Effects of over pressure sintering for Bi-2223 silver-sheathed tape

Y. Himeda [a], M. Kiuchi [a], E. S. Otabe [a], T. Matsushita [a,1], J. Fujikami [b], K. Hayashi [b], K. Sato [b],

[a] *Faculty of Computer Science and Systems Engineering, Kyushu Institute of Technology, 680–4 Kawazu, Iizuka 820–8502, Japan*

[b] *Sumitomo Electric Industries, Ltd., 1–1–3 Shimaya, Konohana–ku, Osaka 554–0024, Japan*

Abstract

The critical current properties of a superconducting Bi-2223 tape produced by the over pressure processing at the final heat treatment were investigated. The critical current density increased more than the factor of densification of the superconducting region. In addition, the irreversibility field also increased. This means that the quality of flux pinning is improved by the new process. From the numerical calculation based on the flux creep and flow model, it is speculated that the fraction of weakly pinning regions decreases due to the improved connectivity of grains.

Key words: Bi-2223 tape, over pressure sintering, critical current density, flux creep-flow model
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[1] Corresponding author: T. Matsushita
Postal address: Department of Computer Science and Electronics, Kyushu Institute of Technology, 680–4, Kawazu, Iizuka 820–8502 Japan
Phone: +81–948–29–7663
Fax: +81–948–29–7661
E-mail address: matusita@cse.kyutech.ac.jp

1 Introduction

Bi-2223 silver-sheathed wire has a high potential for practical use such as magnets, transformers and power cables, since long wires in kilometer-class with the high critical current density have been constantly fabricated. However, further development of the critical current density and reduction of the AC loss are required for the present silver-sheathed Bi-2223 tape to increase the performance for application [1].

One of the important factors which determine the critical current density is the densification of the superconducting Bi-2223 phase as well as the c-axis orientation. For improvement of this densification process the application of high pressure has been investigated in detail [2]. Recently a new over pressure process has been developed and a high isostatic pressure over 20 MPa is applied to the tape during the final heat treatment in a controlled oxygen atmosphere [3,4].

In this study, the critical current properties of a superconducting tape fabricated by the over pressure processing are investigated in detail. The obtained results are theoretically analyzed using the flux creep-flow model in which the distribution of flux pinning strength is taken into account.

2 Experimental

Two Bi-2223 tape specimens were measured. Specimen #1 was fabricated by the over pressure processing and specimen #2 was fabricated in an ambient pressure for reference. The silver ratio of the tape was about 1.5 and the critical current of #1 and #2 at 77.3 K in self field was 126 A and 104 A, respectively.

The mass concentration of superconducting phase is increased by 12 % by an application of the over pressure. On the other hand, the microscopic observation of the cross section revealed that the average filament thickness defined at the center of each filament and its standard deviation reduced by factors of 0.84 and 0.78, respectively. This clarifies that this new process not only densifies the filament but also improves the uniformity of the filament thickness.

The field angle dependence of the critical current density, J_c, of the tape specimens was measured resistively at 77.3 K. The transport J_c in a magnetic filed normal to the tape surface was measured in the temperature region of 65 to 90 K. The n value was estimated from the E-J curve. Magnetization measurement was also done using a SQUID magnetometer in the temperature region of 10 to 77.3 K, and the magnetization critical current density was determined from the hysteresis of magnetic moment Δm using Bean's model. The irreversibility field, B_i, was determined by the magnetic field at which J_c reduces to 1.0×10^6 A/m^2.

3 Flux creep-flow model

According to the flux creep-flow model, the critical current properties can be calculated as a function of the virtual critical current density, J_{c0}, in a creep-free case. The isotropic virtual critical current density is usually expressed by

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

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

In usual oxide superconductors, J_{c0} is known to be widely distributed. Here only the parameter A in Eq. (1) is assumed to be statistically distributed as

$$f(A) = K\exp\left[-\frac{(\log A - \log A_{\mathrm{m}})^2}{2\sigma^2}\right], \tag{2}$$

where A_{m} is the most probable value of A, σ^2 is a parameter representing the degree of distribution width of A and K is a normalizing constant. The local electric field, E', is determined from the mechanism of flux creep and flow. Thus the total electric field is given by

$$E(J) = \int_0^\infty E' f(A)\mathrm{d}A. \tag{3}$$

Hence, the average E-J curve is calculated from Eq. (3). The details of the analysis are described in Ref. [5].

4 Results and Discussion

Figure 1(a) and (b) show the transport and magnetization critical current density, respectively, of the two specimens in the magnetic field normal to the tape surface. Symbols and lines show the experimental and theoretical results based on the flux creep-flow model, respectively. It is found that the critical current density at the low field is enhanced by a factor of 1.5–2.1 in the whole temperature range of measurement by the introduction of the over pressure processing. This explains the enhancement of the critical current in spite of the reduction of the cross-sectional area of the superconducting region.

In the theoretical analysis of J_{c}-B characteristics using the flux creep-flow model, the pinning parameters, m, γ, A_{m} and σ^2, are determined so that a good fit is obtained between the experimental and theoretical results as shown in Fig. 1(a) and (b). The parameters used are shown in Table 1.

Figure 2 shows the magnetic field angle dependence of the transport J_c of specimen #1 at $T = 77.3$ K, where θ is the angle of magnetic field measured from the tape surface. This result shows that the critical current density is uniquely expressed as a function of the magnetic field component normal to the tape surface, $B \sin\theta$, in the large angle region. The value of field angle at which the deviation starts to occur gives approximately the out-of-plane misorientation angle of grains [6,7]. This value for specimen #1 is smaller than that for specimen # 2 as shown in Fig. 3. This result is consistent with a FWHM of a rocking curve for a similar specimen [2].

Figure 4 shows the temperature dependence of the irreversibility field of specimens #1 and #2. The circular and square symbols show the experimental results determined by the magnetic field at which transport and magnetization J_c reduces to 1.0×10^6 A/m^2, respectively. The lines show the theoretical results calculated using the flux creep-flow model with parameters in Table 1. It is found that the irreversibility field is enhanced by a factor of 1.04–1.19 in the both measurements by the introduction of the over pressure processing.

The above experimental results show that the enhancement factor of J_c is larger than the enhancement factor of the mass concentration of 1.12. This means that the quality of flux pinning is also improved by the over pressure sintering. This is consistent with the improvement of the irreversibility field shown in Fig. 4.

Figure 5 shows the distribution of pinning strength obtained from the transport measurement for the two specimens. A similar result is obtained also for the magnetization measurement. The distribution of specimen #1 (solid line) is shaper than that of specimen #2 (dash line). In this measurement the pinning centers responsible for the observed electric field are those with the A-value below 10^9, i.e., in the vicinity of the minimum value of A. The fraction of weak pinning potentials seems to decrease due to the improved connectivity of grains by the over pressure processing. The improvement of the irreversibility field is ascribed to this change. This speculation is consistent with the reduction in the out-of-plane misorientation angle of grains shown in Fig. 3.

It is concluded from the above results that the over pressure processing is effective to improve the connectivity of grains and to enhance the critical current density and the irreversibility field. The process conditions are required to be optimized for further improvement of those properties.

5 Summary

The critical current density and the irreversibility field of the Bi-2223 tape prepared by the over pressure processing is investigated in detail and the results are analysed with the flux creep-flow model.

It is found that the critical current density is drastically improved by the over pressure processing. This cannot be attributed only to the enhancement of mass concentration of the superconducting phase, but also to the improvement of grain connectivity and crystal alignment. The latter fact means that the quality of flux pinning is also improved by the over pressure sintering. This is consistent with the improvement of the irreversibility field. The theoretical results support the expectation that the fraction of weakly pinning regions decreases due to the improvement of the connectivity of grains by the over pressure processing.

From these results, the over pressure processing is promising for the improvement of the critical current property of Bi-2223 tapes and a further improvement is expected by optimization of process conditions.

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Figure 1 (a) Transport and (b) magnetization critical current density of specimens #1 and #2 at various temperatures in a magnetic field normal to the tape surface. Symbols show experimental results and lines show the theoretical results based on the flux creep-flow model.

Figure 2 Transport critical current density of specimen (a) #1 at 77.3 K versus a magnetic field component normal to the tape surface.

Figure 3 Misorientation angle of specimens #1 and #2.

Figure 4 Temperature dependence of irreversibility field of specimens #1 and #2. Circular and square symbol show experimental results estimated from Fig. 1 (a) and (b), respectively. Lines show the theoretical results.

Figure 5 Distribution of the pinning strength estimated from the transport measurement using the flux creep-flow model.

Table 1 : Parameters used for numerical calculation

upper critical field:	$B_{c2}(0) = 50$ T
pinning parameters:	$\gamma = 0.2$, $\delta = 2.0$
	$m = 3.3$(transport), 3.5 (magnetization)
number of flux lines in the flux bundle:	$g^2 = 1.35$ (transport), 1.30 (magnetization)
distribution of pinning strength (transport):	$A_{\rm m} = 2.1 \times 10^9$, $\sigma^2 = 0.035$ (#1), 0.050 (#2)
distribution of pinning strength (magnetization):	$A_{\rm m} = 2.1 \times 10^9$, $\sigma^2 = 0.025$ (#1), 0.038 (#2)

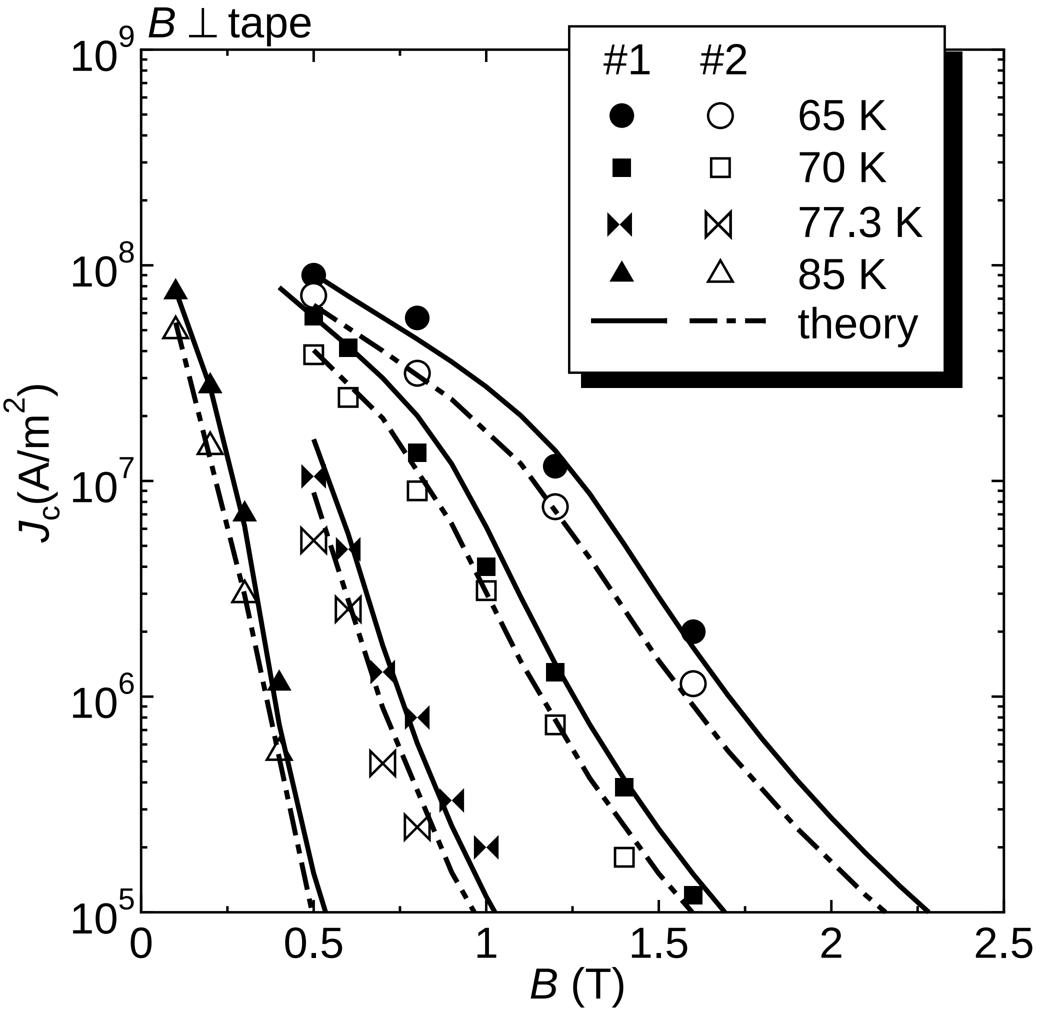

Fig. 1(a): Y. Himeda *et al.* WTP–77/ISS2005

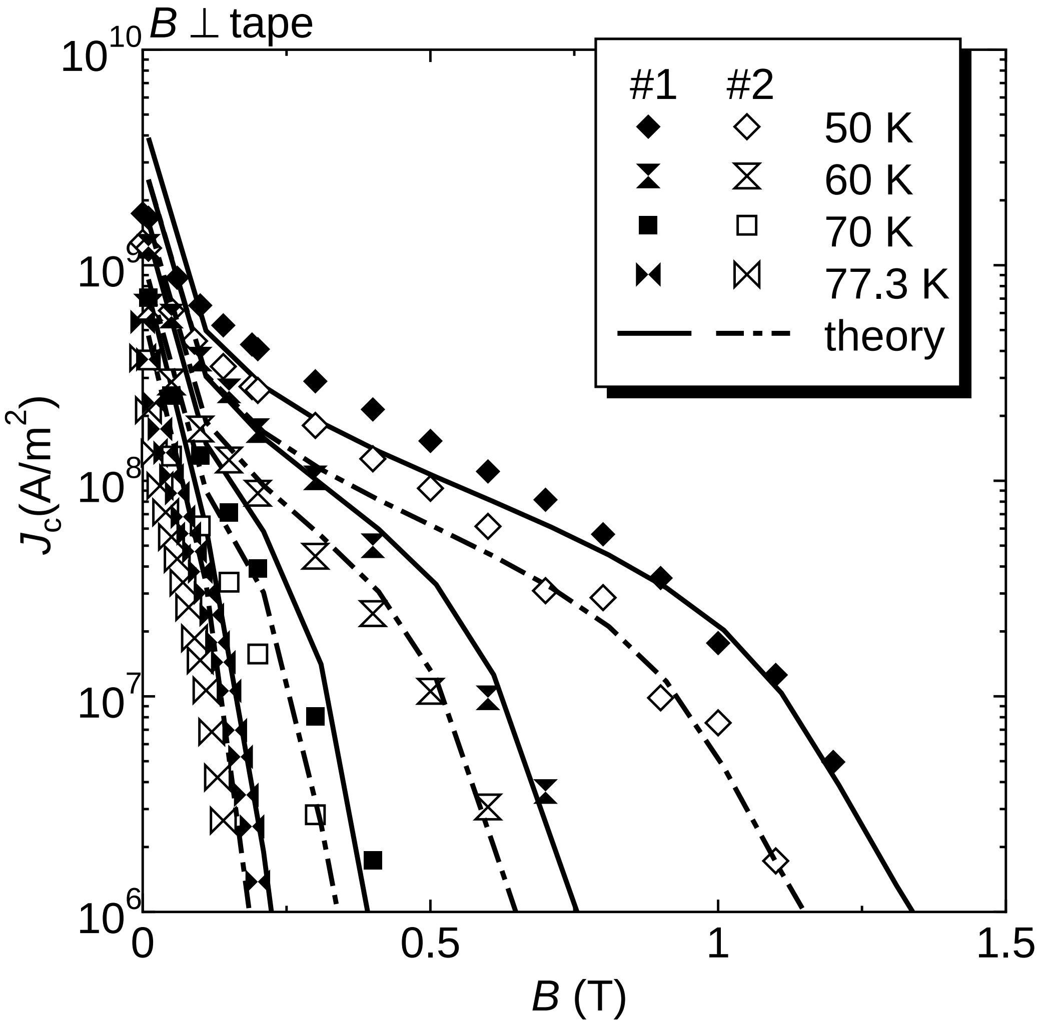

Fig. 1(b): Y. Himeda *et al.* WTP–77/ISS2005

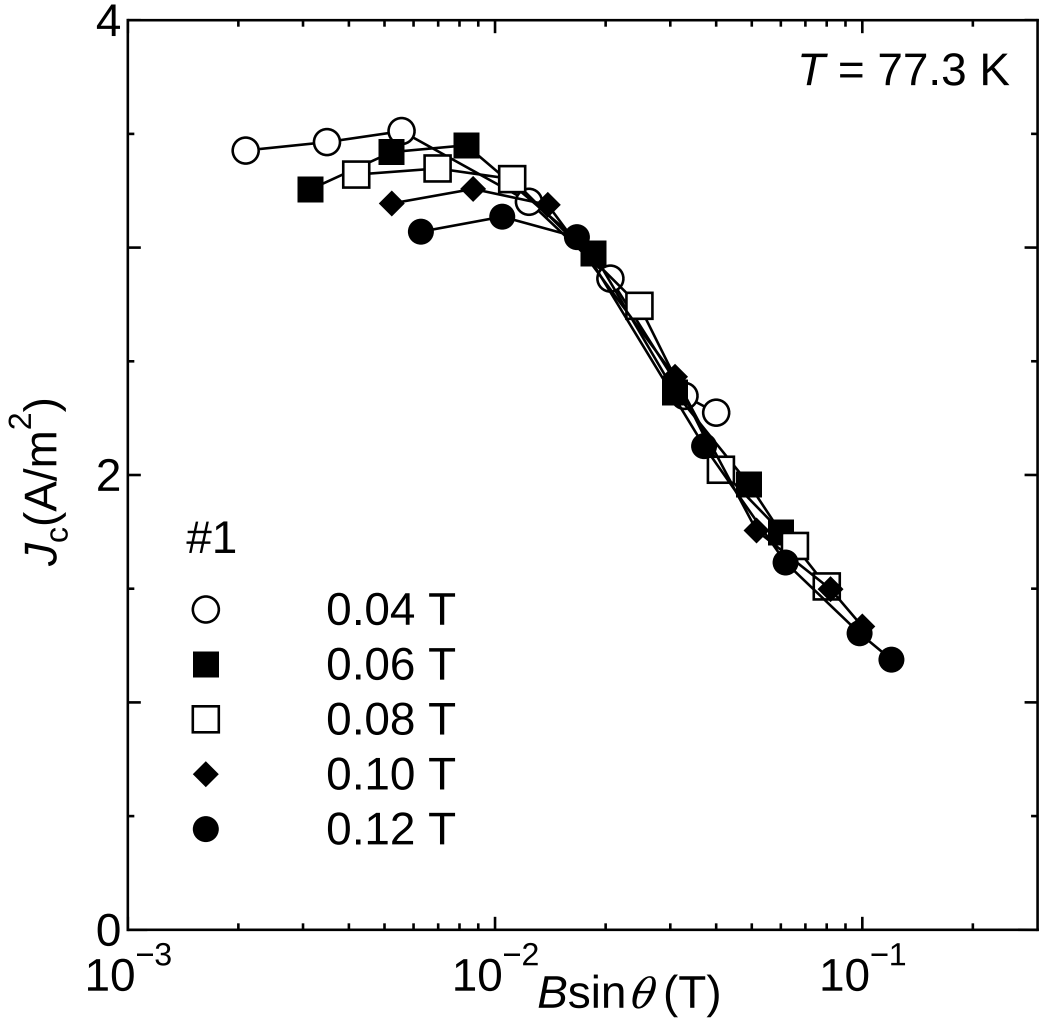

Fig. 2: Y. Himeda *et al.* WTP–77/ISS2005

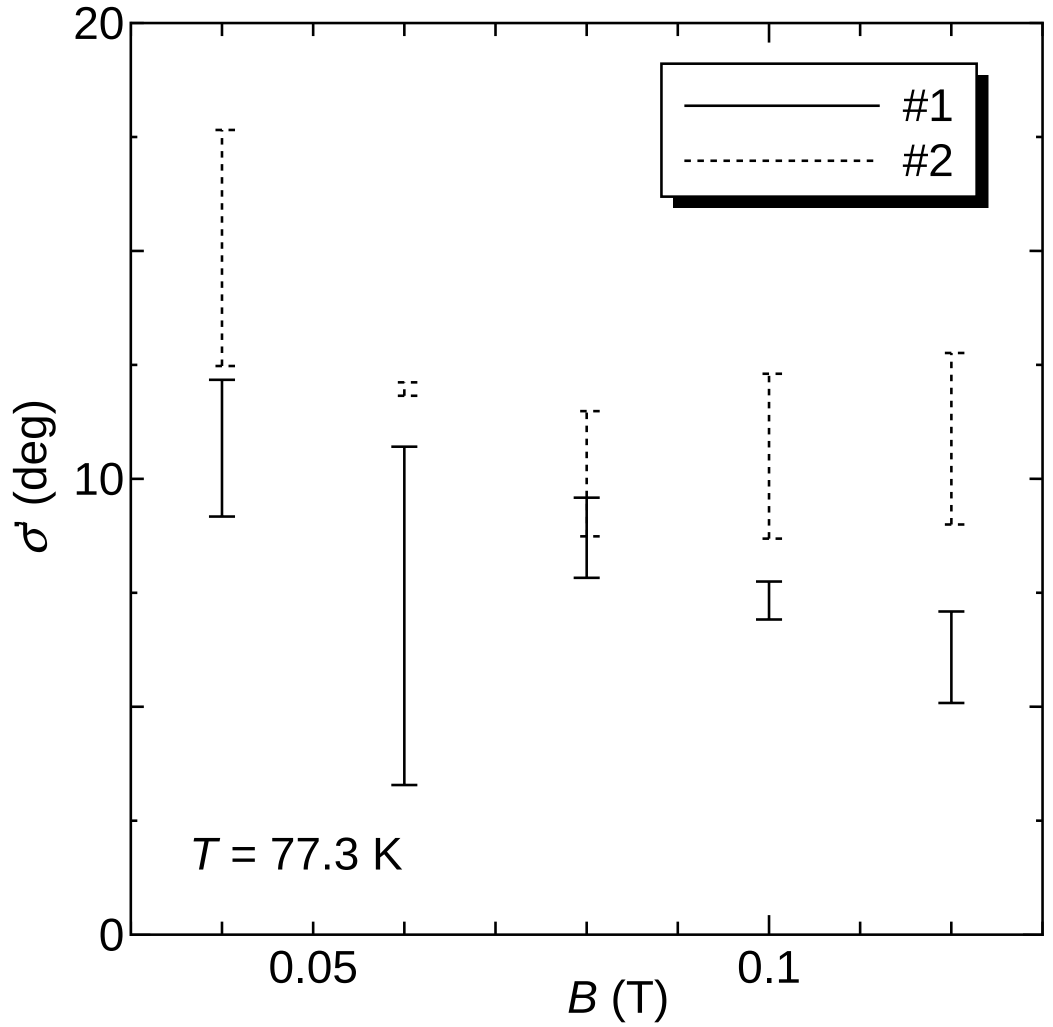

Fig. 3: Y. Himeda *et al.* WTP–77/ISS2005

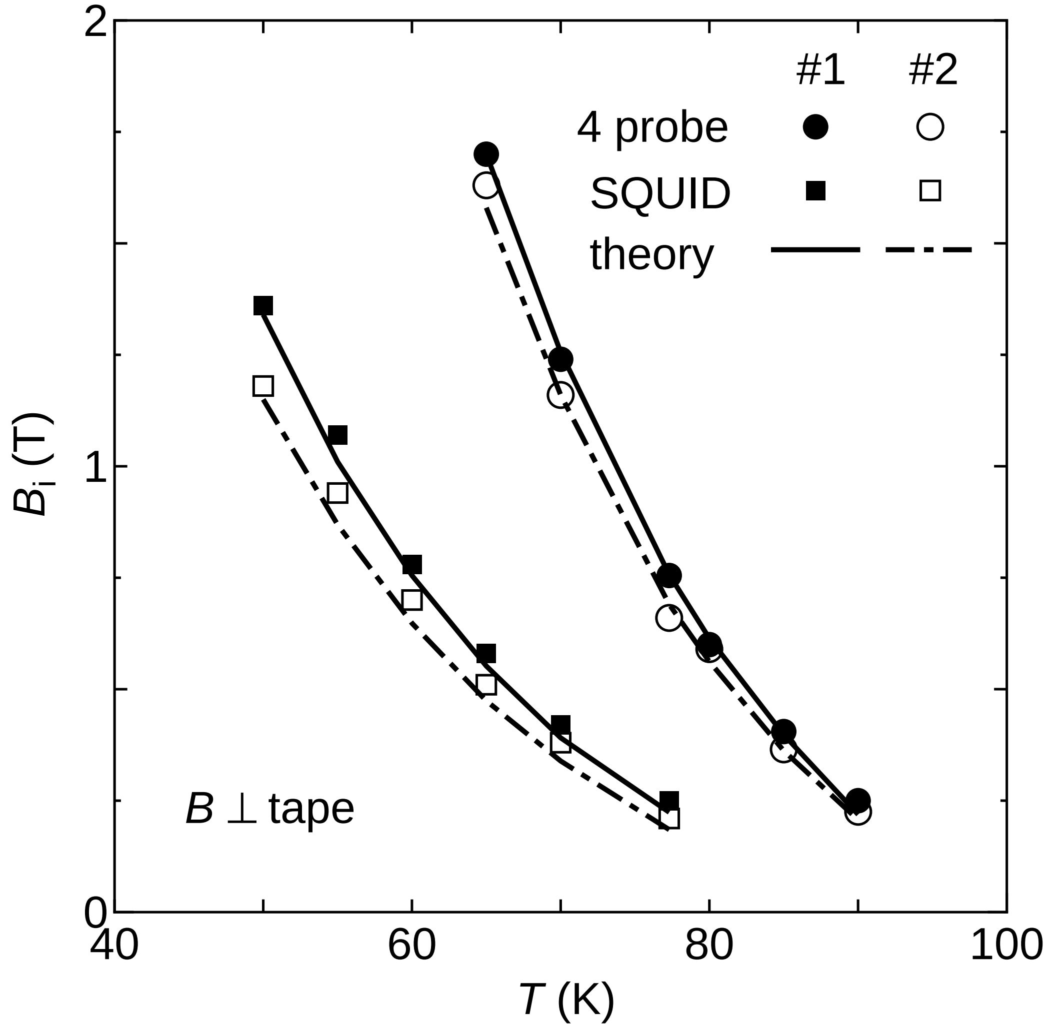

Fig. 4: Y. Himeda *et al.* WTP–77/ISS2005

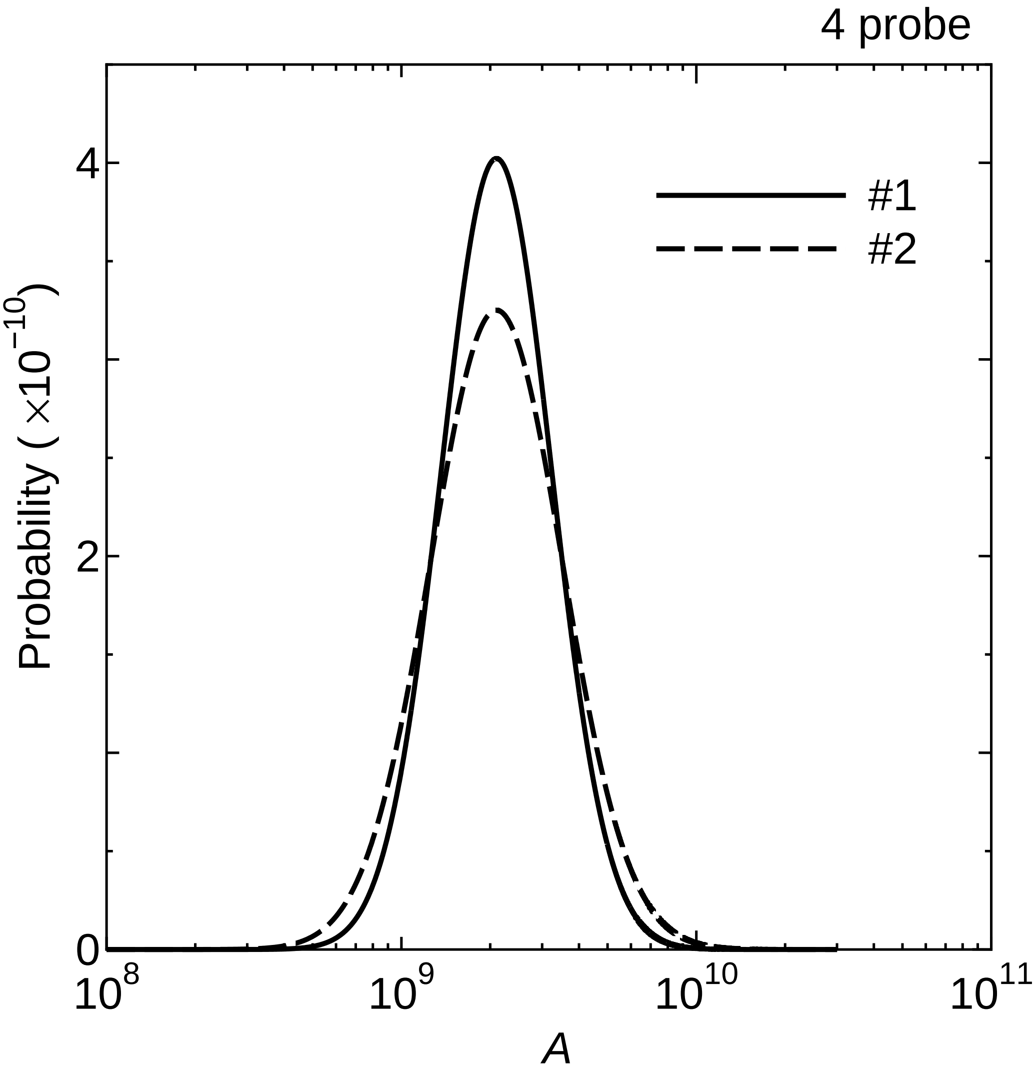

Fig. 5: Y. Himeda *et al.* WTP–77/ISS2005