Critical current density at low temperatures in Bi-2212 superconductor with small anisotropy

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Abstract

The critical current density was measured at low temperatures for Bi-2212 single crystals with small anisotropy prepared by oxygen doping and by addition of Pb. The anisotropy parameters of these specimens were about 66. The Pb-doped specimen showed the peak effect up to $T/T_\mathrm{c} = 0.7$. The critical current density at high fields of these specimens was significantly improved as well as the irreversibility field than specimens with larger anisotropy.

Keywords: critical current density, anisotropy parameter, Pb-doping,

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1 Introduction

It is known that Bi-2212 superconductor has very high critical current density up to high fields at low temperatures. Therefore, applications of this superconductor to power generators, magnets for electric instruments, etc. are expected. However, the critical current density drastically decreases at high temperatures. This is due to the two-dimensional property of the superconductor. That is, Bi-2212 superconductor has thick block layers of almost insulating property. This leads to the low condensation energy density and results in the low critical current density J_c and the low irreversibility field B_i at high temperatures [1]. However, it was recently found that the condensation energy density increases drastically with decreasing temperature [2]. This suggests that the superconductivity in the block layers is greatly improved at low temperatures. In the previous measurement [3] it was found that such a behavior is remarkable in Bi-2212 superconductor with the low anisotropy.

Hence, if we can reduce the anisotropy of Bi-2212 more, a further improvement of the critical current density can be expected. For a reduction of the anisotropy, the oxygen doping and the Pb substitution are generally known to be effective. In this study, we evaluate the critical current density at low temperatures for a Bi-2212 superconducting specimen with more oxygen doping than previous specimens and another specimen substituted by Pb. The results are compared with the critical current properties of previous specimens.

2 Experimental

2.1 Specimens

All Bi-2212 single crystals including the previous ones were prepared by the floating zone method. The condition of oxygen doping of previously measured specimens A $\sim$ D listed in Table 1 was widely distributed from an underdoped one to strongly over doped one. New specimen E was heat treated at 350 ℃ for 72 hours in an oxygen atmosphere of 100 atm to highly dope oxygen. Its size was 1.46 mm×2.61 mm×12 μm.

In the case of Pb-doping, if the amount of Pb exceeds some limit, the lamellar structure composed of Pb-rich and Pb-poor regions appear. This structure contributes to the additional pinning and the pinning property by point-like defects which exist naturally in each specimen cannot be compared. Hence, the nominal composition of Pb was controlled so that 15 % of Bi was substituted by Pb without appearance of the lamellar structure in the another new specimen. This specimen was heat treated at 400 ℃ for 72 hours in an oxygen atmosphere of 2.1 atm. Its size was 1.02 mm×2.20 mm×37 μm.

In the both specimens the wide surface is normal to the c-axis. Specifications of these specimens are also listed in Table 1.

2.2 Measurement

A DC magnetization was measured using a SQUID magnetometer in a magnetic field parallel to the c-axis. The critical current density J_{c} is estimated from a width of magnetization hysteresis, ΔM, with an assumption of Bean's model. J_{c} is given by

$$J_{\mathrm{c}} = \frac{6a}{b(3a-b)}\Delta M, \tag{1}$$

where a and b are the width and the length of the specimen, respectively.

The irreversibility field B_{i} is determined by the magnetic field at which J_{c} is reduced to 1.0×10^{7} A/m^{2}.

The anisotropy parameter γ_{a} is estimated from $\gamma_{\mathrm{a}}^{2} = \phi_0/B_{\mathrm{p}}s^{2}$ [4] at T/T_{c}=0.25 for a consistency with the previous work [3], where B_{p} is a peak field, ϕ_0 is a flux quantum and s($\simeq$1.5 nm) is a distance between the superconducting layers. The anisotropy parameter of the both specimens is 66. This value is about 70% of the lowest value of previous specimens we measured.

3 Results and Discussion

Fig. 1(a) shows the $J_{\rm c}$-B characteristics of specimen E. In this figure, the peak effect is observed within the range of $T = 12 \sim 30$ K, and it is found that the peak disappears at low temperatures. The temperature at which the peak effect terminates is fairly lower than about 20 K for the previous specimens. The $J_{\rm c}$ at high field increases drastically at lower temperatures. In addition, the peak field increases slightly with decreasing temperature, while it was almost the same in the previous specimens.

Fig. 1(b) shows the $J_{\rm c}$-B characteristics of the Pb-doped specimen. The peak effect is observed within the range of $T = 15 \sim 50$ K, and this temperature range is extended to fairly high temperature. And the increase of the peak field with decreasing temperature is much more significant than in specimen E. Furthermore, the $J_{\rm c}$ of Pb-doped specimen is slightly better than that of specimen E at low field. Such a variation in the peak field in each specimen is more clearly seen in Fig. 2.

Fig. 3 shows the critical current density of each specimen at $T/T_{\rm c} = 0.25$. It is found that $J_{\rm c}$ is much larger for a specimen of lower anisotropy at high fields, while $J_{\rm c}$ is rather independent of the anisotropy parameter at a magnetic field below $B_{\rm p}$.

The irreversibility field $B_{\rm i}$ of each specimen is shown in Fig. 4. $B_{\rm i}$ of both specimen E and Pb-doped specimen with low anisotropies are larger than other specimens in the whole range of temperature. The difference of $B_{\rm i}$ between the low anisotropy specimens and other specimens is relatively small at low temperatures. This is simply explained by the weak dependence of the condensation energy density on the anisotropy parameter at these temperatures, at which the condensation energy density shows a linear temperature dependence. On the other hand, the temperature dependence of $B_{\rm i}$ is very strong and the difference of B_i among specimens is extremely large at high temperatures as shown in the insert of Fig. 4. This is caused by the strong dependence of the condensation energy density on the anisotropy parameter and temperature at high temperatures [3]. The deterioration of B_i in Pb-doped specimen at $T/T_\mathrm{c} = 0.69$ is emphasized by a hump at $T/T_\mathrm{c} = 0.63$, which is caused by the peak effect.

Fig. 5 shows the relationship between the anisotropy parameter and the irreversibility field at (a) $T/T_\mathrm{c} = 0.25$ and (b) $T/T_\mathrm{c} = 0.65$. The irreversibility field increases with decreasing anisotropy parameter and its dependence is strong at high temperatures. This explains the high irreversibility field of Pb-doped specimen and specimen E.

Fig. 6 shows the temperature dependence of the critical current density in (a) specimen E and (b) Pb-doped specimen. It is found that the temperature dependence changes at around $T/T_\mathrm{c} = 0.25$: the decrease of J_c with increasing temperature is rapid at low temperatures but is slow at high temperatures. This strong temperature dependence at low temperatures shows a high potential of Bi-2212 superconductors with low anisotropy for application. Introduction of strong pinning centers is needed to realize the application of Bi-2212 superconductors.

4 Summary

The critical current density was measured at low temperatures for Bi-2212 single crystals with small anisotropy prepared by a heavy oxygen doping and by addition of Pb, and the result was compared with properties of specimens measured previously. As a result, characteristics such as the critical current density and the irreversibility field were significantly improved compared with the previous specimens.

The temperature dependence of the critical current density of these specimens was larger at low temperatures than at high temperatures. It shows a high potential of Bi-2212 superconductors with low anisotropy for high-field application at low temperatures.

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Table 1
Specifications of specimens

specimen	state of oxgen doping	T_{c}	size	γ_{a}
A	under dope	89 K	1.82 mm×2.04 mm×13 μm	187
B	optimal dope	90 K	0.72 mm×1.60 mm×11 μm	148
C	over dope	87 K	0.99 mm×2.09 mm×11 μm	127
D	strong over dope	79 K	0.92 mm×2.12 mm×8 μm	93
E	stronger over dope	73 K	1.46 mm×2.61 mm×12 μm	66
Pb-doped	over dope	79.2 K	1.02 mm×2.20 mm×37 μm	66

Figure 1 J_{c}-B characteristic of (a) specimen E and (b) Pb-doped specimen.

Figure 2 Temperature dependence of peak field.

Figure 3 Critical current density of each specimen at $T/T_{\mathrm{c}} = 0.25$.

Figure 4 Irreversibility field of each specimens.

Figure 5 Relationship between anisotropy parameter and irreversibility field at (a) $T/T_{\mathrm{c}} = 0.25$ and (b) $T/T_{\mathrm{c}} = 0.65$.

Figure 6 Temperature dependence of critical current density in (a) specimen E and (b) Pb-doped specimen.

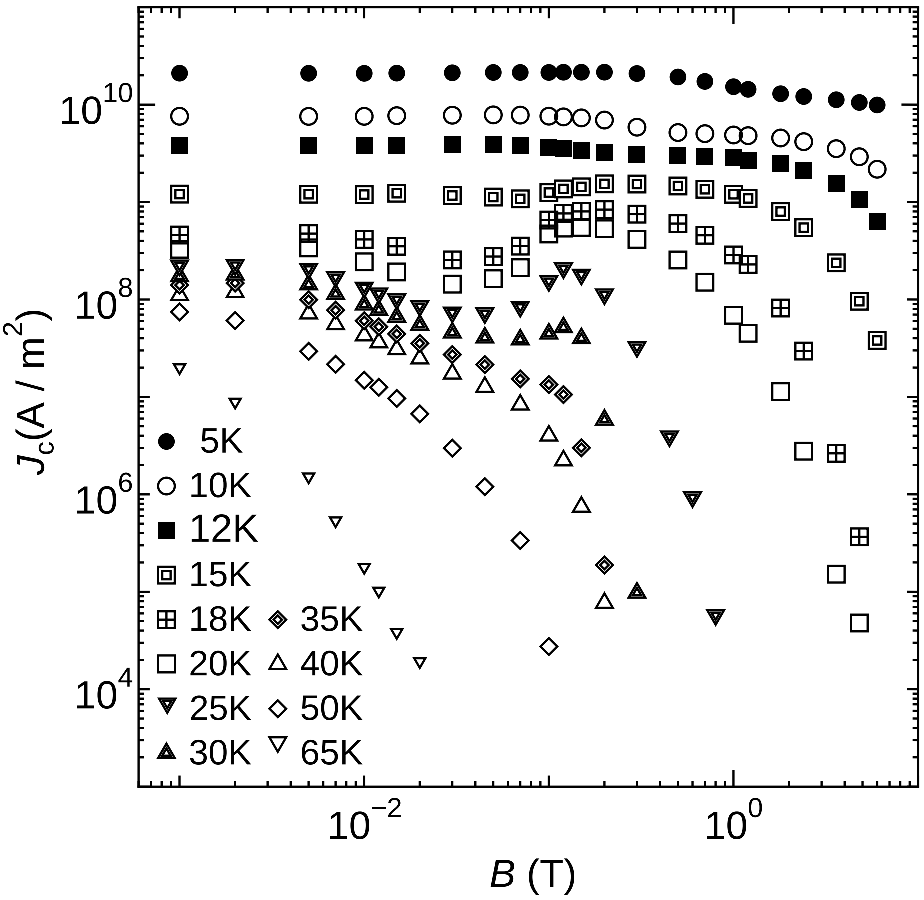
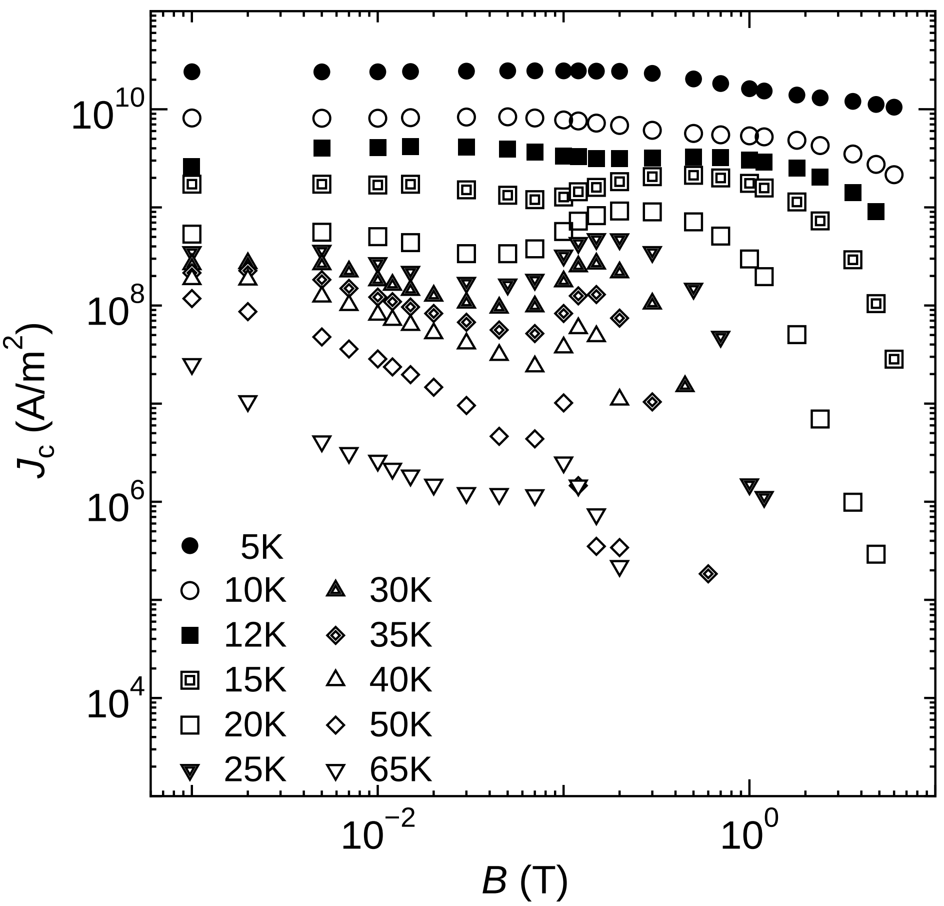


Figure 1(a) T. Haraguchi *et al.* PCP–13/ ISS2004



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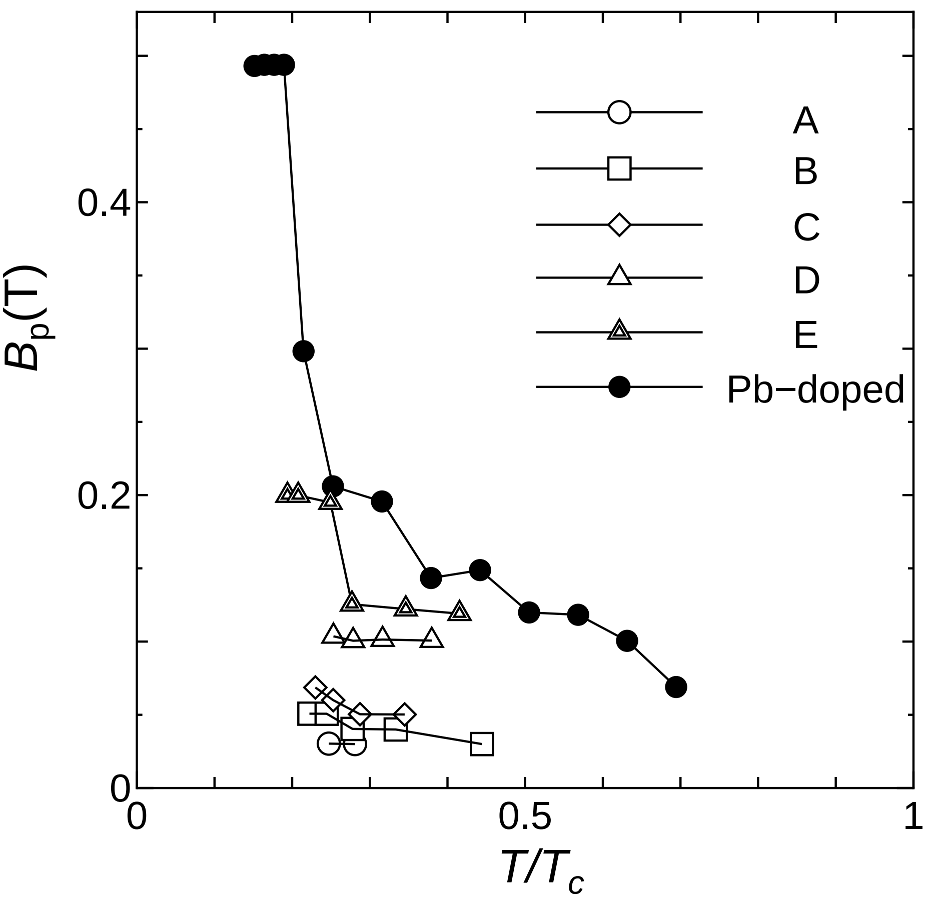

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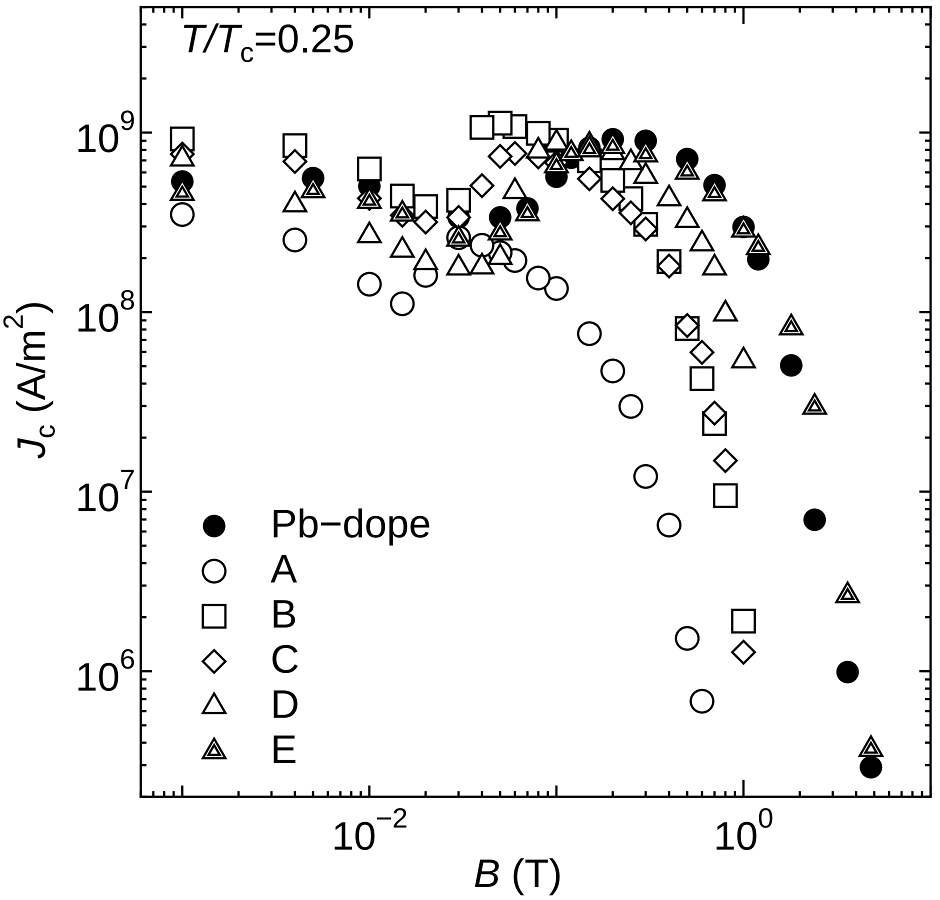

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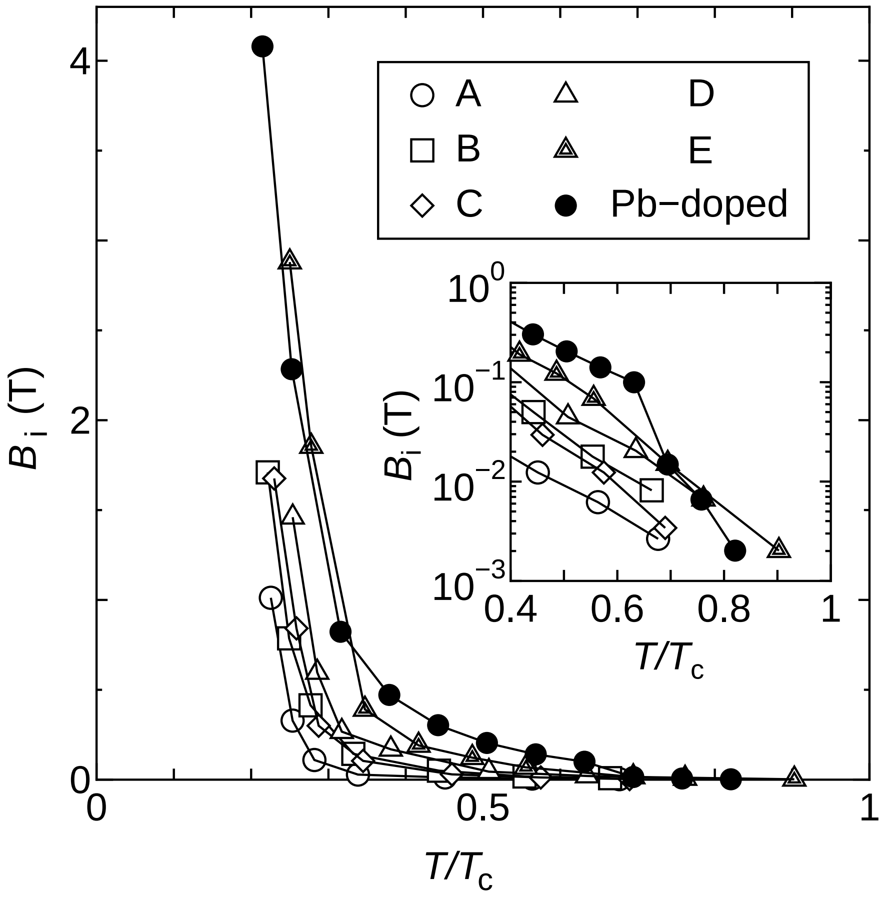

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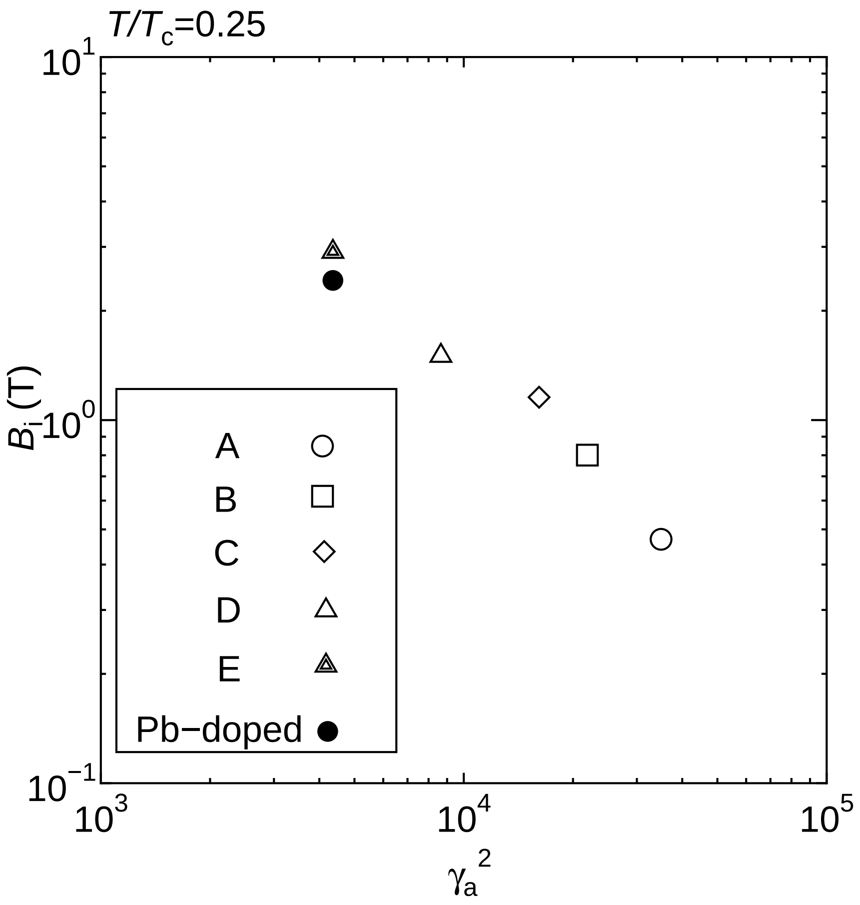

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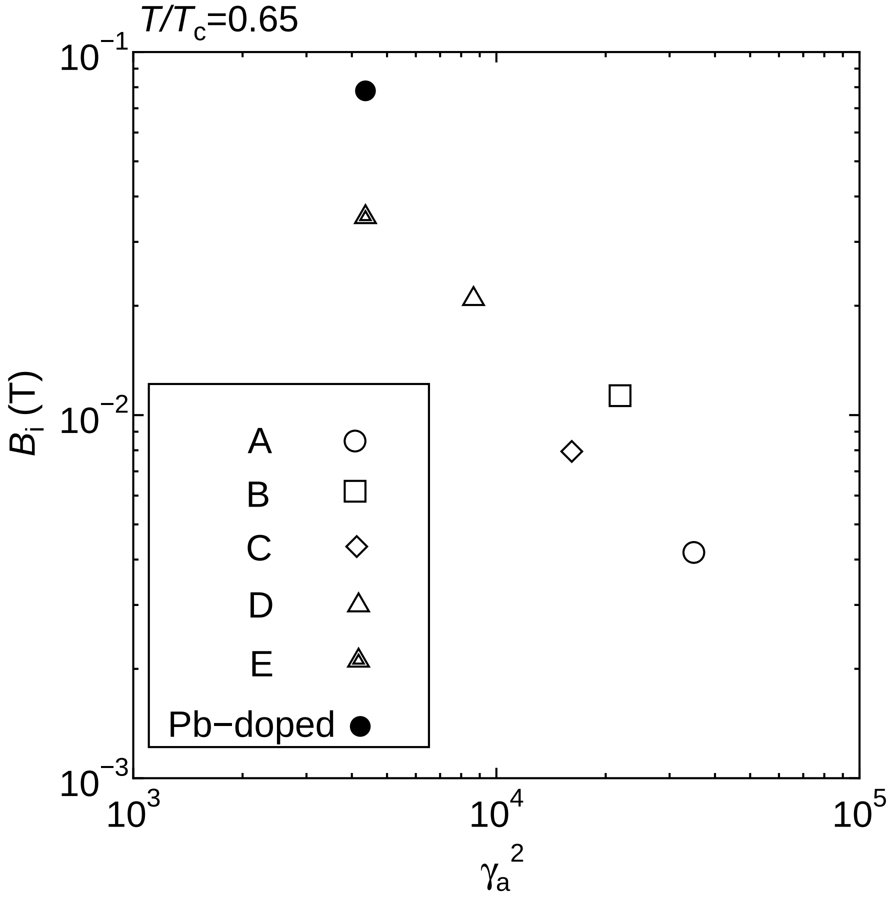

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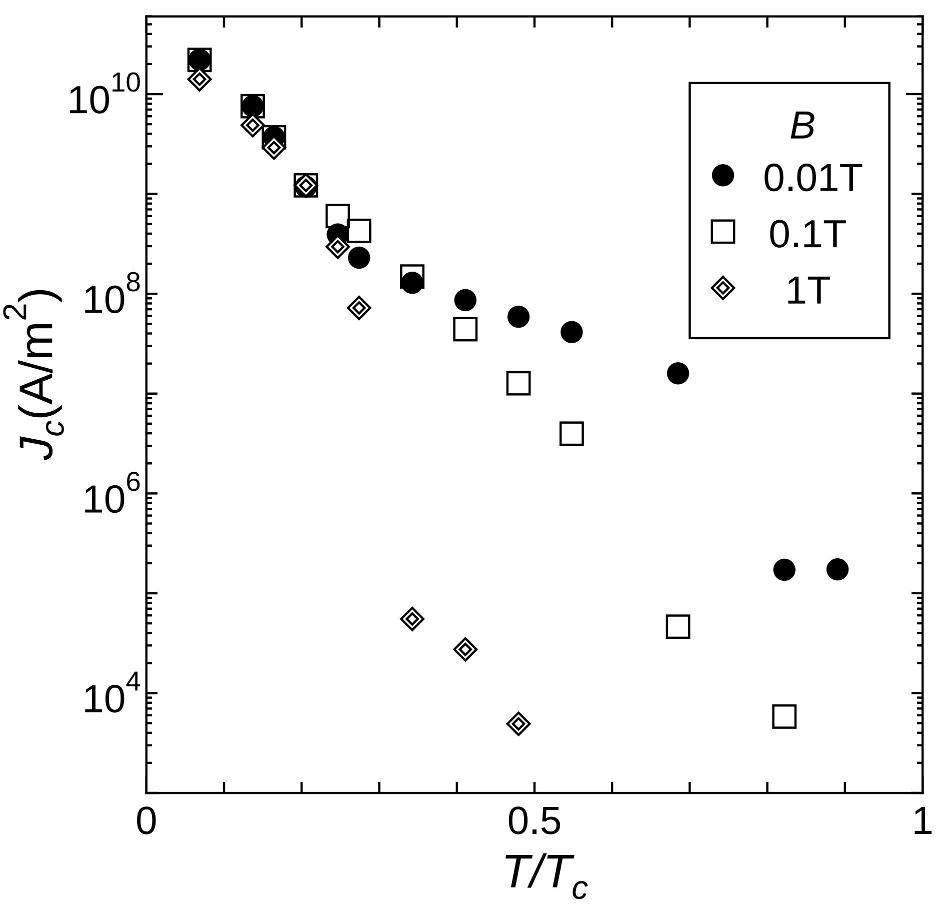

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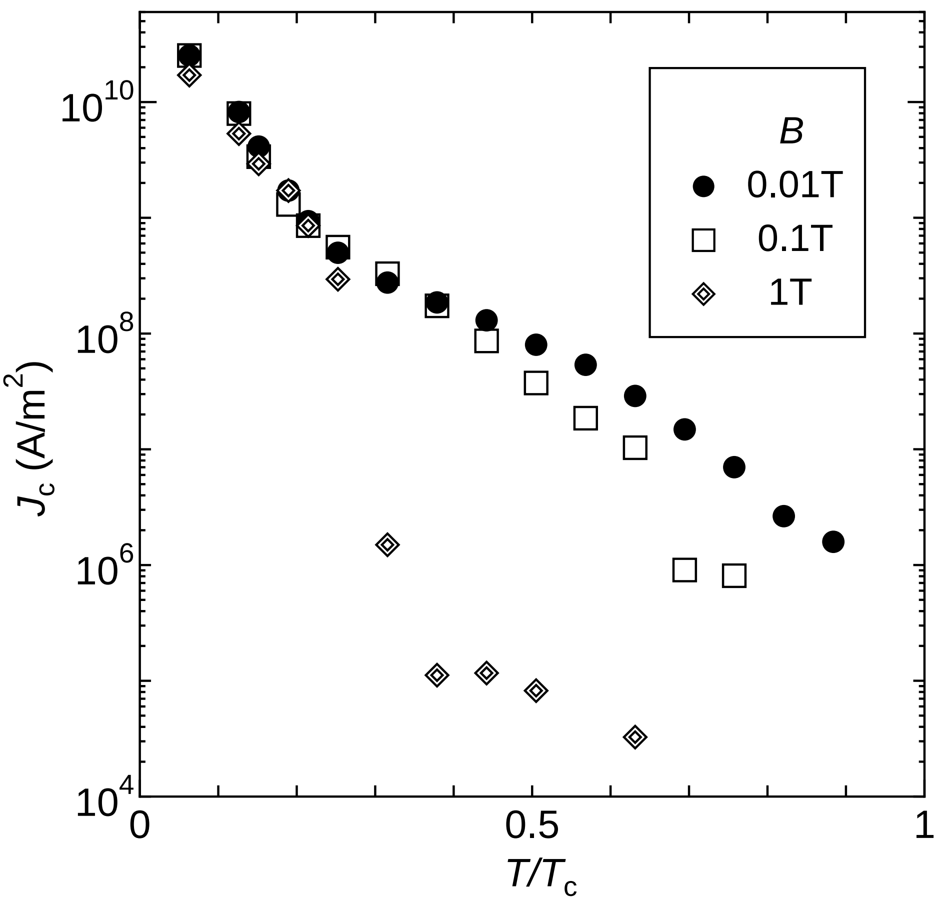

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