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Flux pinning potential in Bi-2223 tapes irradiated by Xe ion

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Abstract

We have investigated the flux pinning potential of Ag–Cu alloy sheathed Bi-2223 tapes with columnar defects parallel to the *c*-axis introduced by Xe-ion irradiation. We measured the magnetic relaxation of the remanent. The sample was cooled in zero field and the field above H^*, where the flux front penetrated at the center of the sample. The time decay of the remanent moment was measured for about 10^5 s. The relaxation of the remanent moment showed the linear $\ln(t)$ dependence in all observed temperature range. The change in the distribution of the activation energies with irradiation was obtained. Since the deeper pinning center were increased, it is expected that the columnar defects will act as effective pinning centers. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

In the field of power applications it is necessary to fabricate superconducting materials with high critical current densities J_c. Higher J_c is in general achieved by increase in the flux pinning energy in superconductors. However, in the high-T_c cuprate superconductors large flux creep effect in the magnetization has been reported [1]. Therefore we have to clarify the origin of pinning mechanism in the high-T_c superconductors. As a first step we introduced columnar defects in the Bi-2223 tapes parallel to the aligned *c*-axis (normal to the tape surface) by Xe-ion irradiation and measured the distribution of the flux pinning energy [2]. In the present paper we studied pinning energy distribution for the Bi-2223 tapes with columnar defects by Xe-ion irradiation.

2. Experimental

The Ag–Cu alloy sheathed tapes were prepared by the powder-in-tube method. Ag–Cu alloy sheaths in this study were filled with the Cu-poor Bi-2223 powder, since copper atoms were expected to diffuse into inner oxide core from the outer Ag–Cu alloy sheath. We have introduced

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Hf elements in the Ag–Cu alloy sheathed Bi-2223 tapes, which result in the improvement of the transport J_c. The details of the preparation method, and the fundamental properties of the samples were reported elsewhere [3]. Bi-2223 tapes with typically $3.0 \times 3.0 \times 0.1$ mm^3 were irradiated with 3.5 GeV $^{163}Xe^{31+}$ ion at the RIKEN ring cyclotron facility to introduce columnar defects along perpendicular to the tape surface direction. The total pin density was estimated to be 7.2×10^{10} cm^{-2}, which corresponded to a dose-equivalent matching field of $B_\phi = 1.4 \pm 0.2$ T. This type of irradiation has produced continuous amorphous tracks with the diameter of ≈6 nm throughout the thickness of the Bi-2223 sample. We estimated sample qualities using X-ray diffraction measurement and high-resolution transmission electron microscope. We confirmed that the Hf atoms were substituted for 0.5–1% of Sr by high-resolution analyzed electron microscopy (HRAEM) [4]. The magnetic properties were measured by using a superconducting quantum interference device (SQUID) magnetometer. Pinning potentials were estimated from the decay profiles of the remanent magnetic moment for the unirradiated and irradiated Bi-2223 tape samples. In magnetic relaxation measurement we adopted the following process: The magnetic field was initialized to zero (about 20 μT); then the sample was loaded at the measurement temperature; after the zero-field cooling, the magnetic field applied ($H = 1$ T), and the relaxation of the magnetization was measured for about 10^5 s. The magnetic field was applied perpendicular to the wide surface of the tape.

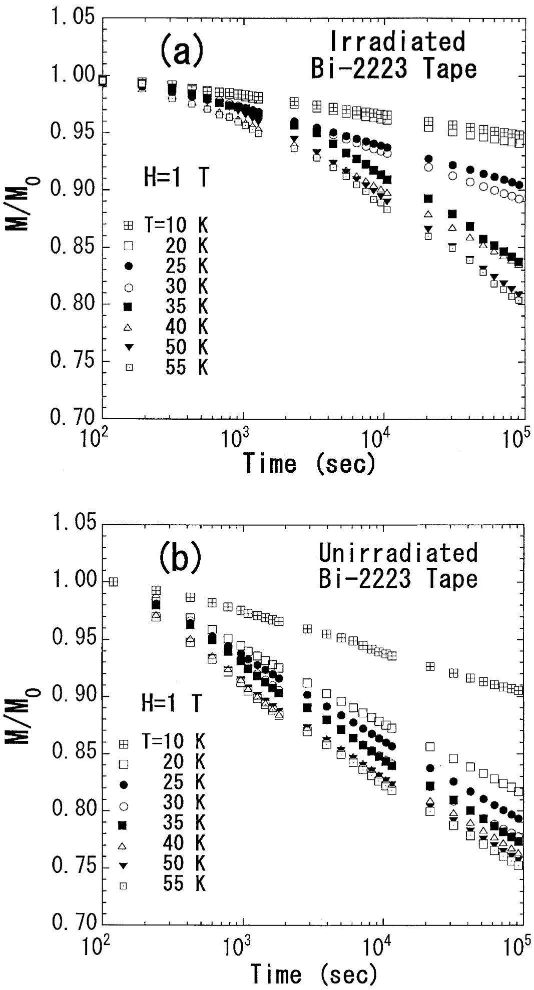
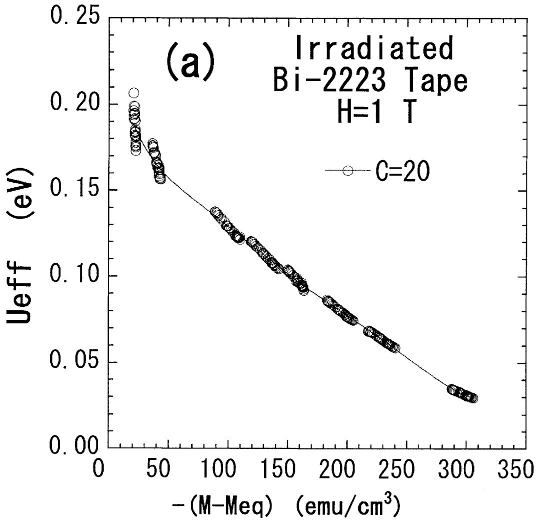


Fig. 1. Magnetic relaxation measured of various temperature at 1 T for (a) the irradiated Bi-2223 tape and (b) the unirradiated ones.

3. Results and discussion

The relaxation of the remanent moment for the irradiated and unirradiated samples shown the linear $\ln(t)$ dependence in all observed temperature range as shown in Fig. 1(a) and (b). In order to study the effects of temperature and irradiation on flux creep, the magnetization M is normalized to the initial magnetization M_0. It is clearly seen that the slope of M/M_0 versus $\ln(t)$ decreases the relaxation rate for the irradiated Bi-2223 tape samples. This result shows the critical current density (J_c) is possible to be improved in all temperature range with the irradiation. The standard model for flux creep in superconductors proposed by Anderson [5] has been used to analyze data on high temperature superconductors. We use the model due to Maley et al. [6] to analyze the data. Using the rate equation of Beasley, Labusch and Webb [7]: $\mathrm{d}M/\mathrm{d}t = (B\omega a/\pi d)\exp(-U_{\mathrm{eff}}/kT)$, where ω and a are the hop frequency and distance for a flux bundle, and d is the grain diameter. This leads to the expression $U_{\mathrm{eff}}/k = -T[\ln(\mathrm{d}M/\mathrm{d}t) - \ln(B\omega a/\pi d)]$ for the effective pinning potential. Here we have estimated the value of the constant $C = \ln(B\omega a/\pi d)$ empirically by plotting the data as U_{eff}/k versus M at each temperature for the irradiated and unirradiated Bi-2223 tape samples and adjusting C to obtain the smoothest curve. The constant values are $C = 20$ for irradiated case and $C = 25$ for unirradiated ones as shown in Fig. 2(a) and (b). The value implies physically reasonable values. It is considered that difference of the C behavior between the irradiated and unirradiated case comes from the difference of the induced defect structure with the irradiation. In the case of the irradiation, since it produces columnar defect (amorphous tracks with the diameter of ≈6 nm), which yield a quite large pinning energy of high temperature superconductors for vortices parallel to the defects.



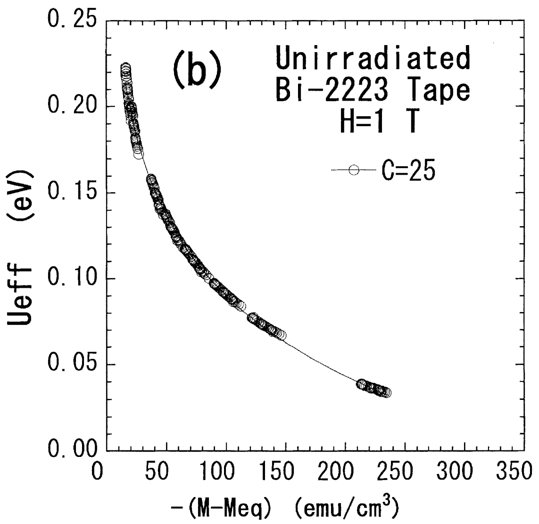


Fig. 2. The effective pinning potential U_{eff} as obtained from the nonlinear equations for flux creep versus the magnetization M for (a) the irradiated Bi-2223 tape and (b) the unirradiated ones.

4. Conclusion

We observed the pinning energy distribution for the unirradiated and irradiated Bi-2223 tape samples. Using the Maley's expression to analyze the data, the change in the distribution of the activation energies with irradiation was obtained. Since the deeper pinning center were increased, it is expected that the columnar defects will act as effective pinning centers.

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