Longitudinal magnetic field effect in critical current characteristics of Bi-2223 superconducting tape

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Abstract. In this study, we focused on the longitudinal magnetic field effect in critical current densities and investigated the enhancement of the electrical conduction properties in a commercial Bi-2223 superconducting tape. Since the samples used in this study were polycrystalline and tape-shaped, the longitudinal magnetic field effect was expected to differ from that in single crystals or conventional superconducting alloys. Therefore, the critical current characteristics at magnetic fields of up to 5 T as well as at various angles between the magnetic field and current were measured in detail.

Keywords: Bi-2223 superconducting tape, critical current density, longitudinal magnetic field effect, anisotropy in upper critical magnetic field

1. Introduction

As one of the important high-$T_c$ superconductors, Bi-2223 superconducting tape has a large potentiality of applications in electric power field. However, at the present stage, the critical current density ($J_c$) is still much lower than the practical level. In order to enhance the critical current properties, many researchers have done a lot of studies on improving $J_c$ through enforcing and optimizing the flux pinning characteristic in superconductors [1], developing new and high-quality coated conductors [2], etc.

On the other hand, it is well known that the value of $J_c$ in a longitudinal magnetic field is much larger than that in a transverse magnetic field (longitudinal magnetic field effect). For example, the difference of these two values could be over 100 times in a Ti-Nb alloy [3]. Recently, we focused on utilizing the longitudinal magnetic field effect to improve the critical current density in Bi-2223, and obtained some preliminary results insisting the validity of the effect. At the same time, some other researchers...
paid their attentions to the effect in YBCO coated conductors [4][5], and also obtained qualitatively similar results. In our previous study, unlike the results in conventional metallic superconductors, the value of $J_c$ in the longitudinal magnetic field increased only by 30% compared with that in the transverse magnetic field. This is ascribed to the polycrystalline property in Bi-2223. In this study, more systematic investigation was carried out.

2. Experimental

2.1. Samples

Bi-2223 superconducting tape, as a commercial product fabricated by SUMIMOTO ELECTRIC company, was adopted in this study. The critical current of the tape is about 170 A at 77 K, and the cross-section of the superconducting phase is about 0.64 mm$^2$. The observed fracture surface of the tape was shown in figure 1. It can be found that Bi-2223 grains in tape are flake-like, $c$-axis orientated to a certain level and densely compacted in the silver-sheath. Because of the limitation on the value of the transport current in the sample in our measurement, which will be mentioned below, the cross-section of the sample was reduced to about 0.21 mm$^2$, i.e., 1.4 mm in width and 0.15 mm in thickness.

![Fracture surface image of sample obtained by SEM.](image)

2.2. Measurement

The cryogenic cooler was utilized in this study to control the temperature ($T$) of the sample in the range from 50 K to 77 K with a precision on the order of 1 K. The resistive method (four-probe method) was adopted for this study to measure the critical current ($I_c$) of the sample. Electric field criterion of 1 $\mu$V/cm was employed for the determination of $I_c$. The magnetic field ($B$) was applied up to 5 T.

2.3. Two kinds of variations in the direction of $B$

In this measurement, the magnetic field was applied in various directions to the current. The angle between the direction of the current and that of the applied magnetic field was defined as $\phi$ (i.e., $\phi = 0^\circ$ denotes the case of the longitudinal magnetic field, and $\phi = 90^\circ$ denotes the case of the transverse magnetic field). There are two kinds of variations of $\phi$: one is the case that the direction of $B$ is always parallel to the $ab$ plane of grains while we change angle $\phi$ (mode A) as shown in figure 2 (a), the other...
is that $B$ is from the direction parallel to the $ab$ plane to the direction parallel to the $c$ axis (mode B), as shown in figure 2 (b). The essential difference of these two cases is that whether the upper critical field ($B_{c2}$) changes at various $\phi$.

3. Results and Discussion

3.1. $B$ dependence of $J_c$  
Figure 3 illustrates the relationship between $J_c$ and $B$ at 50 K, while (a) and (b) represent that in mode A and in mode B respectively. It can be noted that the variation tendency of $J_c$ in mode A is similar with that in mode B when $\phi$ is equal to 0°. However, in mode B, the variation of $J_c$ is much more significant as $\phi$ is close to 90°, which is different from that in mode A. In addition, at 0.1 T (mode A), the enhancement of critical current density due to the longitudinal magnetic field effect is only about 1.4 times (i.e., from $4.29 \times 10^8$ A/m² in the transverse magnetic field to $5.93 \times 10^8$ A/m² in the longitudinal

![Figure 2. Relation between current direction and applied magnetic field.](image)

![Figure 3. $B$ dependence of $J_c$. (a) and (b) are the behaviours in mode A and B, respectively.](image)
magnetic field), while the ratio of enhancement can reach to 1.64 times at 1 T and the largest ratio is 2.9 times at 5 T. In mode B, different from that in mode A, the values of \( J_c \) are enlarged greatly by 1.15 times and 5.56 times at 0.1 T and 1 T, respectively, while the largest increase is about 39 times at 2 T.

The result insisted that \( J_c \) enhancement in mode B was larger than that in mode A. It is considered that \( J_c \) was affected only by the longitudinal magnetic field effect in mode A. For mode B, it was not only influenced by the longitudinal magnetic field effect, but also impaired by the reduction of the upper critical magnetic field while \( \phi \) varies from 0° to 90°. It is well known that a significant anisotropy of \( B_{c2} \) exists in Bi-2223. For some temperatures and magnetic fields, the anisotropy could reach up to nearly a decade [6]. If \( B \) rotates around the \( b \) axis, as shown in figure 2 (b), the critical current density changed sharply with the increase of \( B \). This can be explained by the fact that \( J_c \) was more significantly dominated by smaller \( B_{c2} \) in mode B.

3.2. \( \phi \) dependence of \( J_c \)

Figure 4 demonstrates the relationship between \( J_c \) and \( \phi \) at 77K, while (a) and (b) denote \( J_c \) vs. \( \phi \) in mode A and mode B respectively. At 0.1 T (mode A), the value of \( J_c \) in the longitudinal magnetic field is 2.6 times compared with that in the transverse magnetic field, while the ratio is 3.86 times at 0.2 T. In mode B, the enhancement of \( J_c \) increase to 5.8 times at 0.1 T and 26 times at 0.2 T from the transverse magnetic field to longitudinal magnetic field, respectively. Comparing that in mode B, it can be observed that \( J_c \) changed slowly in mode A with the increase of \( \phi \) except that at zero field. When magnetic field is zero, \( J_c \) keeps unchanged at all angles. This is because the longitudinal magnetic field effect does not exist at zero magnetic field.

3.3. \( T \) dependence of \( J_c \)

Figure 5 (a) and Figure 5 (b) demonstrates the relationship between \( J_c \) and \( T \) in mode A and B respectively. It shows that in the experimental temperature region, if the samples are applied by same \( B \)
and same $T$, $J_c$ in the longitudinal magnetic field is always larger than that in the transverse magnetic field.

4. Conclusions
The critical current characteristics of Bi-2223 tape at various temperatures and magnetic fields were measured. The angle $\phi$ between the transport current and applied magnetic field was varied from 0° to 90°. The results show that, at 50 K, the longitudinal magnetic field effect can be estimated as about 1.4 (at 0.1 T) to 2.9 (at 5 T) times when the magnetic field is applied within the $ab$ plane (mode A), while it increases to the level of over 40 times (at 2 T) when the influence of anisotropy of $B_{c2}$ is taken into account (mode B). Furthermore, in the experimental temperature range, $J_c$ under the longitudinal magnetic field at same $B$ is always larger than that under the transverse magnetic field.

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