Effect of Filament Sausaging on E-J Characteristics in Bi-2223 Tapes

Yuri Ueno, Edmund Soji Otabe, Masaru Kiuchi, Teruo Matsushita

Abstract— **Sausaging of superconducting filaments strongly influences the E-J characteristics in superconducting tapes. In this research the effect of filament sausaging was investigated. It was found that the thickness of filaments was distributed within a factor of about 3.5 along the length. This promises that the uniformity of the critical current density can be drastically improved when the filament thickness can be made uniform.**

Keywords— **Bi-2223 tape, E-J characteristics, sausaging of filaments**

I. Introduction

IT is known that the E-J curve in superconducting Bi -2223 tapes is not so sharp as in metallic superconductors. This feature in the Bi -2223 tapes is characterized by their low n values especially at high fields and at high temperatures. The low n value is caused by a very wide distribution of the critical current density. The wide distribution is attributed to the weak links between superconducting grains as well as an essential random distribution of the pinning strength. However, it is also attributed to the sausaging of superconducting filaments. That is, since the ceramic oxide is much harder than the silver matrix, the oxide layer thickness varies largely along the lengthwise direction of the tape when rolled. In this case the local critical current density also varies along the length in proportion to the cross-sectional area. In order to improve the n value in Bi-2223 tapes, therefore, it is necessary to evaluate quantitatively the effect of each factor on the n value. In this paper, the effect of sausaging is especially focused and the distribution of thickness of superconducting filaments is investigated.

II. Experimental

Specimen was a superconducting multifilamentary Bi-2223 silver sheathed tape prepared by the powder-in-tube method. The cross-section of the specimen was 3 mm × 0.22 mm, and the volume fraction of superconducting filaments was approximately 24%. The c-axis of the specimen was oriented normal to the flat surface of the tape. The critical temperature, T_c, was 109.5 K and J_c in the self-field at 77.3 K was 45 A.

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

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

M. Kiuchi is with kyushu University, 6–8–1, Hakozaki, Higashi–ku,Fukuoka 812–8581,Japan

T. Matsushita is with Kyushu Institute of Technology, 680–4, Kawazu, Iizuka 820–8502 Japan (Telephone: +81–948–29–7663, e-mail: matusita@cse.kyutech.ac.jp)

The lengthwise cross-sectional view of the tape was observed with an optical microscope and the thickness of a superconducting filament was measured every 15.6 μm along the length and the thickness distribution was obtained.

The current-voltage curves were measured by the four probe method under the magnetic field parallel to the c-axis. The pulse transport current with the period of 1 s was applied to the specimen to reduce the joule heat at current leads and the voltage was measured across the voltage terminals separated by 1.0 cm. The critical current density was determined by the electric field criterion of $E = 1.0 \times 10^{-3}$ V/m.

III. Results and Discussion

Fig. 1 shows the obtained histogram of the superconducting filament thickness, d. It is seen that the histogram can be approximately expressed by the Gaussian distribution of $\langle d \rangle = 2.56 \times 10^{-5}$ m and $\sigma^2 = 3.36 \times 10^{-11}\mathrm{m}^2$. If we define the maximum and minimum thicknesses by 5% of the peak in the distribution, the variation factor given by the ratio of maximum value to minimum value is 3.49.

We define the effective virtual critical current density, $\widehat{J}_{c0}$, in the creep-free case and assume that the temperature and magnetic field dependencies are expressed as

$$\widehat{J}_{c0} = \widehat{A}\left[1 - \left(\frac{T}{T_c}\right)^2\right]^m B^{\gamma-1}\left(1 - \frac{B}{B_{c2}}\right)^\delta, \qquad (1)$$

where $\widehat{A}$, m, γ, δ are pinning parameters. In practical superconductors the flux-pinning strength is inhomogeneous and distributed, and the filament thickness is also distributed. For simplicity, we assume that such distributions are approximated by a simple distribution only of $\widehat{A}$ of the form:

$$f(\widehat{A}) = \widehat{K}\exp\left[-\frac{(\log\widehat{A} - \log\widehat{A}_m)^2}{2\widehat{\sigma}^2}\right], \qquad (2)$$

where $\widehat{A}_m$ is the most probable value, $\widehat{\sigma}$ represents the degree of deviation and $\widehat{K}$ is a constant determined by the condition of normalization. In the flux creep-flow model [1] the pinning potential, U_0, is obtained using Eqs. (1) and (2) and the E-J curve can be calculated. Above parameters are adjusted so as to obtain an agreement between experimental E-J curves and theoretical ones. The solid line in Fig. 2 shows the estimated distribution of $\widehat{A}$ with $\widehat{\sigma}^2 = 0.01$ and $\widehat{A}_m = 1.28 \times 10^9$.

From the two distributions in Figs. 1 and 2, the distribution only of the pinning strength, can be estimated. For

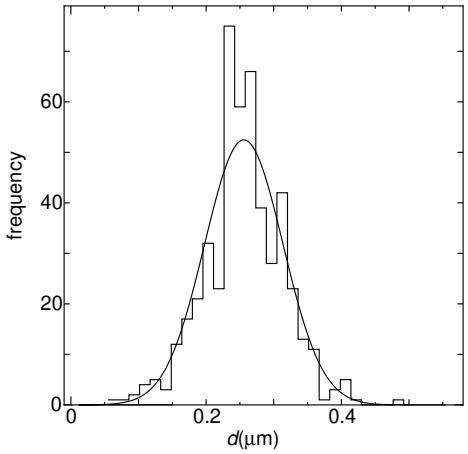

Fig. 1. Distribution of the superconducting filament thickness.The solid line shows the Gaussian distribution of superconducting filament thickness.

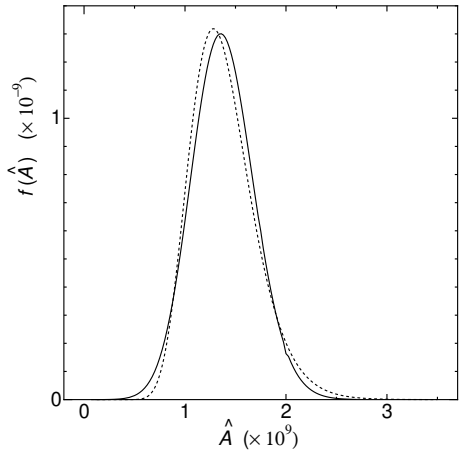

Fig. 2. Distribution of experimental and theoretical values of $\widehat{A}$. The solid and broken lines show the theoretical distribution and the experimentally determined one.

simplicity, we assume that the virtual critical current density, J_{c0}, has the same dependencies as in Eq. (1) and that the parameter representing the pinning strength, A, has the same distribution as in Eq. (2). Since the critical current is proportional to d unless d is smaller than the correlation length of the order of 1μm, the distribution of $\widehat{A}$ can be simply regarded as that of $(d/\langle d\rangle)A$. Thus, the distribution of A is adjusted so that the obtained distribution of $\widehat{A}$ accords with the experimentally determined distribution. Fig. 3 shows the distribution of A with $\sigma^2 = 0.0011$ and $A_{\rm m} = 1.3 \times 10^9$ and the solid line in Fig. 2 represents the distribution resulted from the two distributions. A slight disagreement comes from the assumption that the distribution function of A is of the same form as that of $\widehat{A}$.

Thus, the real distribution of pinning strength is much sharper than the distribution of the effective pinning strength influenced by the sausaging. That is, the influence of sausaging on the E-J characteristics is very large. In other words, there is a large room for improvement of the E-J characteristics by reducing the sausaging of filaments.

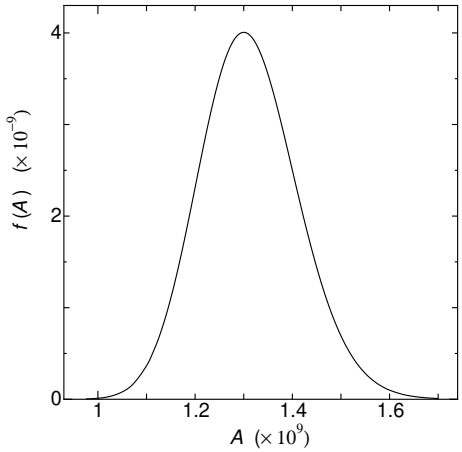

Fig. 3. Distribution of A.

IV. Summary

The effect of sausaging on the E-J characteristics is focused and the distribution of thickness of superconducting filaments is investigated. The following results are obtained.

1. The thickness of filaments is distributed over factor 3.5.
2. The estimated real distribution of pinning strength is much sharper than the directly observed distribution of the effective pinning strength.
3. It is expected the E-J characteristics can be greatly improved by reducing the sausaging of filaments.

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References

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