Experimental Apparatus for Critical Current Measurement above 5 K Using Bi-based oxide current leads

著者	渡辺　和雄
journal or publication title	IEEE Transactions on Applied Superconductivity
volume	7
number	2
page range	707-710
year	1997
URL	http://hdl.handle.net/10097/47116

doi: 10.1109/77.614602

Experimental Apparatus for Critical Current Measurement above 5 K Using Bi-based Oxide Current Leads

T. Hasebe, H. Mitsubori, J. Sakuraba and M. Ishihara
Sumitomo Heavy Industries, Ltd., 63-30 Yuhigaoka, Hiratsuka, Kanagawa 254, JAPAN

S. Awaji and K. Watanabe
Institute for Materials Research, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-77, JAPAN

Abstract - An experimental apparatus for the measurement of temperature dependence of critical current within a strong magnetic field has been developed. Samples, which are tested by the four probe method, are cooled by a Gifford-McMahon (GM) type cryocooler to the lowest temperature of 5K. The sample holder has a diameter of 70 mm and a height of 70 mm. Transport currents, up to 150 A, is supplied to two samples through Bi-based oxide superconducting current leads. An external magnetic field of up to 15 T, which is applied to the samples perpendicularly to sample axis, is generated by a water cooled single Bitter magnet with a room temperature bore of 82 mm. As a performance test, the critical current properties of a silver clad Bi-based oxide tape have been measured at 5.5 K, 30 K and 50 K within a magnetic field up to 15 T. This experiment has demonstrated the validity of this experimental apparatus.

I. INTRODUCTION

A cryogen-free experimental cryostat for critical current measurement has been developed utilizing Bi-based oxide superconducting current leads and GM cryocooler in the previous work [1]. It enables us to perform measurements of critical currents up to 500 A at temperatures ranging from 20 K to 90 K without the need of liquid helium or liquid nitrogen. The external magnetic field of up to 3 T is generated by a compact liquid helium-free Nb_3Sn superconducting magnet. This measurement unit is useful for evaluation of the properties of high Tc superconducting materials. On the other hand, strong magnetic fields above 10 T are needed to evaluate performance of the conventional superconductors and the high Tc materials in the temperature range below 10 K.

GM cryocooler has made great progress in its refrigeration power below 10 K, using magnetic regenerator materials such as $ErNi_{0.9}Co_{0.1}$ [2]. The largest cooling capacity at 4.2 K is above 1 W, and it realizes some practical and reliable applications of the 4 K-GM cryocooler.

We developed a new apparatus for critical current measurements below 10 K using a GM cryocooler with $ErNi_{0.9}Co_{0.1}$. We selected a water cooled single Bitter magnet which generates maximum central magnetic field of 15 T in this study.

II. DESIGN FEATURES

Fig. 1 shows a conceptual drawing of the apparatus. Two samples can be cooled by thermal conduction through the conduction plate and copper leads from the second cooling stage of a 4K-GM cryocooler in vacuum. There are three sets of current leads in this cryostat. Two samples each have its own current lead, and share a common current lead to be energized interchangeably by an external current source.

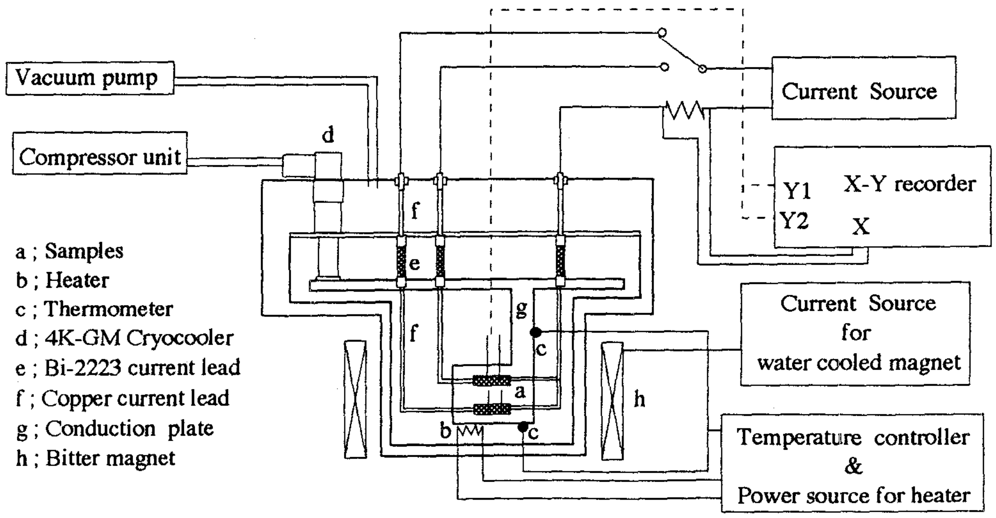

Fig.1 A conceptual drawing of the experimental apparatus.

Manuscript received August 26, 1996.

1051-8223/97$10.00

$Bi_2Sr_2Ca_2Cu_3O_x$ (Bi-2223) superconducting current leads connect the terminals on the first cooling stage with the terminals on the second cooling stage to reduce the heat leakage to the second cooling stage. Estimated heat leakage to the second cooling stage is 0.3 W, and it is 20 W for the first cooling stage. Using data of cooling capacity of the GM cryocooler examined preliminarily, the lowest temperature of each cooling stage with the heat load mentioned above are estimated to be 40 K for the first cooling stage, and 3.8 K for the second cooling stage, respectively. The temperature of sample holder is monitored by ruthenium oxide (RuO) resistance thermometer, and controlled in the temperature range 5 K to 80 K by a Proportional plus Integral plus Derivative action (P.I.D.) controller with resistance heater. A Carbon Grass Resister (CGR) temperature sensor is attached to the conduction plate which connect the sample holder to the second cooling stage.

The sample current is measured by a shunt resistor and recorded by a X-Y pen recorder with the sample voltage.

In this study, the external magnetic field is generated by a water cooled single Bitter magnet. The maximum central field of this Bitter magnet is 15 T. Fluctuation of the external magnetic field, caused by the ripple of excitation current, could cause errors in the measurement. The amplitude of the fluctuation is 0.1 % of the central field and is up to 0.01 T when the central field is 10 T. Eddy currents in the thermal shield and the sample holder caused by the field fluctuation could raise the temperature of the sample. Motions of magnetic flux in the superconducting samples would cause A.C. losses and generate electric fields, and the induced electric field could cause errors in the measurement of critical current. On the other hand, the frequency of the ripple is 600 Hz and the skin depth in the copper cylinder which consists of the tail portion of the thermal radiation shield could be calculated to be less than 3 mm. Therefore the samples which are surrounded with a thermal radiation shield would not be affected by the field fluctuation.

Fig. 2 shows a structural view of the developed cryostat for this measurement apparatus and Fig.3 shows a detailed view of the sample holder for the critical current measurement of short sample. The sample holder, which has a diameter of 70 mm and a height of 70 mm, is held in the tail portion of thermal shield and vacuum chamber by a copper conduction plate with a length of 485 mm. The copper conduction plate and three current leads which are made of copper are tied up in parallel with insulators between. Glass Fiber Reinforced Plastics (GFRP) is used for the insulators. Promoting heat exchange between leads and conduction plate, aluminum nitride (AlN) plates are also used for some portions of insulators.

Bi-2223 superconducting current leads are fabricated by the powder sintering process in a shape of cylindrical bulk having a length of 190 mm, an inner diameter of 20 mm and an outer diameter of 23 mm. Each end portions of 20 mm long of the lead are coated with silver for electrical contact using plasma

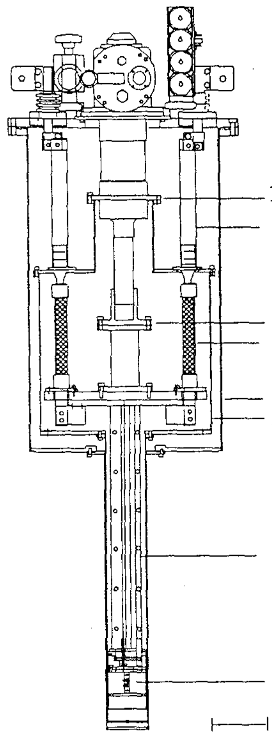

Fig.2 A structural view of the developed cryostat for the experimental apparatus for critical current measurement. The outer diameter of tail portion is 80 mm.

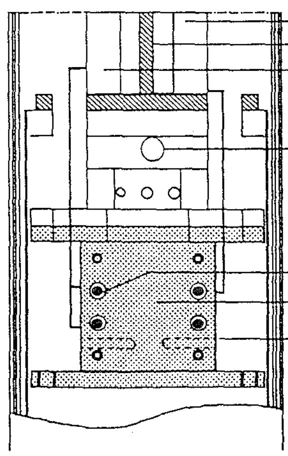

Fig.3 A detailed view of the sample holder for critical current measurement of short sample. There are two pairs of copper electrodes on the bed with AlN insulators between.They have a diameter of 5 mm and a distance of 30 mm between. Surface of the sample bed is coated with fluorocarbon polymers for electrical insulation.

spray. One end portion which is thermally connected to the first cooling stage is in the presence of leakage magnetic field of 0.09 T. And the other end portion connected to second stage is in the presence of leakage magnetic field of 0.25 T. Referring to field dependence of the critical current in various temperatures for Bi-2223 current lead [3], it could be predicted that the Bi-2223 current leads with a transport current of 200 A would be kept in superconducting state below 75 K at 0.09 T and below 65 K at 0.25 T. There is no need to restrict the magnitude of transport current for the end portion on the first stage which is designed to be 40 K at 0.09 T. Considering the critical current of end portion on the second cooling stage at 0.25 T, the supplied current must be restricted to 200 A when the sample temperature is 65 K.

The sample bed made of copper, which is shown in Fig.3, is coated with fluorocarbon polymers for electrical insulation. There are two pairs of copper electrodes on the bed with AlN insulators between.They have a diameter of 5 mm and a distance of 30 mm between.

A RuO resistance thermometer and a stainless sheathed resistance heater are mounted as shown in Fig. 3. This sample holder can be replaced by another configuration such as a bobbin of small coil. The outer diameter of tail portion of the vacuum chamber is 80 mm, and it fits in the inner diameter of room temperature bore of the Bitter magnet (82 mm). The outer diameter of main part of the vacuum chamber is 360 mm. The total height of the cryostat is 1138 mm, and the weight is about 80 kg.

III. Experimental Results

Initial cooling time from ambience to the lowest temperature was about 14 hours without temperature control. The lowest temperature without any power into the heater was 40 K at the first cooling stage and 4.2 K at the second cooling stage respectively. It shows a good agreement with the estimated figures mentioned above. The temperature of the sample was 5.2 K. It was higher than that of the second cooling stage. The reason for this difference of the temperatures is heat flux through the copper leads and their connections.

A test sample of silver clad Bi-2223 tape with a length of 35 mm was soldered to the terminals on the sample bed and a pair of voltage taps was soldered on the surface of the sample with a distance of 5 mm. In this configuration, the direction of the applied magnetic field is parallel to the surface of the tape and perpendicular to the sample current. The test current was swept at a rate of 1 A/sec. The criterion of the critical current was 1 μV/cm.

Temperature stability was examined when the supplying current of 100 A continuously flowing through the sample. The temperature of the copper leads which connect the sample holder to the terminals on the second cooling stage rose about 0.8 K from 10 K with a supply current of 100 A. On the other hand, the sample temperature kept constant with the continuous supplying current of 100 A by means of P.I.D. controller.

Fig.4 shows the temperature changes of the sample holder, conduction plate and second cooling stage during a sweep of external magnetic field from 0 T to 12 T without any temperature control. The sweep rate was 0.05 Tesla per second. On its way to 12 T, the field was held at 3 T, 6 T and 9 T for 540 seconds, respectively. Each temperature rose at the moment of field sweep, but the temperature fell again and settled in a while. The stationary temperature varies with intensities of the external magnetic field, and it holds a maximum value of 5.5 K above 9 T. Existing no different profiles in the temperature change of two different temperature sensors, RuO and CGR, the temperature drift is not an error of the sensor in the magnetic field but real change of the temperature. Because of the drift of the lowest cooling temperature within a strong magnetic field as shown in Fig.4, the lowest temperature of critical current measurement is set to 5.5 K.

Fig.5 shows profiles of the sample holder temperature and the external magnetic field during the measurement of critical current on the Bi-2223 tape at 5.5 K. The sample holder temperature was set to 5.5 K by the P.I.D. controller. Though the temperature rise due to field sweep was also observed in Fig.5, there were only small drifts less than 0.1 K during the measurements of critical current. Dependence on magnetic field of transporting critical current of Bi-2223 tape were also measured at 30 K and 50 K, respectively.

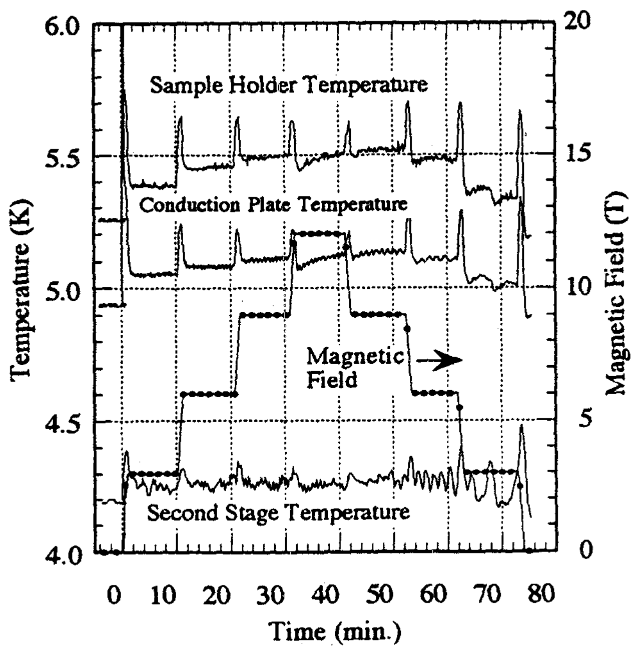

Fig.4 The temperature changes of the sample holder ,conduction plate and second cooling stage during sweep of external magnetic field from 0 T to 12 T without any temperature control.

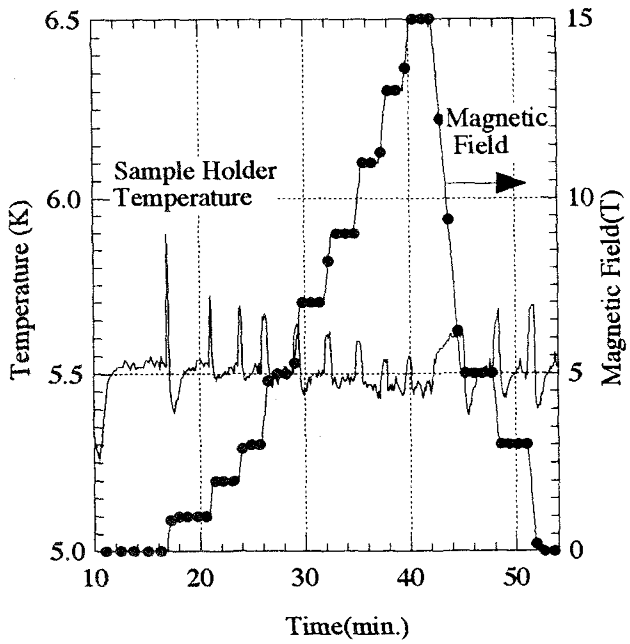

Fig.5 Profiles of the sample holder temperature and the external magnetic field during the measurement of critical current on Bi-2223 tape at 5.5 K.The sample holder temperature was set to 5.5 K by P.I.D. controller.

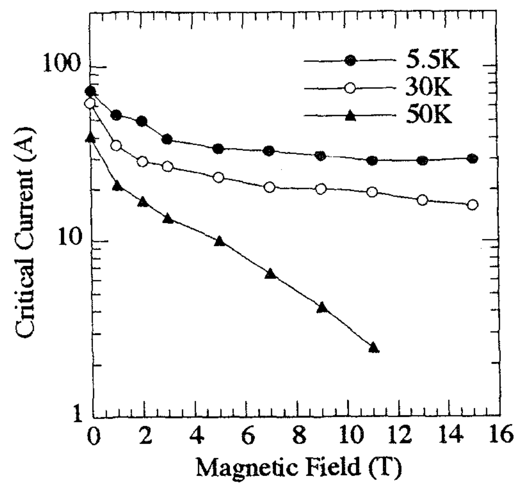

Fig.6 The properties of silver clad Bi-2223 oxide superconducting tape measured at the temperatures of 5.5 K, 30 K and 50 K under the magnetic field of 0 T to 15T.

There were no drifts of temperature during the measurements at each temperature. Fig.6 shows the properties of silver clad Bi-2223 oxide superconducting tape measured at the temperatures of 5.5 K, 30 K and 50 K under the magnetic field of 0 T to 15T. It was confirmed that the critical current density of Bi-2223 material is drastically decreased by the presence of magnetic field above 50 K [3].

IV. Conclusions

The experimental apparatus for the measurement of temperature dependence of critical current within a strong magnetic field has been developed. A new designed cryostat with 4 K-GM cryocooler enables critical current measurements at temperatures from 5.5 K to 80 K. The external magnetic field up to 15 T is applied by the water cooled single Bitter magnet. Temperature drift is less than 0.1 K during the critical current measurement at 5.5 K within magnetic field up to 15 T.

The critical current properties of a silver clad Bi-2223 tape have been measure at 5.5 K, 30 K and 50 K within a magnetic field up to 15 T. This experiment has demonstrated the validity of this experimental apparatus.

References

[1]T.Hasebe, T.Tsuboi, K.Jikihara, J.Sakuraba, M.Ishihara and Y.Yamada, "Critical Current Measurement Unit Utilizing Bi-Based Oxide Superconducting Current Leads and Cryocoolers," IEEE Trans. on Applied Superconductivity, Vol.5, No.2, pp.821, June 1995.

[2] T.Satoh, A.Onishi, R.Li, H.Asami and Y.Kanazawa, "Development of 1.5 W 4K-GM Cryocooler With Magnetic Regenerator Material," Adv. Cryog. Eng. Vol.41 (1996) in press.

[3]T.Hasebe, T.Tsuboi, K.Jikihara, J.Sakuraba, M.Ishihara and Y.Yamada, "Dependence On Temperature And Magnetic Field of Transport Critical Current of Bi-2223 Bulk," Critical States In Superconductors, Proceedings of 1994 topical International Cryogenic Materials Conference, pp.303, 1995.