Flux Pinning Property in Superconducting Sm-123 Powder

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Abstract— **The size dependence of flux pinning property was investigated for superconducting Sm-123 powder specimens. It was found that the peak effect disappeared when the particle size became smaller than the longitudinal correlation length. This suggests that the peak effect originates from a certain cooperative phenomenon associated with the transitional change in the state of flux lines but not directly from the elementary pinning mechanism such as the field-induced pinning mechanism.**

Keywords— **Sm-123, peak effect, disorder transition, size dependence**

I. Introduction

THE critical current density vs. magnetic field curve in RE-123 (RE = Sm, Nd, Y) frequently shows a peak in a medium magnetic field. Although it is known that oxygen vacancies or regions where Ba site is substituted by a RE element are relevant pining centers to the peak effect, the pinning mechanism of these regions is still under discussion. On the other hand, the disorder transition of flux line lattice was proposed to explain the peak effect [1]. According to this model, the peak effect is a cooperative phenomenon of flux lines accompanied by a plastic deformation of the flux line lattice, which occurs independently of the kind of elementary pinning mechanism. That is, the peak effect is caused by an enhancement of the pinning efficiency due to the plastic deformation of flux lines. Therefore, for the occurrence of the peak effect, the specimen size should be larger than the longitudinal correlation length, l_{44}, over which length each flux line moves coherently. This suggests that, when the specimen size is smaller than l_{44}, the disorder transition of flux line lattice is considered to be diminished, resulting in no peak effect.

In this work, superconducting Sm-123 superconducting powder specimens with different particle sizes were prepared and the peak effect of the critical current density was investigated from the viewpoint of the relationship between the particle size and the longitudinal correlation length.

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TABLE I

Average and standard deviation of particle size in each specimen. The ratio of the average size to the longitudinal correlation length is also listed.

specimen	1	2	3	4	5
average size $\langle d \rangle$ (μm)	49.8	8.5	5.0	4.4	2.2
standard deviation (μm)	15.4	4.5	2.9	3.0	1.3
$\langle d \rangle / l_{44}$ at 77.3 K, 1.5 T	5.83	0.82	0.55	0.12	0.06
peak effect	yes	(yes)	(yes)	no	no

II. Experimental

Specimens were prepared by a sintering method and a post annealing was performed for pellets at 350°C for 40 h in an oxygen gas flow. The pellet was first powdered and then separated in five specimens with different average particle sizes by using sieves of different mesh sizes and an elutriation technique in which the size dependence of the falling velocity of particles in ethanol is used [2]. The average value and the standard deviation of particle size are listed in Table 1. Specimen 1 has the largest particle size of about 50 μm and other is less than 10 μm. The powder was mixed with insulating Y_2O_3 powders for the purpose of the restriction of the percolating current among the superconducting powders, and then pressed into a form of pellet. The c-axis of the specimen was roughly oriented to the press direction.

The magnetization of specimen in the magnetic field parallel to c-axis was measured with a SQUID magnetometer. The critical current density was estimated from the hysteresis width of the magnetization.

III. Result and Discussion

Fig. 1 shows the magnetic field dependence of the critical current density, J_c, at 77.3 K and 80 K for each specimen. The peak effect of J_c is appreciable in specimen 1 and slightly observed in specimens 2 and 3, while it is not seen in specimens 4 and 5 with much smaller particle sizes. Specimen 1 with the largest size shows the lowest J_c at low fields. The density of pinning sites is supposed not to be greatly different among the specimens. It is considered that the degree of flexibility of flux lines to meet pinning sites is higher for a specimen with the particle size smaller than the longitudinal correlation length, l_{44}, because the area in

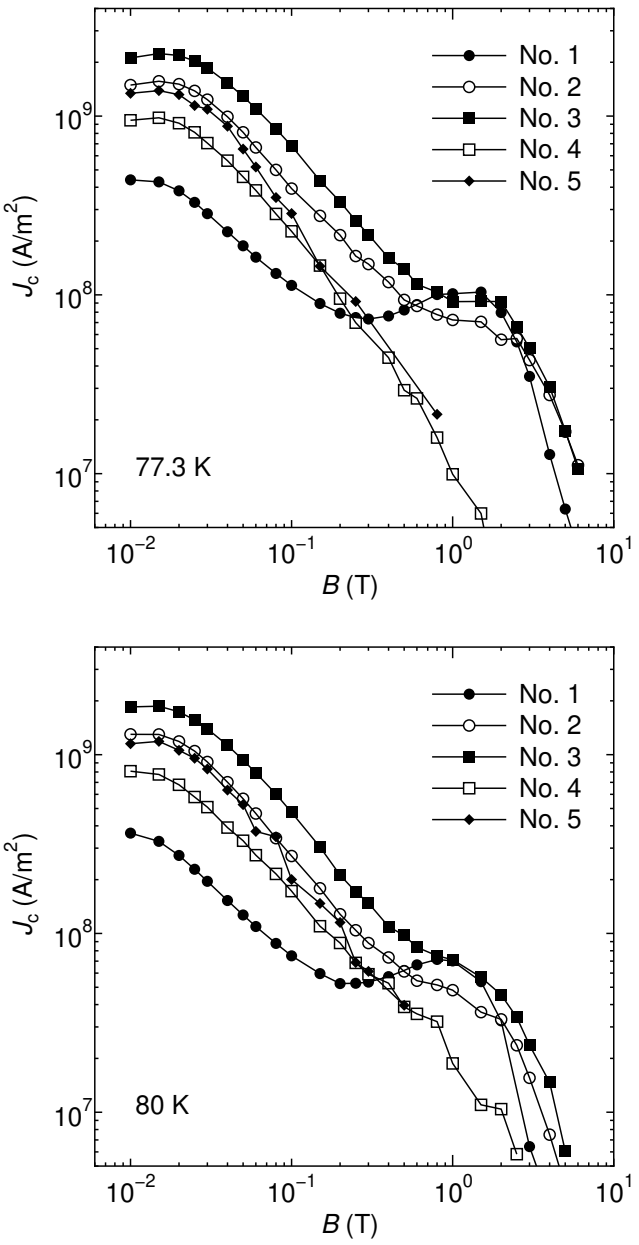

Fig. 1. Magnetic field dependence of the critical current density at 77.3 K and 80 K for each specimen.

which the interference among pinning forces takes place is limited by the particle size. Here, l_{44} is theoretically given by

$$l_{44} = \left(\frac{C_{44}}{\alpha_L}\right)^{1/2} \simeq \left(\frac{Ba_{\rm f}}{2\pi\mu_0 J_{\rm c}}\right)^{1/2}, \qquad (1)$$

where $C_{44} = B^2/\mu_0$ is the elastic tilt modulus of flux lines, $\alpha_{\rm L}$ is the Labusch parameter and $a_{\rm f}$ is the flux line spacing. This value can be estimated using observed results of $J_{\rm c}$.

The ratio of the average particle size $\langle d\rangle$ to l_{44} at 77.3 K and 1.5 T, where the peak effect is observed, is listed in Table 1. The obvious peak effect is observed only when $\langle d\rangle/l_{44}$ is enough larger than unity, while even an indication of the peak effect is not seen for specimens 4 and 5 in the opposite case. This result agrees with the prediction as abovementioned. That is, the enhancement of the critical current density in medium magnetic fields originates from the enhanced flexibility of the flux line lattice as predicted in [1]. This is consistent with the tendency that the specimen with smaller particle size has lower $J_{\rm c}$ at low fields. That is, the peak effect originates from the cooperative phenomenon associated with the transitional change in the state of flux lines, but not directly from the elementary pinning mechanism such as the field-induced pinning mechanism.

The irreversibility field, $B_{\rm i}$, is determined by the magnetic field at which $J_{\rm c}$ decreases to 10^7 A/m^2. It is found that the specimen with smaller particle size shows lower $B_{\rm i}$. This is attributed to the lower pinning potential. That is, the pinning potential, U_0, is given by

$$U_0 = \widehat{U}_0 V, \qquad (2)$$

where $\widehat{U}_0$ is the pinning energy density averaged over unit volume and V is the volume of the flux bundle [3]. In the above the volume is $V = l_{44}l_{66}^2$ when $d > l_{44}$, while it is restricted as $V = dl_{66}^2$ when $d < l_{44}$, where l_{66} is the transverse correlation length. Therefore, when d is small, the effect of the flux creep is pronounced, resulting in smaller $B_{\rm i}$.

IV. Conclusions

- The peak effect is only observed when the average particle size, $\langle d\rangle$, is larger than the correlation length, l_{44}. This shows that the enhancement of $J_{\rm c}$ is attributed to the enhanced flexibility of the flux line lattice, and supports the mechanism of the disorder transition of flux lines. At the same time it is concluded that the peak effect is not caused by the elementary field-induced pinning mechanism.
- The irreversibility field is smaller in the specimen with smaller particle size, since the pinning potential is restricted by the size of superconductor.

References

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