Critical current properties in multifilamentary Bi-2223 tape produced by the over pressure processing

M. Kiuchi [a,1], S. Takayama [a], E.S. Otabe [a], T. Matsushita [a], 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, Fukuoka 820–8502, Japan*

[b] *HTS R&D Department, Electric Power & Energy Research Laboratories, Sumitomo Electric Industries, Ltd., 1–1–3 Shimaya, Konohana-ku, Osaka 544–0024, Japan*

Abstract

Investigation is done on the effect of ConTrolled Over Pressure (CT-OP) processes on the critical current properties in multifilamentary Bi-2223 tapes. It is found that the critical current density at low magnetic fields is remarkably improved by the new CT-OP process. This result with those on irreversibility field and n-value are compared with the numerical calculation based on the flux creep and flow model. The analysis reveals that the most probable value is increased, although the statistical distribution width is increased for the flux pinning strength. This result indicates that the critical current density at high magnetic fields is deteriorated by the widened distribution. If such an inhomogeneity can be reduced to the level of previous tapes by improving the CT-OP process, the high field performance is shown to be significantly improved.

Key words: Bi-2223 tape, Over pressure sintering, critical current density, irreversibility field, flux creep-flow mode

PACS: : 74.72.Hs; 74.25.Sv; 74.25.Qt

---

[1] Corresponding author. Postal address: Department of Computer Science and Electronics, Kyushu Institute of Technology, 680–4 Kawazu, Iizuka 820–8502, Japan Phone/fax: +81–948–29–7661

E-mail address: kiuchi@cse.kyutech.ac.jp (M. Kiuchi)

1 Introduction

The critical current property of Bi-2223 silver sheathed tape has been significantly improved by application of ConTrolled Over Pressure (CT-OP) process at the final heat treatment [1]. That is, not only the critical current density but also the critical current, the n-value and the irreversibility field have been increased by the development of the CT-OP process. Just after the introduction of CT-OP process, the improvements were mainly attributed to the improved connectivity of superconducting grains due to the better c-axis alignment which resulted from the elimination of voids [2]. After that the critical current property was further improved and tapes of 150 A class were achieved. This improvement was attributed to the enhancement of the flux pinning strength, which was considered to result from development of the condition of the CT-OP process [3]. Thus, further improvement can be expected by optimizing the condition of the process. In fact, the tape of 200 A class was recently developed.

The condensation energy density which determines the pinning properties was found to reach about 14% of that of Y-123 at 77.3 K for a superconducting Bi-2223 single crystal [4]. This indicates that Bi-2223 superconductor has a sufficient room for further improvement of the critical current properties and thus has a large potential for application. For further improvement of the critical current property of Bi-2223 tapes, it is necessary to exactly understand the factor which determines the present properties.

In this paper, the critical current property of a new CT-OP processed Bi-2223 tape is measured and the result is compared with those in previous CT-OP processed tapes. The obtained property is characterized by the theoretical analysis using the flux creep-flow model [5]. Based on the result, the possibility of the further improvement in the future is discussed.

2 Experiments

The specimen was a new CT-OP processed Bi-2223 tape with a self-field critical current of 197 A at 77.3 K. The transport and magnetization critical current densities in a magnetic field normal to the tape surface were measured in the temperature regions of 45–77.3 K and 20–77.3 K, respectively. A SQUID magnetometer was used for the measurement of the magnetization critical current density. The electric field criteria used were 1.0×10^{-4} V/m for the four terminal method and about 10^{-10} V/m for the DC magnetization method. The n-value was also estimated in the electric field range of 10^{-4} to 10^{-3} V/m. The irreversibility field was determined as the magnetic field at which the obtained critical current density decreased to 1.0×10^{7} A/m^2. The information of the present and previous specimens is listed in Table 1.

3 Results and Discussion

Fig. 1(a) and (b) show the transport and magnetization critical current density of the new specimen, respectively. For comparison the results of previous specimens are also shown. It is found that the critical current density at low magnetic fields is significantly improved in the new CT-OP processed specimen. Appreciable difference of J_c value between (a) and (b) is caused by a very large difference in the electric field of about six orders of magnitude.

Fig. 2 shows the irreversibility field determined by the both measurement methods. The irreversibility field determined by the DC magnetization measurement is lower due to the much lower electric field criterion for the determination of the critical current density. The value of the irreversibility field in the new specimen determined by the four terminal method is lower than that in #2, although it is slightly higher than that in #3. In the DC magnetization measurement the irreversibility field in the new specimen is almost the same as that in #3. Fig. 3 shows the n-value at 77.3 K. It is found that n-value in the new specimen is not high taking into account of its high J_{c} value.

Here the observed results are compared with the theoretical analysis based on the flux creep-flow model to characterize the new specimen. In the model the virtual critical current density J_{c0} in a creep-free case is defined as a parameter representing the flux pinning strength. Its dependence on temperature and magnetic field is assumed as

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

where m, γ and δ are the pinning parameters and $\delta = 2$ is used. It is also assumed that A which represents the magnitude of J_{c0} obeys the statistical distribution of

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

where A_{m} is the most probable value of A, σ^2 is a parameter associated with the distribution and K is a normalization constant. The pinning potential U_0 which determines the flux creep property is described in terms of J_{c0}. In the three-dimensional pinning regime where the superconducting filament thickness is larger than the pinning correlation length, U_0 is given as

$$U_0 = \frac{0.835 k_\mathrm{B} g^2 J_{\mathrm{c0}}^{1/2}}{(2\pi)^{3/2} B^{1/4}}, \tag{3}$$

where g^2 is the number of flux lines in the flux bundle. This is determined so that the critical current density under the flux creep is maximized and is theoretically derived in Ref. [6]. However, g^2 is used here as a fitting parameter for simplicity with assumption that g^2 depends only on the temperature. This seems to be allowed, since the treated range of magnetic field is much narrower in comparison with the value of the upper critical field.

The E-J curve can be calculated based on the mechanism of flux creep and flow as was done in [5]. The critical current density, the irreversibility field and the n-value are determined from the E-J curve as done in experiments. The pinning parameters are determined so as to get a good agreement between the theory and the experiments. These are listed in Table 2. g^2 takes a larger value at a higher temperature. This agrees with the theoretical predication [6]. The obtained theoretical results on the transport critical current density, irreversibility field and n-value are compared with the experimental results for the four specimens in Figs. 4. 5 and 6, respectively. It is seen that agreement is satisfactory.

The obtained parameters show that the value of A_m is the largest in the new specimen. That is, the most probable value of J_{c0} is the largest, being increased from the previous specimen, which may result either from improved superconducting property or strengthened flux pinning. Although the reason for the enhancement of A_m is unknown, this shows that there is still a room for further improvement. On the other hand, the value of σ^2 in the present specimen is the largest among the specimens prepared by the CT-OP process.

That is, the statistical distribution is relatively wide with a rather low value of the minimum J_{c0}. Such "weak" regions may be responsible for the rather poor performance at high fields and the poor n-value. Thus, if σ^2 can be reduced by optimizing the CT-OP process, as has been realized for the previous specimens, the high field performance and the n-value are expected to be improved.

Here the critical current properties are calculated assuming that the value of σ^2 are reduced to 0.021, the value of specimen #2, with keeping the present A_m value. The expected critical current density, irreversibility field and n-value at 77.3 K are shown in Figs. 4, 5 and 6. Especially, the improvements of the irreversibility field in the medium temperatures and the n-value in the low magnetic field regions are significant.

4 Summary

The critical current density of the Bi-2223 superconducting tape in the low field region can be significantly improved by employing the new CT-OP process. This can be attributed to the enhancement of A_m which represents the mean flux pinning strength, although the reason for this enhancement is not known yet. On the other hand, the critical current density at high magnetic fields and the n-value are not improved by the new process. These seem to be caused by weak pinning regions suggested by the widened statistical distribution of the flux pinning strength. For elimination of such weak pinning regions, a further improvement of the process condition is necessary. If this is achieved, a significant improvement of the critical current property is expected, especially at high fields.

References

[1] N. Ayai, T. Kato, J. Fujikami, K. Fujino, S. Kobayashi, E. Ueno, K. Yamazaki, M. Kikuchi, K. Ohkura, K. Hayashi, K. Sato, R. Hata, J. Phys., Conference Series 43 (2006) 47.

[2] T. Matsushita, Y. Himeda, M. Kiuchi, J. Fujikami, K. Hayashi, K. Sato, IEEE Trans. Appl. Supercond. 15 (2005) 2518.

[3] T. Matsushita, Y. Himeda, M. Kiuchi, J. Fujikami, K. Hayashi, K. Sato, Supercond. Sci. Technol. 19 (2006) 1110.

[4] E. S. Otabe, I. Kohno, M. Kiuchi, T. Matsushita, T. Nomura, T. Motohashi, M. Karppinen, H. Yamauchi, S. Okayasu, Adv. Cryog. Eng. 52 (2006) 805.

[5] M. Kiuchi, K. Noguchi, T. Matsushita, T. Kato, T. Hikata, K. Sato, Physica C 278 (1997) 62.

[6] T. Matsushita, Physica C 217 (1993) 461.

Table 1: Specifications of specimens

	Condition at final heat treatment	I_c A (77.3 K, s.f.)
#1	over pressure	197
#2	over pressure	147
#3	over pressure	126
#4	ambient pressure	104

Table 2. Parameters used of the numerical calculation

	A_m	σ^2	γ 60 K/65 K 70 K/77.3 K	m	g^2 60 K/65 K 70 K/77.3 K
#1	3.94×10^9	0.026	0.47/0.41 0.38/0.33	3.91	1.02/1.04 1.11/1.24
#2	3.63×10^9	0.021	0.51/0.59 0.52/0.46	3.88	1.01/1.03 1.10/1.23
#3	3.16×10^9	0.024	0.47/0.60 0.49/0.46	3.61	1.01/1.08 1.16/1.24
#4	3.16×10^9	0.044	0.66/0.55 0.46/0.43	3.61	1.01/1.14 1.20/1.25

Figure captions

Fig. 1. (a) Transport and (b) magnetization critical current density in Bi-2223 tapes.

Fig. 2. Transport and magnetization irreversibility field in Bi-2223 tapes.

Fig. 3. Magnetic field dependence of n-value at $T = 77.3$ K.

Fig. 4. Comparison of critical current density between experimental (symbols) and theoretical results (lines). The dotted line shows the theoretical prediction of critical current density of specimen #1 when σ^2 is reduced to 0.021.

Fig. 5. Comparison of irreversibility field between experimental (symbols) and theoretical results (lines). The dotted line shows the theoretical prediction of irreversibility field of specimen #1 when σ^2 is reduced to 0.021.

Fig. 6. Comparison of n-value of specimen #1 between experimental (symbols) and theoretical results (dotted lines) at $T = 77.3$ K. The line shows the theoretical prediction of n-value when σ^2 is reduced to 0.021.

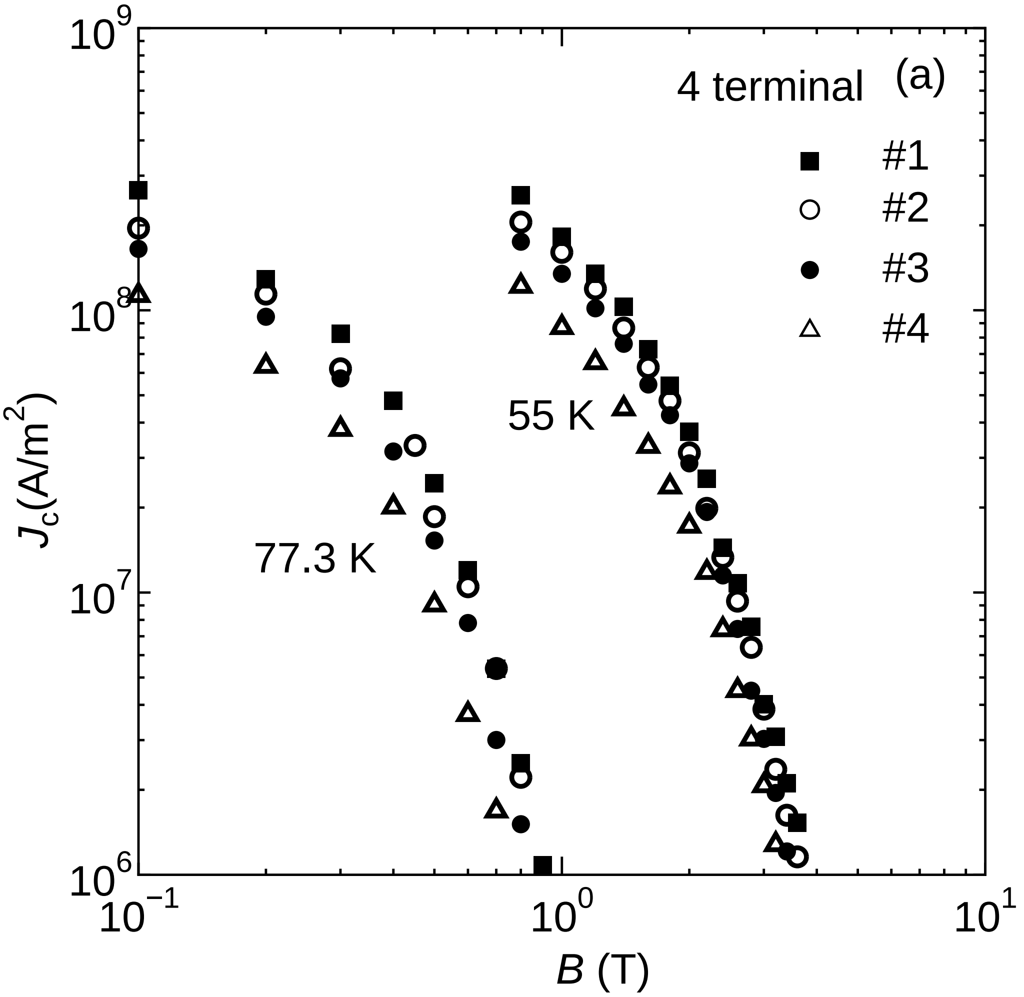

Fig. 1(a): M. Kiuchi *et al.*/WTP-115/ ISS2006

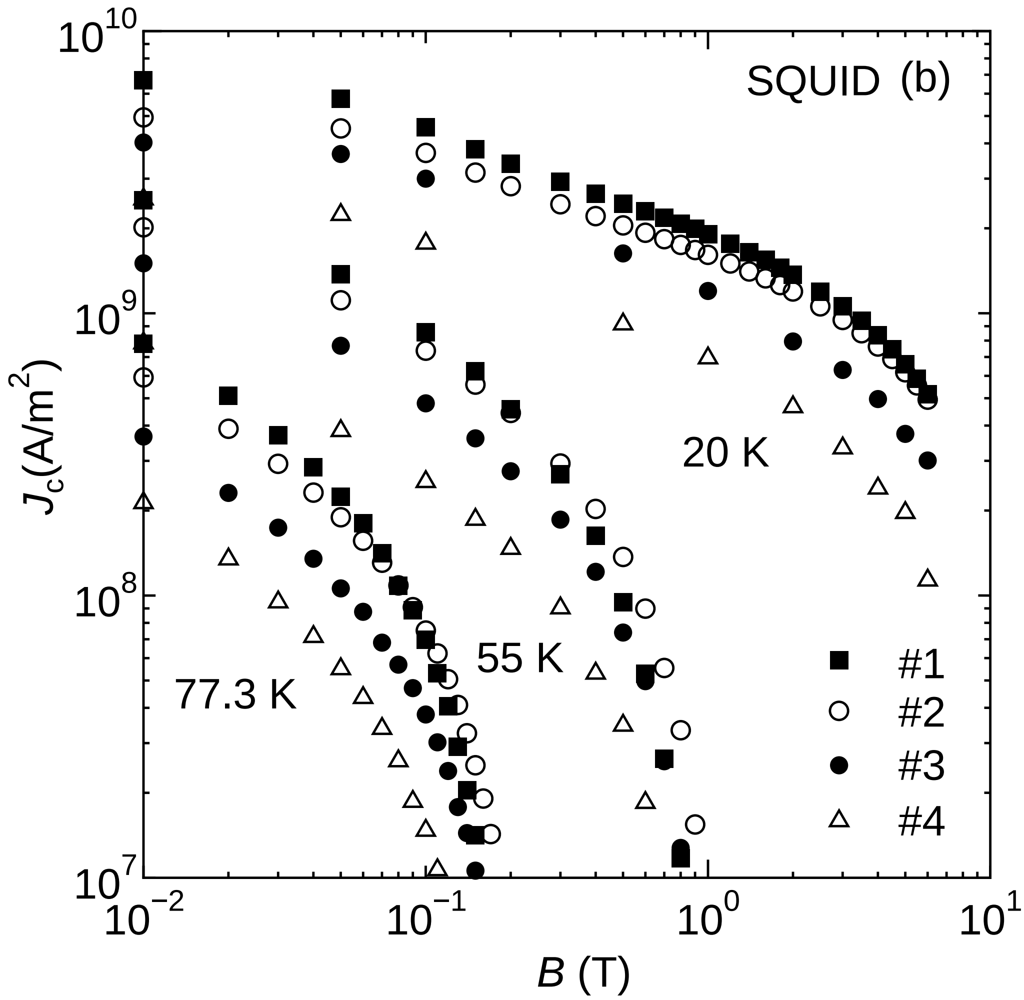

Fig. 1(b): M. Kiuchi *et al.*/WTP-115/ ISS2006

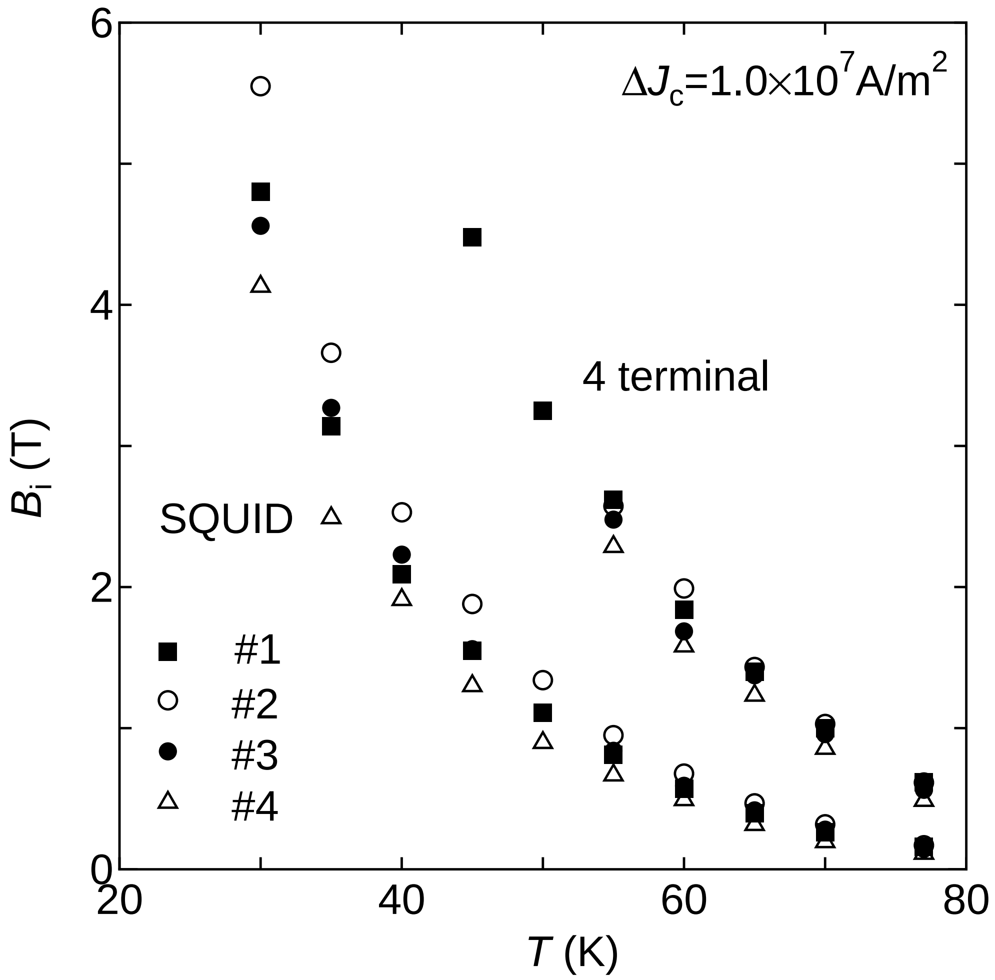

Fig. 2: M. Kiuchi *et al.*/WTP-115/ ISS2006

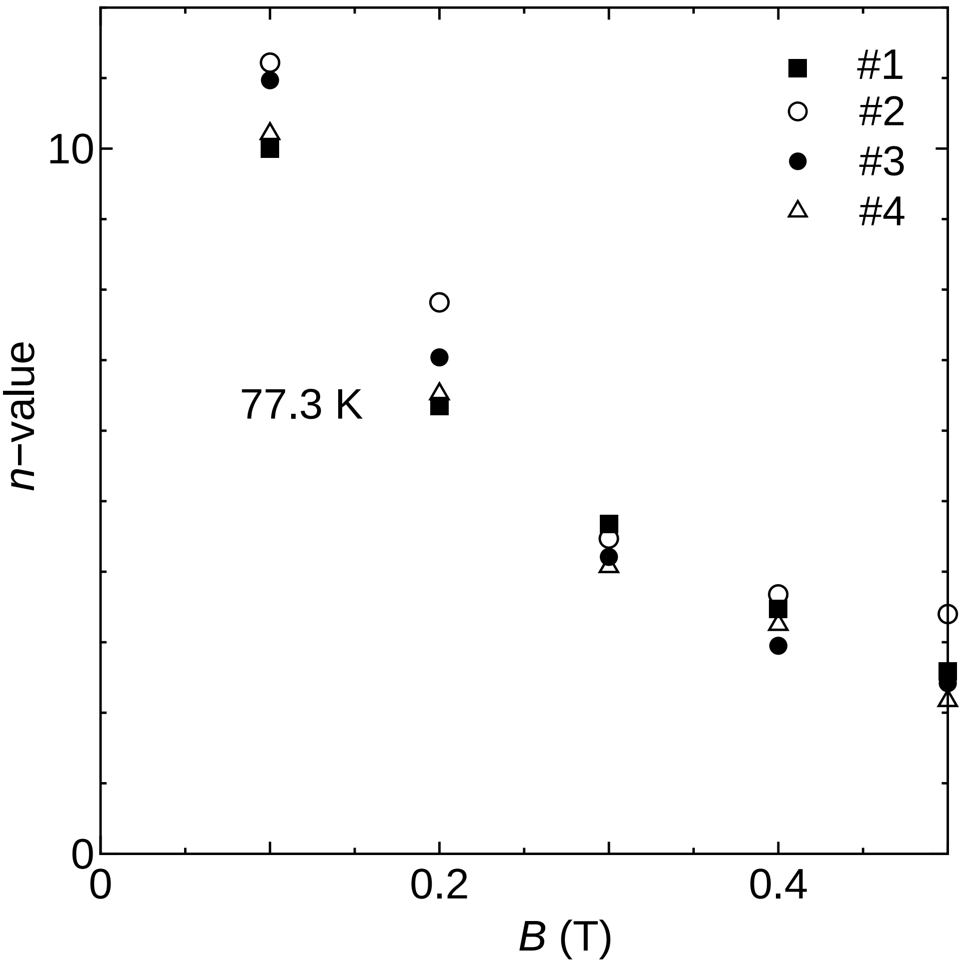

Fig. 3: M. Kiuchi *et al.*/WTP-115/ ISS2006

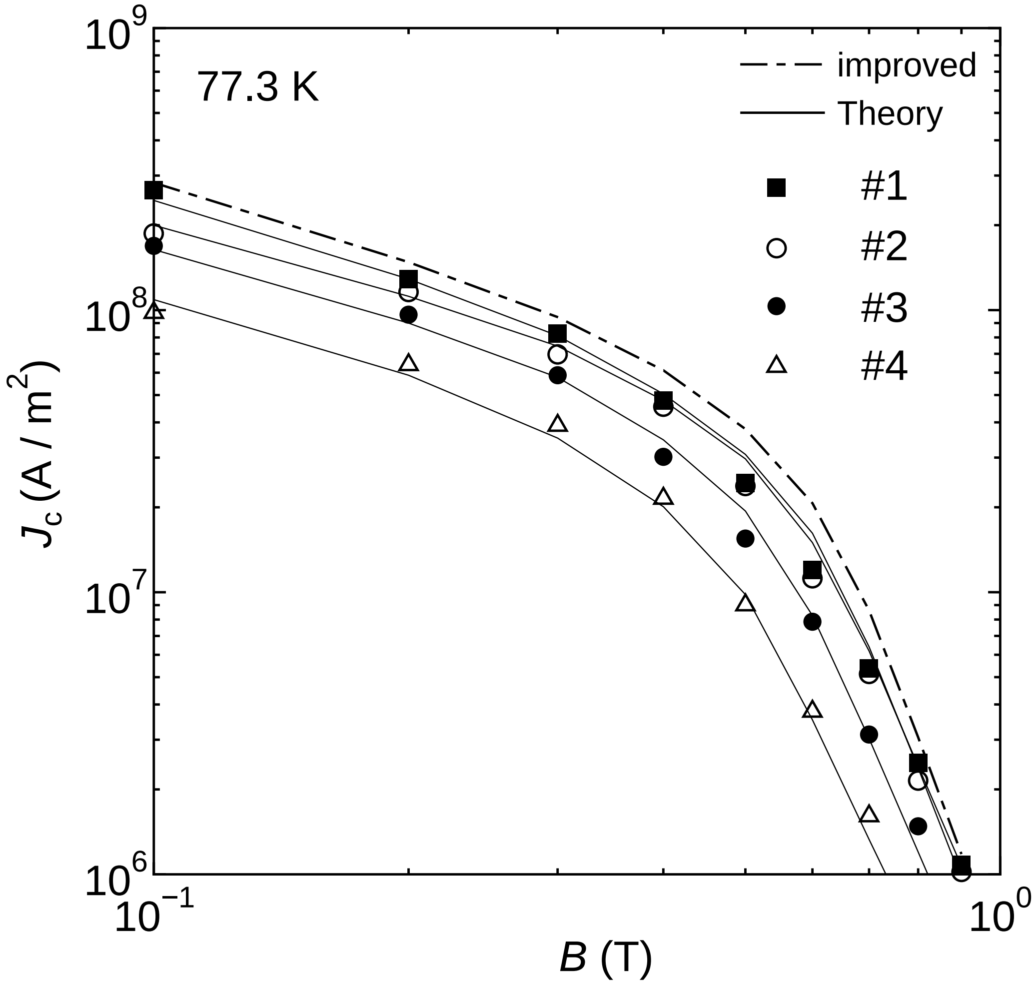

Fig. 4: M. Kiuchi *et al.*/WTP-115/ ISS2006

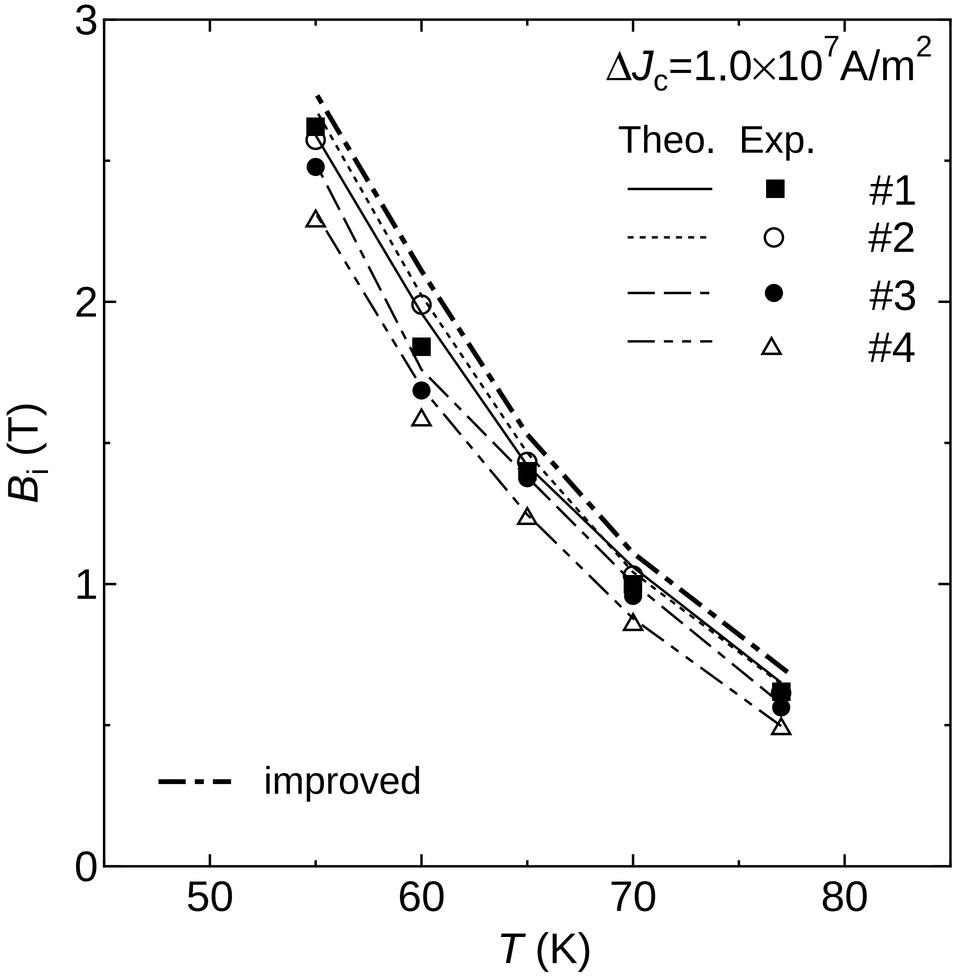

Fig. 5: M. Kiuchi *et al.*/WTP-115/ ISS2006

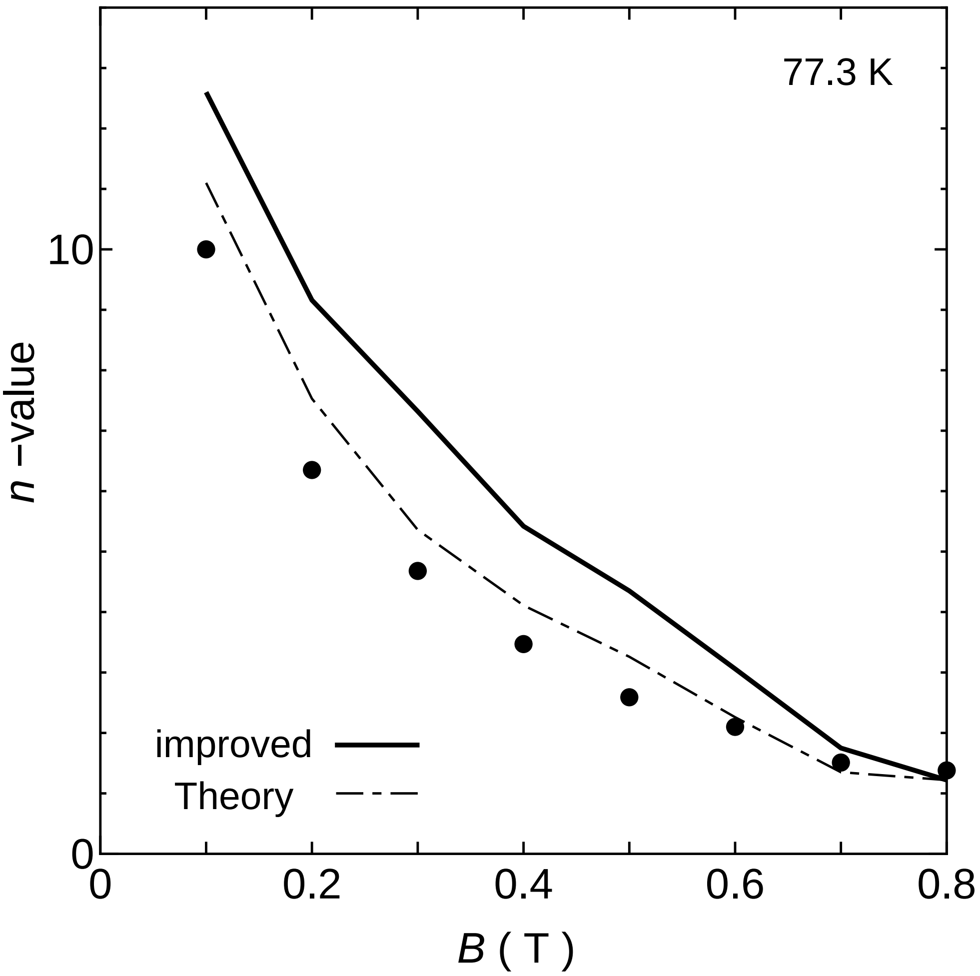

Fig. 6: M. Kiuchi *et al.*/WTP-115/ ISS2006