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Thermal conductivity of DI-BSCCO tapes with stacked or sandwiched structure

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Abstract. We have measured the temperature dependence of the thermal conductivity, $\kappa(T)$, for DI-BSCCO tapes sandwiched by various kinds of alloy tapes and for a stacked bundle in which six DI-BSCCO tapes were soldered. For the sandwiched samples, the shape of $\kappa(T)$ is qualitatively the same as that for the bare DI-BSCCO tape and the absolute value of $\kappa(T)$ depends on the species and the thickness of the alloy tape. $\kappa(T)$ for the stacked bundle nearly coincides to that for the bare DI-BSCCO. The $\kappa(T)$ for the sandwiched and stacked samples can be reproduced by the $\kappa(T)$ of each constitutional part.

1. Introduction

High temperature superconductive tape named DI-BSCCO is a commercial silver sheathed Bi2223 tape which is produced by Sumitomo Electric Industries, Ltd. [1]. Recently, a higher critical current I_c=218 A has been achieved at 77 K in self-field [2] and the DI-BSCCO tape has a potential for various superconducting devices and large scale applications [3].

For the applications, the heat intrusion through the tape from the outside and the heat generation in the inside of the tape affect the operating condition of the apparatus. The thermal conductivity, $\kappa(T)$, is a basic and important parameter to estimate the heat transfer, Q_t, through the material by the relation,

$$Q_{\rm t} = \frac{S}{L}\int_{T^{\rm l}}^{T^{\rm h}} \kappa(T)dT,$$

where S is the cross section, L the length of the material, and $T^{\rm l}$ and $T^{\rm h}$ are the temperatures at the low- and high-temperature ends of the material.

To increase the mechanical strength, the DI-BSCCO tapes are usually reinforced by various kinds of alloy tapes such as stainless steel and brass. In this paper, we report the thermal conductivity, $\kappa(T)$, of DI-BSCCO tapes sandwiched by various kinds of alloy tapes. The $\kappa(T)$ for a stacked bundle which consists of six DI-BSCCO tapes was also measured. The measured $\kappa(T)$ was compared with the $\kappa(T)$ which was estimated using the $\kappa(T)$ values of the bare DI-BSCCO tape, the reinforcing alloy tape and the solder.

2. Experimental procedure

DI-BSCCO tapes were fabricated by the powder in tube (PIT) method with the Controlling-Overpressure (CT-OP) sintering technique. The details of sample preparation have been

Table 1. Specifications of the DI-BSCCO tapes

Type	H	HT-SUS20	HT-Bz50	HT-Bs50	HT-Bs100	H6
alloy tape	–	SUS	Bronze	Brass	Brass	–
thickness of alloy (μm)	–	20	50	50	100	–
cross section (mm^2)	0.94	1.35	1.59	1.58	2.03	5.88
width (mm)	4.25	4.50	4.55	4.50	4.50	4.42
thickness (mm)	0.22	0.28*	0.35*	0.35*	0.47*	1.33*

* including the thickness of solder layers.

described elsewhere [1]. The DI-BSCCO tape sheathed with silver ("type H") is a standard tape. The Ag/Bi2223 ratio, which is defined by the ratio of the volume fraction between the Bi2223 core and the Ag sheath, was about 1.8. The type HT tape was prepared to achieve a high yield stress, in which the type H tape was sandwiched from both surfaces by the thin alloy tapes with various thicknesses using the commercial solder (LFM-48). A stainless steel (SUS), bronze (Bz) or brass (Bs) were used as the reinforcing material. The type HT tape with SUS tapes 20 μm in thickness was named HT-SUS20. Other HT samples were named by this rule as shown in Table 1, in which the specifications of the DI-BSCCO tapes studied here were summarised. A stacked bundle was also prepared, consisting of six type H tapes that were joined by the solder. Hereafter, we refer to this sample as type H6.

The thermal conductivity along the tape surface, i.e., along the ab plane of the Bi2223 filament, was measured by a steady-state heat-flow method [4]. The experimental setup for the $\kappa(T)$ measurement is illustrated in Fig. 1. One end of the tape was soldered to the sample stage, and a small metal chip resistor (1 kΩ) was adhered to the other end of the tape as a heater using GE7031 varnish. κ is estimated by the relation, $\kappa = (Q/\Delta T)\cdot(L/S)$, where Q is the applied heat flow, ΔT the temperature difference, L the distance between the thermocouples, and S the cross section of sample. ΔT was measured using two chromel-constantan thermocouples (76 μm in diameter) that were adhered to the sample with GE7031 varnish. Q was generated by flowing current to the chip resistor and was automatically controlled to maintain ΔT of 0.5–0.8 K. To eliminate the radiation loss, κ was measured below 200 K. The temperature of the sample stage was controlled using a Gifford-McMahon cycle helium refrigerator.

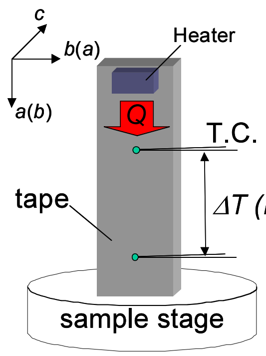


Figure 1. The schematic experimental setup for the $\kappa(T)$ measurement, where the coordinate axes represent the crystallographic axes of Bi2223 filaments.

3. Results and Discussion

Figure 2(a) shows the temperature dependence of the thermal conductivity $\kappa(T)$ for the type H, four sandwiched type HT and type H6 tapes. On the cooling run, $\kappa(T)$ of the type H tape decreases moderately from 200 K down to 100 K and subsequently increases below 100 K. It begins to increase rapidly below 60 K, and takes a maximum of about 800 W m^{-1} K^{-1} around 15 K. The shape of $\kappa(T)$ for all the type HT tapes is qualitatively similar to those for the type H and the type H6. However, the absolute value of the thermal conductivity, $\kappa_{\text{abs}}(T)$, depends on the species and thickness of the alloy tape, because $\kappa_{\text{abs}}(T)$ of alloy strongly depends on the species of element and the composition. Figure 2(b) shows the measured $\kappa(T)$ for the SUS tape 20 μm in thickness and the solder (LFM-48). The reported data for bronze (Cu:Sn=9:1) [5] and

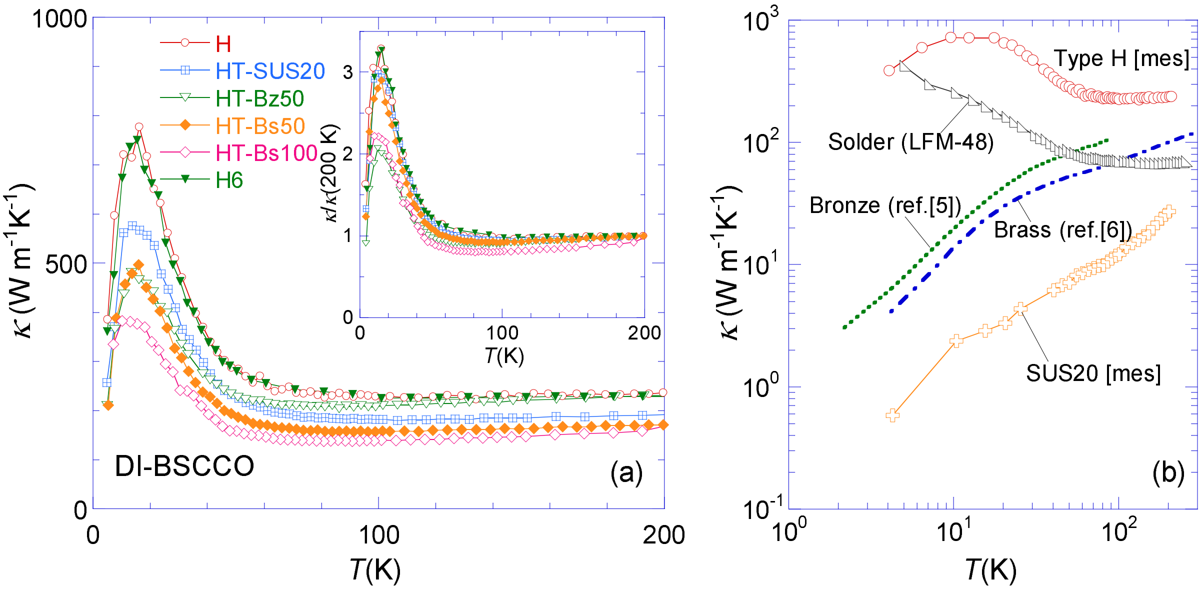


Figure 2. (a) The temperature dependence of the thermal conductivity, $\kappa(T)$, for the type H, four kinds of type HT and the type H6 tapes. The inset shows the $\kappa(T)/\kappa(200\text{ K})$ for the same samples. (b) The measured $\kappa(T)$ for the type H tape, the SUS tape 20 μm in thickness and the solder (LFM-48), the reported $\kappa(T)$ for bronze (Cu:Sn=9:1) [5] and the recommended $\kappa(T)$ for brass (Cu:Zn=7:3) [6].

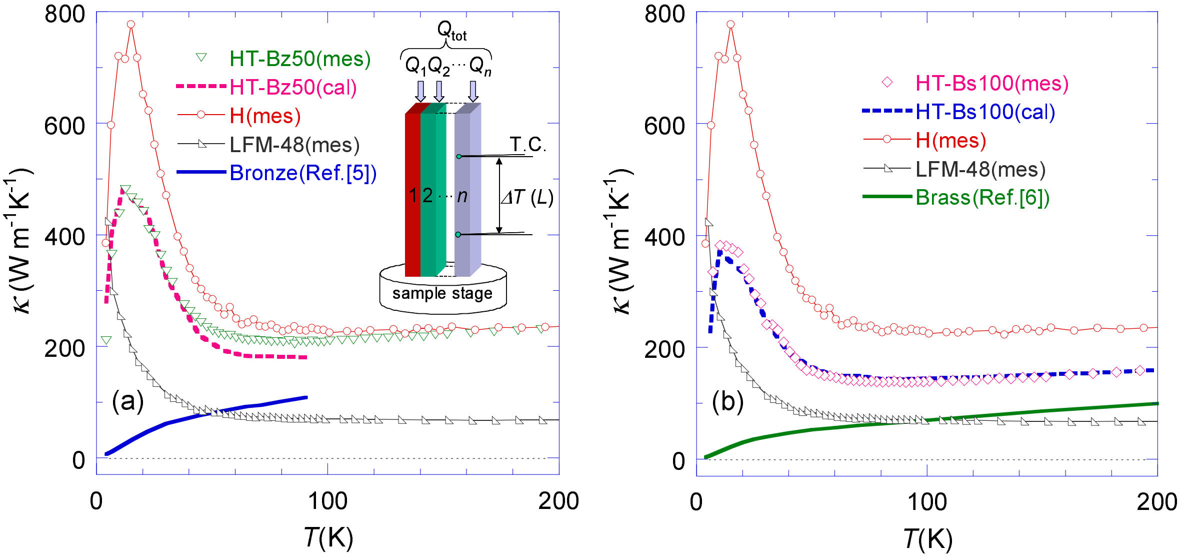
the recommended data for brass (Cu:Zn=7:3) [6] are also shown. $\kappa(T)$ for the solder increases very gradually with decreasing temperature from 200 K down to around 40 K. It begins to increase rapidly below 40 K with decreasing temperature. $\kappa(T)$ for other alloys (SUS, bronze, brass) decreases monotonically with decreasing temperature. The $\kappa_{\rm abs}(T)$ for the SUS tape is about one to three orders of magnitude smaller than that for the type H tape. For bronze and brass, $\kappa_{\rm abs}(T)$ is somewhat smaller than that for the type H tape above 30 K and is one to two orders of magnitude smaller below 30 K. The inset of Fig. 2(a) shows the $\kappa(T)$ normalized by the κ value at 200 K, $\kappa(T)/\kappa(200\text{ K})$. The $\kappa(T)/\kappa(200\text{ K})$ curves for the types H, HT-SUS20, HT-Bs50 and H6 tapes almost coincide with each other, which means that the contribution of the alloy tape to the heat transport can be neglected and the applied heat almost flows through the silver sheath in the type H tape. On the other hand, the $\kappa(T)/\kappa(200\text{ K})$ for the types HT-Bz50 and HT-Bs100 tapes deviates from that for the type H tape, indicating that the contribution of the alloy tapes cannot be ignored to the heat transport.

We try to estimate the $\kappa(T)$ for both HT-Bz50 and HT-Bs100 tapes using $\kappa(T)$ for each elemental material. The schematic image of the heat flow through a composite sample which consists of n kinds of materials is illustrated in the inset of Fig. 3(a). Assuming that the applied heat flows in parallel, the total heat through the composite sample, $Q_{\rm tot}$, is given by

$$Q_{\rm tot} = \sum_{i=1}^{n} Q_i,$$

where, Q_i is the heat flow through the i-th part. Since the ΔT and L are the same for all the parts, the total thermal conductivity, $\kappa_{\rm tot}$, can be estimated by

$$\kappa_{\rm tot} = \left(\sum_{i=1}^{n} (\kappa_i \times S_i) \right) / S_{\rm tot},$$



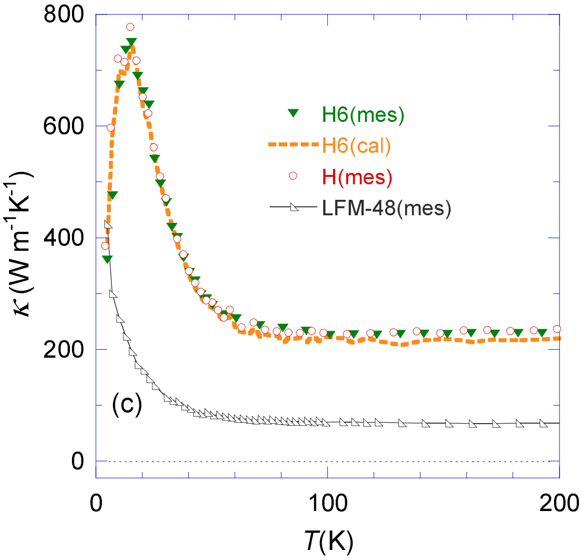


Figure 3. The measured and calculated $\kappa(T)$ for the types (a) HT-Bz50, (b) HT-Bs100 and (c) H6 tapes for each element. The inset of (a) demonstrates that a schematic image of the heat flow through the composite sample consisting of n kinds of materials.

where, κ_i is the thermal conductivity and S_i is the cross section for i-th part. Figures 3(a) and 3(b) show the calculated $\kappa(T)$ for the types HT-Bz50 and HT-Bs100 tapes, respectively, using this relation. The calculated $\kappa(T)$, which is depicted as the broken line, nearly corresponds to the measured one for both tapes. We note that the disagreement between the measured and calculated $\kappa(T)$ is found for the type HT-Bz50 tape above 40 K, which indicates the possibility that the amount of Cu in bronze for reported $\kappa(T)$ is somewhat smaller than that in the brass tape of the type HT-Bz50 tape. The similar estimation was performed for the type H6 tape in Fig. 3(c). The measured $\kappa(T)$ was well reproduced by the calculated one. These results indicate that the $\kappa(T)$ for the composite sample can be estimated from $\kappa(T)$ for each part using the equivalent circuit for the heat flow with the simple sum rule.

4. Summary

We have measured the temperature dependence of the thermal conductivity, $\kappa(T)$, for various DI-BSCCO samples with sandwiched and stacked structure. The $\kappa(T)$ for a sandwiched sample, which consists of the silver-sheathed DI-BSCCO (type H), the reinforcing alloy tapes and the solder parts, is similar to $\kappa(T)$ for the type H tape. The absolute value of $\kappa(T)$ for the sandwiched sample depends on the species and the thickness of the alloy tape. When the contribution of the alloy tape to the heat transport is negligible small, the absolute value of $\kappa(T)$ for the sandwiched sample depends on the volume fraction of the type H tape in the whole sample. The $\kappa(T)$ for a stacked bundle consisting of six type H tapes almost coincides to that for the type H tape. The measured $\kappa(T)$ for the sandwiched and stacked samples is well reproduced by the estimated $\kappa(T)$ which was calculated using measured $\kappa(T)$ for each part. This procedure can be applicable to estimate the thermal conductivity for the composite cryogenic device such as a coil which consists of the superconducting tape, insulator and so on.

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