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Effect of damage morphology on the pinning and vortex dynamics in $Bi_2Sr_2CaCu_2O_{8+\delta}$ irradiated with GeV heavy ions

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Abstract

$Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) single crystals have been irradiated with swift heavy ions: 0.7 GeV ^{84}Kr, 3.8 GeV ^{181}Ta and 3.1 GeV ^{209}Bi. The critical current density, J_c, deduced from the DC magnetization measurement tends to increase with the size of columnar defects. The Bose-glass behavior is observed in vortex dynamics for 3.8 GeV ^{181}Ta or 3.1 GeV ^{209}Bi ion irradiation. For Kr irradiation, however, a deviation from the Bose-glass behavior occurs. Effects of damage morphology on the pinning and vortex dynamics are discussed.

Keywords: AC susceptibility; Irradiation; Bi-2212; Magnetization; Swift heavy-ion irradiation; Vortex dynamics; Vortex pinning

1. Introduction

Experiments of swift heavy-ion irradiation on high-T_c superconductors [1] show that the damage morphology evolves with the electronic stopping power dE/dx of irradiating ion. The defect evolves from elliptical defect located at intervals along ion path into columnar defect with increasing dE/dx. We study the effect of damage morphology on the pinning and vortex dynamics in high-T_c superconductor, $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) single crystals.

2. Experimental

Bi-2212 single crystals ($T_c \approx 90$ K) with thickness of 30 μm were irradiated at RIKEN Ring Cyclotron Facility. The direction of the ion beam was parallel to the *c*-axis of the specimen. The irradiation dose was $4\times10^{10}/\text{cm}^2$ corresponding to the dose-equivalent matching field B_Φ of 0.8 T. After the irradiation, T_c decreased to 87–88 K. In order to characterize the structure of irradiation-induced defects, transmission electron microscopy (TEM) observation was carried out with the view direction parallel to the ion tracks. To determine the critical current density, the DC magnetization measurements were performed by using a SQUID magnetometer. The temperature dependence of the AC magnetic susceptibility $\chi' - i\chi''$ was measured under the AC magnetic field $H_{AC}\sin(2\pi ft)$ with a low amplitude $H_{AC} = 0.5$ Oe and the external DC magnetic field B_{ex}. The relation between the frequency and the loss peak temperature (T_p) at which χ'' became maximum was investigated at $B_{ex} = 0.3\ \text{T} < B_\Phi$.

3. Results and discussion

Fig. 1 shows the statistical distribution of the radii of irradiation-induced defects for 0.7 GeV ^{84}Kr (dE/d$x \approx$ 1.4 keV/Å), 3.8 GeV ^{181}Ta (dE/d$x \approx 3.1$ keV/Å), and

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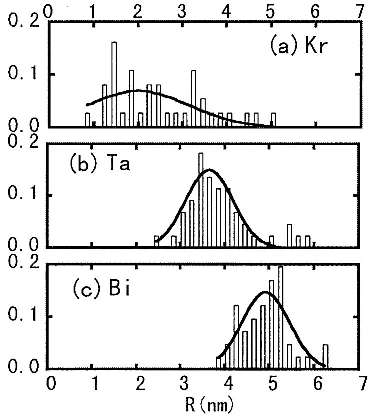

Fig. 1. The statistical distribution of the radii of irradiation-induced defects for (a) 0.7 GeV ^{84}Kr, (b) 3.8 GeV ^{181}Ta, and (c) 3.1 GeV ^{209}Bi.

3.1 GeV ^{209}Bi ($dE/dx \approx 4.1$ keV/Å) in an *ab*-plane. The radius of defect is 2.0 ± 1.2 nm for Kr, 3.6 ± 0.5 nm for Ta, and 4.9 ± 0.5 nm Bi. For Kr irradiation with $dE/dx \approx 1.4$ keV/Å, the observed radii of defects in an *ab*-plane widely distribute because of the strong fluctuation in the radius of defect along the ion path. On the other hand, the defect is a continuous column with almost uniform radius along the ion track for Ta or Bi irradiation. The critical current density, J_c, derived from the hysteresis loops using the Bean model tends to increase with the radius (size) of defect.

Fig. 2 shows the relation between frequency and T_p. The power-law behavior $f \sim (T_p - T_g)^n$ expected in the glass transition [2] was observed. The exponent $n = 4.3$ ($T_g = 68.7$ K) for the Bi irradiated specimen and $n = 3.9$ ($T_g = 67.5$ K) for Ta irradiated crystal. The values of n are close to the Bose-glass exponent $n \equiv [\nu'(z' - 2)]$ of 3.5–4.5 [3,4]. On the other hand, the value of n for Kr irradiation is 9.6 ($T_g = 60.2$ K), deviating from that of Bose-glass. The present result suggests that for the defects with strongly fluctuated radius, a different mechanism from Bose-glass has to be considered.

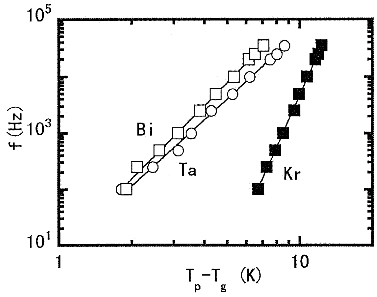

Fig. 2. Frequency versus $T_p - T_g$ on a log–log plot. (H_{AC}, $B_{ex}//c$).

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