Dependence of Irreversibility Field of Bi-2223 Silver-Sheathed Tape Wire on Different Electric Field Criteria

Mitsuhiro Fukuda, Takeshi Kodama, Kazuo Shiraishi, Shoichi Nishimura, Edmund Soji Otabe, Masaru Kiuchi, Takanobu Kiss, Teruo Matsushita, Kikuo Itoh

Abstract— **Dependence of the irreversibility field(B_i) on the electric field criterion (E_c) was measured for a Bi-2223 silver-sheathed tape wire using various measuring methods. It was found that B_i increased monotonically with the electric field criterion. A good agreement was obtained for B_i between experiments and the theoretical analysis using the flux creep-flow model. This implies that the resistive property of superconducting wires can be well described by the mechanism of flux creep and flow.**

Keywords— **Irreversibility field, electric field criterion, flux creep-flow model.**

I. Introduction

IT is empirically known that the determination of the irreversibility field (B_i) is strongly influenced by both the electric field criterion (E_c) for the determination of the critical current density (J_c) and the criterion of J_c (ΔJ_c). Hence, it is needed to describe B_i as a function of E_c and ΔJ_c. In this study, we observed B_i in a Bi-2223 silver-sheathed tape wire by various measuring methods:

- imaginary AC susceptibility
- current-voltage characteristic using a four probe method
- DC magnetization hysteresis
- current-voltage characteristic estimated from the relaxation of magnetization

The irreversibility field was also compared with the vortex glass-liquid transition field (B_g) obtained from the scaling of E-J curves. The experimental result was compared with the theoretical analysis using the flux creep-flow model.

II. Experimental

The measured specimen was a Bi-2223 silver-sheathed tape wire prepared by the powder-in-tube method. The sizes of specimen were 3.7 mm wide and 270 μm thick. The tape was cut in a length of l = 4.2 mm for the magnetic measurements. The number of filaments (f) was 59 and the averaged width (w) and thickness (d) of the filaments were 320 μm and 11 μm, respectively. T_c measured from DC susceptibility was 110 K. In all the measurements the magnetic field was applied parallel to the c-axis.

(1)In the AC susceptibility measurement the AC magnetic field was applied parallel to the c-axis at various temperatures. The frequency and the amplitude of AC magnetic field were 35.0 Hz and 0.1 mT, respectively. The irreversibility temperature (T_i) was determined by the temperature at which an imaginary AC susceptibility appeared. B_i was determined from the magnetic field dependence of T_i.

(2)In the current-voltage characteristics measurement using a four probe method, J_c was determined with the electric field criterion $E_c = 10^{-4}$ V/m, and $\Delta J_c = 1.0 \times 10^7$ A/m^2 was used for the determination of B_i.

(3)In the DC magnetization measurement a SQUID magnetometer was used. J_c was determined by

$$J_c = \frac{6\Delta m}{w^2 df(3l - w)},$$

where, Δm was the hysteresis of magnetic moment. For the determination of B_i, $\Delta J_c = 1.0 \times 10^7$ A/m^2 was used.

(4)In the magnetic relaxation measurement, the electric field(E) and the current density(J) were respectively estimated by

$$J = \frac{12m}{w^2 df(3l - w)},$$

$$E = -\frac{\mu_0}{2df(l + w)} \cdot \frac{\mathrm{d}m}{\mathrm{d}t}.$$

Then, J_c was determined at $E = 10^{-10}$ V/m. $\Delta J_c = 1.0 \times 10^7$ A/m^2 was used for the determination of B_i.

The scaling of E-J curves was examined for the results obtained in the measurements (2) and (4) and the vortex glass-liquid transition field (B_g) was determined.

III. Results and Discussion

Fig. 1 shows B_i determined with various measurements in which different electric field criteria are used and B_g estimated from two current-voltage characteristics in the low and high electric field regions.

M. Fukuda is with Kyushu Institute of Technology, 680–4, Kawazu, Iizuka 820–8502, Japan (Telephone: +81–948–29–7683, e-mail: fukuda@aquarius10.cse.kyutech.ac.jp)

K. Shiraishi is with Kyushu University, 6–8–1, Hakozaki, Higashi–ku, Fukuoka 812–8581, Japan

S. Nishimura is with Kyushu University, Fukuoka, Japan

E. S. Otabe is with Kyushu Institute of Technology, Iizuka Japan

M. Kiuchi is with Kyushu University, Fukuoka, Japan

T. Kiss is with Kyushu University, Fukuoka, Japan

T. Matsushita is with Kyushu Institute of Technology, Iizuka Japan

K. Itoh is with National Research Institute for Metals, 3–13, Sakura, Tsukuba 305–0003, Japan

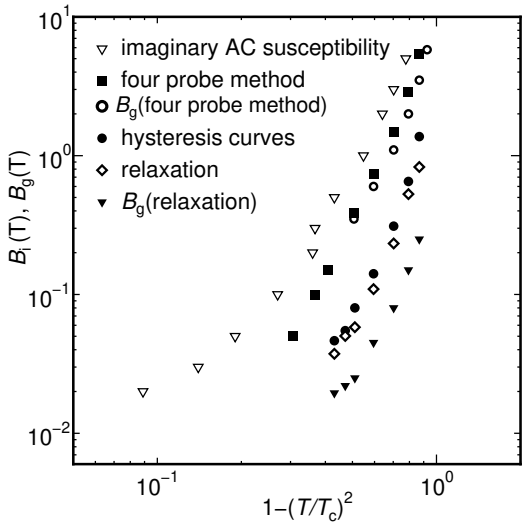

Fig. 1. Irreversibility field of Bi-2223 silver-sheathed tape wire determined with different electric field criteria and transition field.

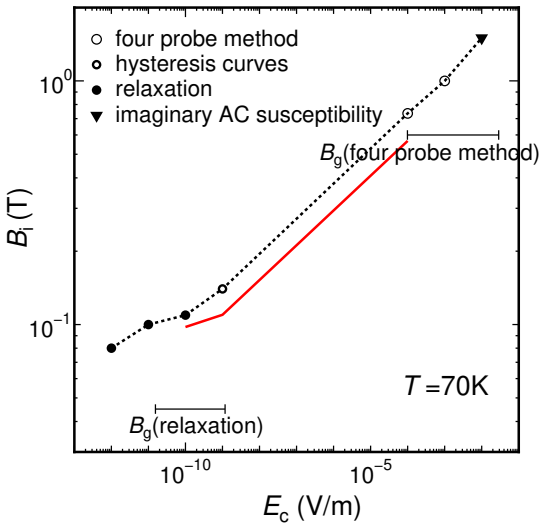

Fig. 2. Dependence of irreversibility field on electric field criteria at $T = 70$ K.

Fig. 2. shows E_c dependence of B_i at $T = 70$ K under the condition of $\Delta J_c = 1.0 \times 10^7$ A/m^2. B_i depends largely on the electric field criterion for the definition of J_c. In the figure B_g is also shown for comparison. It is found that B_g also takes on a high value when the range of electric field is high. This is consistent with the previous measurement on a Y-123 thin film [1] and incompatible with the prediction of the vortex glass-liquid transition theory.

The E-J characteristics can be calculated theoretically with the aid of the flux creep-flow model [2]. From the results B_i can be estimated with the same E_c and ΔJ_c as in experiment. The temperature dependence of B_i is compared between the experiment and the theory in Fig. 3. It is seen that the flux creep-flow model can describe B_i in a wide range of the electric field.

In the AC susceptibility measurement, the conditions of the determination of B_i are about $E_c = 3.5 \times 10^{-6}$ V/m and $\Delta J_c = 1.0 \times 10^5$ A/m^2. Hence, the value of B_i is strongly influenced by the choice of these conditions. If we express the relationship between E and J as $E \propto J^n$, we have $n = 2.82$ in the vicinity of the irreversibility field. Hence, a similar relationship $E_c \propto \Delta J_c^n$ holds, and if the same condition of $\Delta J_c = 1.0 \times 10^7$ A/m^2 is chosen, the corresponding value of E_c is $E_c = 10^{-2}$ V/m. Thus, if B_i could be obtained in the same conditions as in other measurements, B_i from the AC susceptibility measurement would be located as shown by the solid triangle in Fig. 2. Therefore, all the measurements seem to be described well by the flux creep-flow model.

IV. Summary

The electric field criterion dependence of the irreversibility field was measured for a Bi-2223 silver-sheathed tape wire and the following results were obtained:

(1)B_i depends largely on the electric field criterion and this behavior can be well described by the flux creep-flow model in a wide range of the electric field.

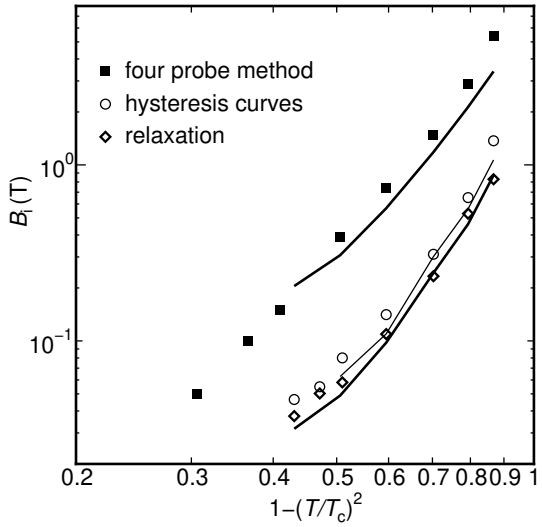

Fig. 3. The theoretical analysed B_i(solid lines) compared with the experimental results(symbols).

(2)The vortex glass-liquid transition field depends also on the range of electric field. This is incompatible with the prediction of the vortex glass-liquid transition theory.

References

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