Irreversibility Field in Bi-2212 Thin Films

Syunsuke Yamaura, Edmund Soji Otabe, Teruo Matsushita, Tetsuji Uchiyama

Abstract— **The irreversibility field along the c-axis was measured for two Bi-2212 thin films with different thicknesses. This result is compared with the measurements for thick tapes. The irreversibility field at the same reduced temperature decreased according as the thickness decreased. This result suggests that flux lines are fairly strongly coupled along their length over the distance longer than the film thickness investigated here even in two-dimensional superconductor. This contradicts the prediction of the pancake vortex model.**

Keywords— **Bi-2212 thin film, irreversibility field, film thickness, flux creep-flow model**

I. Introduction

IT was known that irreversibility field depends on the flux pinning strength and the dimension of superconductor. In addition, it was shown that the irreversibility field of a thin film is lower than that of a thick tape wire for Bi-2223 superconductor [1], although the flux pinning strength of a thin film is stronger than that of a tape wire. This result suggests that flux lines are fairly strongly coupled along their length even in two-dimensional superconductors. This is explained by the flux creep theory from the viewpoint of difference of the flux bundle size. That is, the flux bundle size is limited by the film thickness under a magnetic field along the c-axis. This leads to the small pinning potential in thin films, because the pinning potential is proportional to the volume of flux bundle. Therefore, the flux bundle size strongly influences the flux creep and the irreversibility field.

It was found that the longitudinal elastic correlation length of flux lines is much longer than the distance between the CuO_2 layers [2], [3]. This indicates that flux lines are fairly strongly coupled along their length even in two-dimensional superconductors and is consistent with the thickness dependence of the irreversibility field.

This speculation is quite different from the prediction of the pancake vortex model [4]. It is necessary to investigate directly the thickness dependence of the irreversibility field for the most two-dimensional Bi-2212 in order to ascertain the above speculation. In this study, the irreversibility field of two Bi-2212 thin films with different thicknesses is measured. This result is compared with the measurements for silver-sheathed thick tapes [5]. The observed result is compared with the result on silver-sheathed Bi-2212 superconducting thick tapes.

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II. Experiments

The specimens were two Bi-2212 thin films prepared by a laser ablation method. The films were deposited on MgO substrates in an oxygen atmosphere of 400 mTorr. The thickness of each thin film was about 200 nm(Sample1) and 100 nm(Sample2). The critical temperature of these films was 72 K and 60 K, respectively. The c-axis was directed normal to the flat wide surface of the film. The DC magnetization in a magnetic field parallel to the c-axis was measured using a SQUID magnetometer. The critical current density was estimated from the magnetization hysteresis and the irreversibility field was determined by the field at which J_c was reduced to $1.0 \times 10^6 \mathrm{A/m^2}$.

III. Results and Discussion

Fig. 1 shows the critical current density in Sample1 in wide range of temperature. The critical current density decreases monotonously with increasing magnetic field and does not show the peak effect. The critical current density in Sample2 was similar but lower than that in Sample1. Fig. 2 shows the temperature dependence of the irreversibility field for Samples 1 and 2. The temperature was normalized by the critical temperature because the critical temperature is different between the two samples. The irreversibility field in Sample2 is fairly lower than that in Sample1 at the same reduced temperature.

This result is compared with the irreversibility field of silver-sheathed multilayered Bi-2212 tape wires with the average thickness of superconducting layers of about

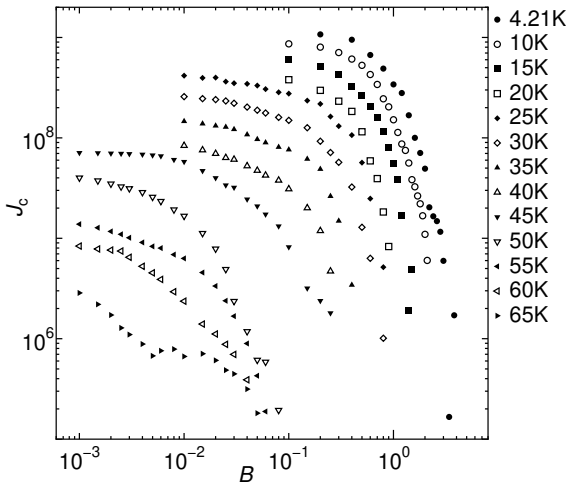

Fig. 1. Critical current density vs magnetic field in Sample1.

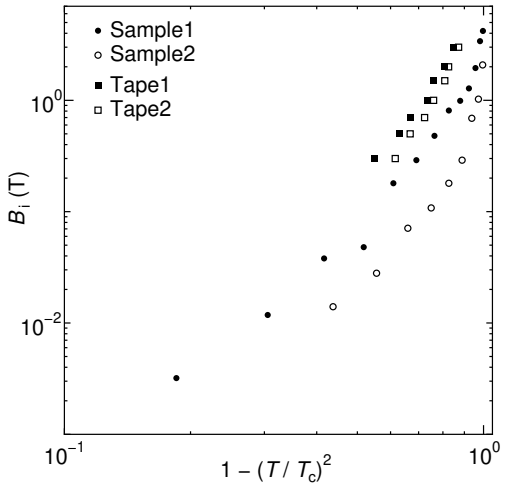

Fig. 2. Temperature dependence of irreversibility field.

Fig. 3. Thickness dependence of irreversibility field at $T/T_c = 0.42$. Each line shows the theoretical prediction.

5 μm(Tape1) and 10 μm(Tape2) [5]. The critical temperature of Tapes 1 and 2 was 86.0 K and 90.0 K, respectively. These results are also plotted in Fig. 2. It is found that the irreversibility field in Tape1 is highest and the irreversibility field decreases monotonically with the decreasing thickness of superconductor.

According to the collective flux creep theory the pinning potential, U_0, is described in terms of the virtual critical current density, J_{c0}, in the creep-free case. It is known that U_0 depends on the flux pinning strength and the volume of the flux bundle. The longitudinal flux bundle size, L, was

$$L = \left(\frac{B a_f}{2\pi \mu_0 J_{c0}} \right)^{1/2}, \tag{1}$$

with a_f denoting a flux line spacing. If the thickness of superconductor, d, is thinner than L, we have [6]

$$U_0 = \frac{4.23 g^2 k_B J_{c0} d}{2\pi B^{1/2}}, \tag{2}$$

where g^2 is a number of flux lines in the flux bundle. On the other hand, if d is thicker than L, we have

$$U_0 = \frac{0.85 g^2 k_B J_{c0}^{1/2}}{(2\pi)^{3/2} B^{1/4}}. \tag{3}$$

It is assumed that the dependences of J_{c0} on temperature and magnetic field are expressed as

$$J_{c0} = A \left[1 - \left(\frac{T}{T_c} \right)^2 \right]^m b^{\gamma - 1} \left[1 - \frac{B}{B_{c2}} \right]^\delta, \tag{4}$$

where A, m, γ and δ are the pinning parameters.

Fig. 3 shows the thickness dependence of the irreversibility field at $T/T_c = 0.42$, where the points are experimental values. The thickness dependence of the irreversibility field is numerically analyzed for each sample. The results of numerical analysis are shown by lines in Fig. 3. The difference of each line comes from different pinning parameters. The irreversibility field generally increases with increasing d and is saturated when d is longer than L. It was found that d is shorter than L in Samples 1 and 2 and longer than L in Tapes 1 and 2.

The above results are contradictory to the prediction of the pancake vortex model. That is, the flux lines are considered to be fairly strongly coupled along their length even in the most two-dimensional Bi-2212 superconductors. This is supported by the measurement of longitudinal correlation length of the order of 10 μm [5].

IV. Summary

The irreversibility field was measured for two Bi-2212 thin films with different thicknesses. The observed result was compared with the result on silver-sheathed Bi-2212 superconducting thick tapes. The following results are obtained.

1. The irreversibility field of thicker specimen was generally higher. This agrees with the theoretical prediction of the flux creep-flow model.
2. This shows that the flux lines magnetically strongly coupled along their length even in two-dimensional superconductors and do not behave as predicted by the pancake vortex model.

References

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