Characteristics of Ag-Au alloy sheathed Bi-Pb-Sr-Ca-Cu-O superconducting tapes for current leads

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Oxide superconductor tape with Ag-Au sheath was studied for current leads. A 100-cm-long current lead of 1000 A with 0.2 W/kA heat leakage was designed using Ag-11 at. % Au alloy sheath with low thermal conductivity. The overall current density of the superconducting tape is required to be 350–770 A/cm^2 at 77 K when the superconductor cross-section ratio in the tape is 0.35–0.7. Bi-Pb-Sr-Ca-Cu-O superconducting tape with Ag-11 at. % Au alloy sheath was fabricated and the critical current density J_c was measured. The *overall-*J_c was 1700 A/cm^2 at 77 K under 0 T. The possibility of the current lead of 1000 A under 0.28 T with 0.2 W/kA was made clear.

Use of high T_c superconductor in current leads has been studied as one of the most practical applications of oxide superconductors.[1] The current leads for liquid helium cooled superconducting magnets are expected to reduce the heat leakage into the coolant. Current leads using $YBa_2Cu_3O_x$ bulk rods were fabricated and tested,[2] and the results up to 2 kA showed that the heat input at the cold end was 40% less under the self-cooling condition than that of conventional copper leads. However, these bulk rod type current leads are known to have weak points of mechanical cracking and superconductive stabilization.

A new type of current lead with a stacking structure made by assembling Ag-sheathed superconducting tapes of Bi-Pb-Sr-Ca-Cu-O (Bi-2223) or Tl-Ba-Sr-Ca-Cu-O has been proposed. The concept is shown in Fig. 1.[3,4] This has several advantages of high J_c, high mechanical strength and good superconductive stabilization. The only weakness is heat leakage caused by high thermal conductivity of Ag. Sheath materials with lower thermal conductivity have been investigated considering the influence on superconductors of Bi-Sr-Ca-Cu-O (Bi-2212), and Ag-Au alloy have been noted,[5,6]

In this letter, 100-cm-long current leads of 1000 A with heat leakage 0.2 W using the Ag-11 at. % Au alloy sheathed superconducting tapes of Bi-2223 are proposed and the possibility investigated by measurements of the thermal conductivity and critical current density J_c of the fabricated samples.

Heat leakage Q (W) through the superconducting tapes depends on the thermal conductivity κ (W/K cm) and the cross section $f \times S$ (cm^2) of the alloy sheath of the current lead, where f is the cross-section ratio of the sheath to the total area S. The heat leakage Q of the current lead in the area between 77 and 4.2 K is given by Eq. (1):

$$Q=\frac{f\times S}{L}\int_{4.2}^{77}\kappa\, dT, \tag{1}$$

where L (cm) is the length of the current lead and T (K) is the temperature. Defining *overall-*J_c by the critical current divided by the cross section of the tape, S is written as Eq. (2).

$$S=\frac{I}{overall\text{-}J_c}, \tag{2}$$

where I (A) is the rated current of the lead. From Eqs. (1) and (2), it is understood that the rated current I and the heat leakage Q of the current lead depend on the thermal conductivity κ of the alloy sheath, the sheath ratio f and the *overall-*J_c of the tape.

To evaluate the thermal conductivity k of the Ag-Au alloy sheath compared with that of pure-Ag, Ag-11 at. % Au alloy and pure-Ag tape were prepared. Both tapes were heat treated at 840 °C in air. The thermal conductivity was measured by a steady heat flow method. The measured values of the thermal conductivities are plotted in Fig. 2. The Ag-11 at. % Au alloy drastically decreased the thermal conductivity relative to the pure-Ag. From Fig. 2, the thermal conductivity of Ag-11 at. % Au below 40 K can be assumed to be proportional to the temperature.

From the assumption values of Ag-11 at. % Au alloy in Fig. 2

$$\int_{4.2}^{77}\kappa\, dT=20 \ \text{(W/cm)} \tag{3}$$

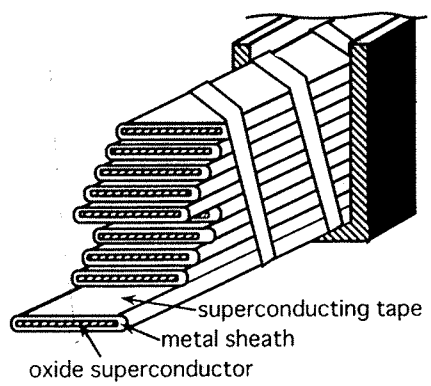

FIG. 1. Structure of current lead assembled metal sheathed oxide superconducting wires.

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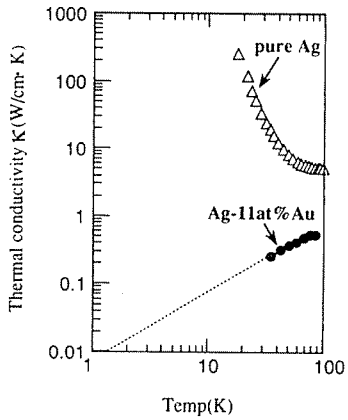

FIG. 2. Temperature dependence of the thermal conductivity of Ag-11 at. % Au and pure Ag.

are obtained. Substituting Eq. (3) into Eq. (1), we obtain $f \times S = 1.0$ at $Q = 0.2$ W and $L = 100$ cm. Therefore, for rating 1000-A current at the cross section, the *overall-*J_c must be 350 A/cm^2 in $F = 0.35$ and 770 A/cm^2 in $f = 0.75$ at 77 K. These calculated results of relation between the Q and *overall-*J_c are shown in Fig. 3.

Lower f is desired by reducing of the sheath thickness, but this may cause the degradation of J_c. To learn the influence of Ag-Au alloy sheath on J_c, Ag-11 at. % Au alloy sheathed Bi-2223 superconducting tape was prepared. Appropriate amounts of Bi_2O_3, PbO, $SrCO_3$, and CuO powders with 4N purity were mixed. The nominal composition ratio Bi/Pb/Sr/Ca/Cu was 1.8/0.4/2.0/2.2/3.0. The mixed powder was wrapped in the Ag-Au alloy tape and in the pure-Ag tape for comparison, then worked and sintered three times at

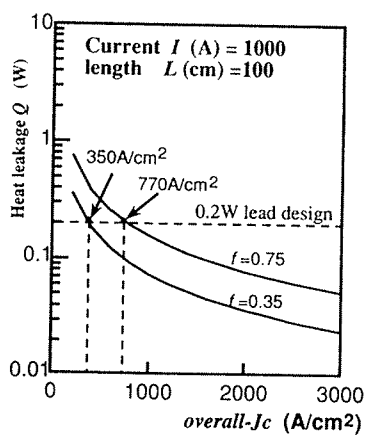

FIG. 3. The calculated Q dependence of *overall-*J_c in superconducting current lead.

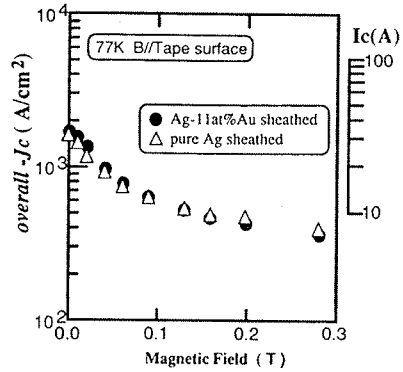

FIG. 4. The *overall-*J_c characteristics of Bi-2223 suoperconductor under the magnetic fields.

780–845 °C. Tapes were 0.3 mm thick and 8 mm wide, and the sheath ratio f of both tapes was 0.35.

Critical current I_c was measured at 77 K with the four-probe method under the magnetic fields parallel to the tape surface and perpendicular to the transport current flow. The *overall-*J_c was calculated by I_c and the cross section of the tape. The criterion of the critical current I_c was 1 μV/cm. The measured *overall-*J_c is shown in Fig. 4; there is no difference between the two samples. This means that the Ag-11 at. % Au alloy can be used as sheath material for synthesizing Bi-2223 superconductor and will not cause degradation of J_c.

The *overall-*J_c required for design index 0.2 W/kA current lead has been 350 A/cm^2 at 77 K, and the fabricated Bi-2223/Ag-11 at. % Au sheathed tape satisfied the *overall-*J_c under the magnetic field less than 0.3 T. By assembling 143 sheets of the superconducting tape, whose I_c is 7 A according to the required *overall-*J_c=350 A/cm^2 as shown in Fig. 4, it is possible to construct a rated current 1000 A with 0.2 W heat leakage.

In summary, superconducting current leads with stacking structure of Ag-11 at. % Au alloy sheathed Bi-2223 tapes have been designed. Specifications of the leads are a rated current of 1000 A under 0.28 T, a heat leakage of 0.2 W, and a length of 100 cm.

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