Flux Pinning and Peak Effect in Y-123 Superconductor

Daisuke Yoshimi, Minoru Migita, Edmund Soji Otabe, Teruo Matsushita

Abstract—
It is known that the peak effect in Y-123 superconductors is caused by oxygen deficient regions with lower T_c. In order to study the flux pinning mechanism of these defects, the effect of addition of 211 particles on the peak effect was measured. It was found that the addition of 211 phase deteriorated the pronounced peak effect at medium magnetic fields. This shows that the pinning mechanism of the oxygen deficient regions is different from the condensation energy interaction known for 211 particles. The results on the critical current density and the irreversibility field were compared with the theoretical predictions of the flux creep-flow model.

Keywords— **Peak effect, flux pinning mechanism, melt-processed Y-123, flux creep-flow**
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I. Introduction

The peak effect of the critical current density, J_c, is observed in oxide superconductors at certain regions of temperature and magnetic field. It is well known that melt-processed Y-123 bulk superconductors have a broad peak in $J_c(B)$ at medium fields in the medium range of temperature. It has been revealed that oxygen deficient regions with lower T_c are relevant to the peak effect, while 211 phase particles are not. As for the mechanism of these pinning centers, the attractive field-induced pinning from the condensation energy interaction and the repulsive pinning from the kinetic energy interaction under the proximity effect have been proposed.

Mochida *et al.* [1] found that, while J_c increased in the low and high field regions by addition of Nd-422 phase particles to Nd-123 bulk superconductors, it decreased and the peak effect reduced in the medium field region. In these superconductors the relevant pinning centers are considered as substituted regions where a Nd atom sits on a Ba site and/or oxygen deficient regions. It is speculated that the pinning mechanism of these lower T_c regions is not the attractive pinning centers but repulsive pinning centers [2]. The origin of the repulsive pinning is the kinetic energy interaction under the proximity effect. In this model the reduction of the peak effect is ascribed to the interference between the repulsive pinning of the lower T_c regions and the attractive pinning of Nd-422 phase particles.

To confirm this mechanism, in this study, the elementary pinning mechanism relevant to the peak effect was investigated by measuring the change in the pinning property by addition of 211 phase particles in melt-processed Y-123 specimens, similarly to the case of Nd-123 superconductor. The results on the critical current density and the irreversibility field were compared with the theoretical predictions of the flux creep-flow model.

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II. Experimental

Specimens were Y-123 superconductor prepared by the melt process with different conditions of additions of 211 particles and platinum to make the 211 particles fine. These conditions are listed in Table 1. The size of four specimens was about 3.14 × 2.09 × 0.82 mm^3. The c-axis was directed along the long axis of the specimen. The critical temperature was about 90 K∼91 K. The magnetization in a magnetic field along the c-axis was measured using a SQUID magnetometer. The critical current density was estimated from the measured hysteresis of the magnetization and the irreversibility field was determined by the field at which J_c was reduced to 1.0 ×10^5 A/m^2.

TABLE I
Conditions of specimens.

specimen	addition of		211 particle	
	211	Pt	size(μm)	volume
00	no	no	∼10	10 Vol%
01	25 wt%	no	∼10	25 Vol%
10	no	yes	∼1	2∼3 Vol%
11	25 wt%	yes	∼1	25 Vol%

III. Results and Discussion

Fig. 1 shows the magnetic field dependence of J_c at 77.3 K. The peak effect was observed for specimen 00. When 211 phase particles are added as in specimen 01, J_c increased in the low and high field regions, while it decreased and the peak effect disappeared at a medium field. The disappearance of the peak effect is speculated to be caused by an interference between two different pinning mechanisms, because if the pinning mechanism of the oxygen deficient regions is similarly attractive, J_c must increase. Since 211 phase particles act as attractive pinning centers due to the condensation energy interaction, oxygen deficient regions are considered to act as repulsive pinning centers. The kinetic energy interaction due to the longer coherence length under the proximity effect is considered as a candidate of the repulsive pinning mechanism [2].

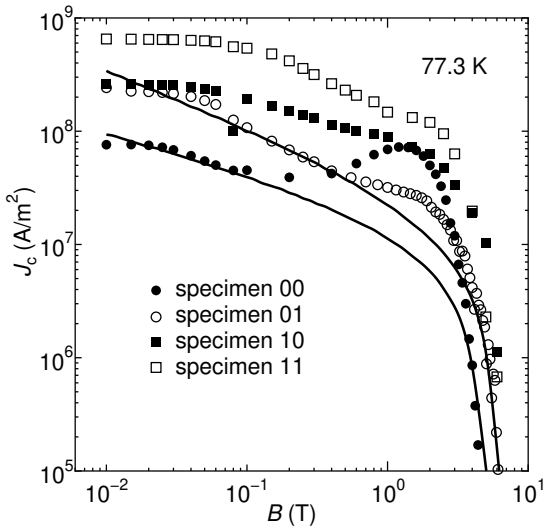

Fig. 1. Magnetic field dependence of critical current density at 77.3 K in each specimen.

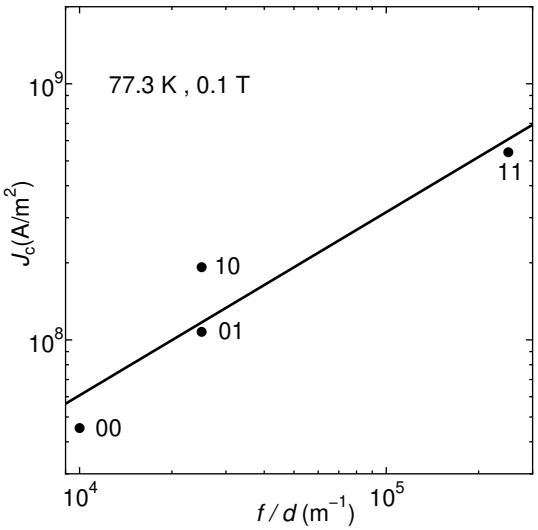

Fig. 2. Critical current density at 77.3 K and 0.1 T vs effective surface area of 211 particles in a unit volume.

It should be noted that the elementary pinning force of kinetic energy interactions decreases monotonically with the increasing magnetic field. Hence, the peak effect is considered to be caused by some transitional change in the property of flux lines as assumed in the disorder transition [3]. This is consistent with the conclusion by Küpfer *et al.* [4]

In the low field region, J_c increase monotonously with increasing 211 phase particles. Fig. 2 shows the relationship between J_c and the effective surface area of 211 phase particles in a unit volume at 77.3 K and at 0.1 T, where f and d are the volume fraction and the size of 211 particles, respectively. This clearly shows that 211 particles are dominant pinning centers at low fields. It seems to be strange that the interference between the two kinds of pinning interactions does not take place in this field regions. Because the spacing of flux lines is fairly long, elementary flux pinning interactions are performed almost independently of each other, resulting in no significant interference between the two kinds of pinning interactions.

In the high field region, J_c shows again the correlation with f/d. This suggests that the pinning interactions of 211 particles are again dominant in this field region. In this region the flux line spacing is so short that almost every oxygen deficient regions are occupied by flux lines. In this case, if the superconductivity is induced in the oxygen deficient regions, it brings about a high kinetic energy due to the spatial variation of the order parameter of flux lines. Hence, it is considered that the superconductivity in oxygen deficient regions and surrounding matrix is degraded and that the repulsive flux pinning interactions disappear. Thus, only the attractive condensation energy interactions by 211 phase particles are considered to remain. It should be noted that the correlation between J_c and f/d is not as strong as in low field region. This is attributed to the influence of flux creep.

Here we shall analyze J_c for specimens 00 and 01 using the flux creep-flow model [5]. In the model, the pinning potential, the most important quantity, can be theoretically estimated in terms of the virtual critical current density in the creep-free case, J_{c0}, which is used as a parameter representing the pinning strength. The temperature and magnetic field dependences of J_{c0} are given by

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

where A, m and γ are pinning parameters. The distribution of J_{c0} is for simplicity assumed to originate only from the distribution of A in (1) of the form:

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

where A_m is the most probable value of A, σ^2 is a parameter representing the degree of distribution width of the pinning force and K is a constant. The E-J characteristics were calculated with the parameters listed in Table 2. A_m, m, γ, g^2 and σ^2 are adjusting parameters to get a good agreement between the theory and experiment for J_c, where g^2 is the number of flux lines in the flux bundle. The values of m and γ are approximately equal to 3/2 and 1/2, respectively, which are the theoretical values for the pinning of 211 phase particles. In addition, A_m in specimen 01 is about two times as large as that in specimen 00. These results support the speculation that the pinning by 211 phase particles is dominant. J_c was determined from the E-J curve at the electric field $E = 1.0 \times 10^{-9}$V/m. In Fig. 1, the solid lines are the theoretical results of the flux creep-flow model for specimens 00 and 01. It is found that the agreement is good in the low and high field regions.

The irreversibility field are also determined theoretically with the same definition as in experiment. The experimental and theoretical results are compared for specimens 00

TABLE II

Pinning parameters used for calculation in all ranges of field and temperature.

specimen	$A_{\rm m}$	m	γ	g^2	σ^2
00	1.30×10^9	1.69	0.68	4.17	0.04
01	2.31×10^9	1.68	0.52	4.39	0.04

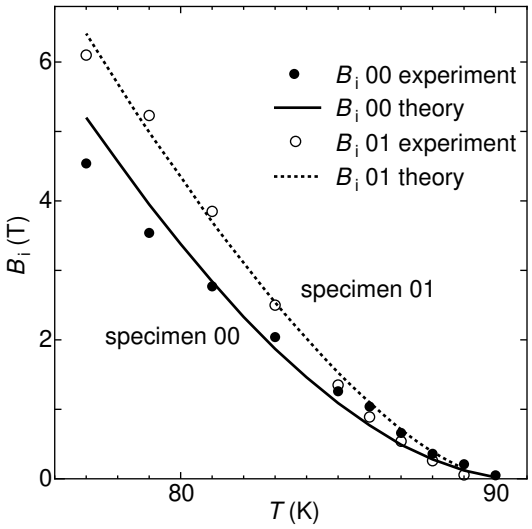

Fig. 3. Irreversibility lines of specimens 00 and 01.

and 01 in Fig. 3. It is found that the agreement is good. This also proves that the flux pinning by 211 phase particles is dominant in the high field region.

IV. Summary

The elementary pinning mechanism for the peak effect was investigated for melt-processed Y-123 specimens. The following results are obtained.

1. When 211 phase particles were added as in specimen 01, the critical current density decreased and the peak effect disappeared in the medium field region. This interference shows that oxygen deficient regions relevant to the peak effect act as repulsive pinning centers by the kinetic energy interaction under the proximity effect.
2. The peak effect in Y-123 superconductors is considered to originate from some transitional variation in the property of flux lines under a strong pinning by an oxygen deficient regions.
3. The flux pinning by 211 phase particles is dominant at low and high magnetic fields. Especially, the irreversibility field is determined by this pinning mechanism.

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