductors have been prepared by the diffusion process. The HTS diffusion layer, about 150 μm in thickness, mostly consists of thin plate-like and a-axis textured grains. The critical temperature of transport current of 1000 A at 0.5 T for the specimen is 57.4 K, which corresponds to the current density of 33 A/mm^2 for the Bi2212 layers. The transport current decreases with increasing temperature at the warm end of the conical specimen, and is about 800 A at 60.2 K and 600 A at 62.5 K. The joint voltage of 20 μV at cold end was generated at 50 K and 0.5 T with transport current of 1000 A, which corresponds to the small heat load of 20 mW resulted from the Joule heating. Present Bi2212 conical tubes seem to be promising as current leads for superconducting magnets.

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References

[1] K. Tachikawa, Y. Yamada, M. Satoh and Y. Hishinuma, “Structure and superconducting properties of oriented Bi-2212 oxide layer synthesized by a diffusion process,” Proc. 1994 Topical International Cryogenic Materials Conference, World Scientific, (1995), pp.307-310.
[2] Y. Yamada, F. Yamashita, K. Wada and K. Tachikawa, “Structure and superconducting properties of Bi-2212 cylinders prepared by diffusion process”, Advances in Cryogenic Engineering (Materials) vol.44, (1998), pp.547-554.
[3] Y. Yamada, M. Takiguchi, O. Suzuki, K. Tachikawa, A. Iwamoto, H. Tamura and T. Mito, “Transport performance of Bi-2212 current leads prepared by a diffusion process,” IEEE Trans. Appl. Supercond., Vol.11, (2001), pp.2555-2558.
[4] H. Tamura, A. Iwamoto, T. Mito, K. Tachikawa and Y. Yamada, “Mechanical properties and reinforcement of

Bi2212 cylindrical bulk superconductor for current lead," IEEE Trans. Appl. Supercond., Vol.12, (2002), pp.1319-1322.
[5] Y. Yamada, M. Enomoto, K. Tachikawa, H. Tamura, A. Iwamoto, and T. Mito, "Structure and Performance of Bi-2212 hollow cylinders prepared by a new diffusion process," Physica C, Vol. 386, (2003), pp.110-114.
[6] Y. Yamada, S. Chikai, M. Watanabe, K. Tachikawa, H. Tamura, A. Iwamoto, and T. Mito, "Transport Performance in Bi2212 Cylinders Prepared by the Diffusion Process for Current Lead Application," IEEE Trans. Appl. Supercond., Vol.14, (2004), pp.638-641.
[7] M. Ogata, K. Nagashima, M. Iwamatsu, A. Inoue and Y. Miyazaki, Abstracts of Cryogenic Society of Japan conference, Vol. 74, (2006), pp.154 (in Japanese).
[8] J. Ohkubo, Y. Yamada, K. Tachikawa, H. Tamura, and T. Mito, Fusion Engineering and Design, Vol. 81, (2006), pp.2449-2455.