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Physica C 357–360 (2001) 501–504

PHYSICA C

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Pinning properties of quenched and melt growth method-YBCO bulk samples

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Received 16 October 2000; accepted 26 January 2001

Abstract

A comparison between two different irradiation effects was accomplished on bulk YBCO samples synthesized with the quenched and melt growth method (QMG-YBCO) to investigate strong pinning properties. High-energy proton-irradiation introduces small defects comparable to unit cell size into the sample, and they act as effective pinning centers for all temperature range in low field around 1 T. No enhancement, however, can be seen in higher field range. The defects introduced with the irradiation reinforce the pinning properties of preexisting pinning centers randomly distributing in the sample. Column-like defects with 3.5 GeV Xe-irradiation were introduced but the pinning properties show no significant enhancement except higher temperature region. This indicates that pre-existing pinning centers are strong enough than the columnar defects. In higher field region, the contribution of columnar defects for pinning becomes relatively large. For both irradiation cases, almost pinning properties are determined by the pre-existing pinning centers. © 2001 Elsevier Science B.V. All rights reserved.

PACS: 74.72.Bk; 74.60.Ec; 74.60.Ge

Keywords: Quenched and melt growth method; YBCO; Ion irradiation; Pinning properties

1. Introduction

For high-T_c superconductors, three different energies, such as pinning, vortex interaction, and thermal fluctuation, are very close. And these materials show very complicated phase diagram of mixed state. For applications of high-T_c superconductors, it is important to know the relation among the vortex matters and pinning centers. We investigated the irradiation effects on pinning introducing two different pinning centers.

2. Experiments

Samples were synthesized with the quenched and melt-growth method (the QMG-method) in Advanced Research Institute, Nippon Steel Co. They contain Y211 small inclusions ($d \sim 1$ μm) up to 30 mol%. Samples were cut into small pieces for

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PII: S0921-4534(01)00306-9

each irradiation. Ion irradiation with 30 MeV-protons was accomplished at the Tandem Accelerator in JAERI. The irradiation dose was 1×10^{16} ions/cm^2. Irradiation with 3.5 GeV-Xe ions was also carried out at the Ring Cyclotron Facility in RIKEN. The irradiation dose was 1×10^{11} ions/cm^2 (corresponding matching field $B_\phi = 2$ T). Pinning properties, such as magnetizations, critical current densities, long-time magnetization decays, were measured with a commercial SQUID and a usual magnetometer (MPMS and PPMS, Quantum Design).

3. Results and discussion

Critical current densities (J_c) after proton irradiation are enhanced for all temperature range at around 1 T field region. Effective activation energies are also enlarged around 1 T [1,2]. On the other hand, no significant change on J_c can be observed for the Xe-irradiated sample [3]. For the Xe-irradiated case, a curious recovery of magnetization around 60 K can be observed on long-term magnetization decay measurements above the matching field region. This can be considered the change of pinning host from the inclusions to the columnar defects at that temperature range.

It is known that two empirical power-laws are valid for high-T_c superconductors [4]; one is the relation between the irreversibility temperature and the irreversibility field, and the other is that between the irreversibility field and the maximum value of the pinning force. The former can be expressed as $H_{irr} = A(1 - T_{irr}/T_c)^\alpha$, and the latter as $F_{p\text{-max}} = BH_{irr}^\beta$, where A and B are the fitting constants and α and β are the powers obtained from the fitting. Fig. 1 shows the two power-laws above 60 K. The relations mentioned above are valid for each case, unirradiated, proton-irradiated and Xe-irradiated, respectively. Another empirical relation for field dependence of the pinning force is also known as $F_p/F_{p\text{-max}} = Cb^\gamma(1 - b)^\delta$, where C is a normalized constant and $b = B/\mu_0 H_{irr}$. Combining these relations, we can derive the following formula for the pinning force as $F_p = CBA^\beta(1 - T_{irr}/T_c)^{\alpha\beta} b^\gamma (1 - b)^\delta$. Using the result of Fig. 1 and choosing appropriate γ and δ, we can calculate the pinning forces and compare them with the data. Fig. 2 shows the result. The agreement is excellent except the regions around the second peak (for unirradiated one). For all cases, the powers of b (field dependence) below $F_{p\text{-max}}$ are almost 1. The powers of $(1 - b)$ are 3–4 for unirradiated and p-irradiated case. Furthermore, agreement between measured data and fitted values are also good enough below 60 K using the same fitting parameters

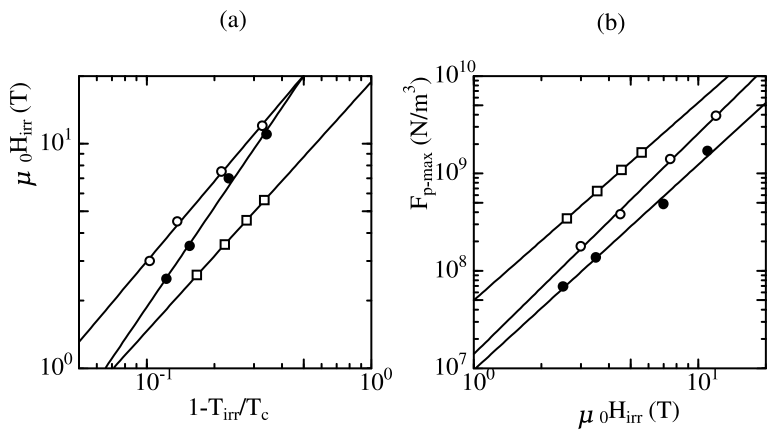

Fig. 1. Two power-law relations; (a) between the irreversibility fields (H_{irr}) and the irreversibility temperature (T_{irr}), (b) between the maximum values of pinning forces ($F_{p\text{-max}}$) and the irreversibility fields (H_{irr}). All data were taken above 60 K. Symbols: (●) are for unirradiated case, (○) are for proton-irradiated case, and (□) are Xe-irradiated case, respectively.

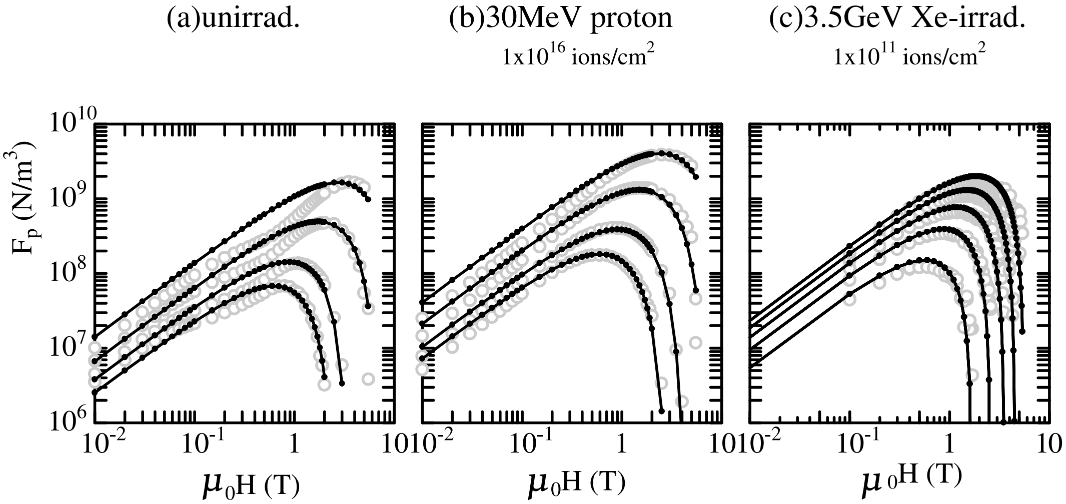

Fig. 2. Comparison between the measured data and calculated values using the formula $F_p = F_{p\text{-max}} b^{\gamma}(1-b)^{\delta}$ above 60 K; (a) unirradiated sample, (b) 30 MeV proton irradiated sample, (c) 3.5 GeV Xe-irradiated sample, and temperatures are 60, 70, 77 and 80 K, respectively. Large open circles are measured data and small solid circles are the fitting results. The fitting parameters were taken from the results of Fig. 1. The value of γ is 1 for all cases, and δ is 4 for (a) and (b), but 2 for (c). This indicates the pinning host is different at the temperature range for the Xe-irradiated sample from others.

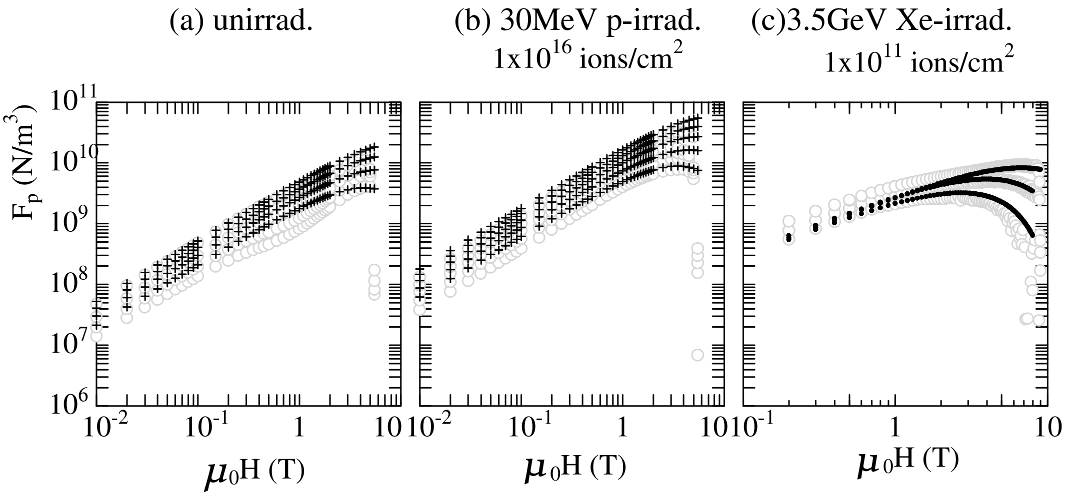

Fig. 3. (a) and (b): An extension of the fitting below 60 K using with the same parameters of Fig. 2, large open circles are measured data and crosses are the fitting results at 10, 20, 30, 40, and 50 K. The fittings are good for the both. (c): other possible fittings derived from low temperature data (see Ref. [2]). Large open circles are measured data and small solid circles are the fitting results at 30, 40, and 50 K. The power of $(1-b)$ changes from 2 above 60 K to 4 below 60 K. This indicates that pinning properties change below and above 60 K due to the change of pinning hosts.

above 60 K for unirradiated and proton-irradiated cases (Fig. 3). Parameters obtained at higher temperature range are valid even at lower region. This suggests that pinning properties does not change essentially for both two cases. Randomly distributed pinning centers govern the pinning.

The sample irradiated Xe-ions shows a different property of F_p. The power of $(1 - b)$ is 2 above 60 K, but it changes to almost 4 below 60 K. This may indicate that the dominant pinning host changes around this temperature. Pinning centers change from Y211 inclusions (dominants at lower temperature) to the columnar defects (dominant at higher temperature). This is consistent with the result of long-term decays.

Acknowledgements

The authors would like to thank to Dr. H. Teshima in Nippon Steel Co. for preparation the QMG samples. We also thank Dr. A. Nakamura in JAERI for our SQUID measurements. This work was supported by the MULTICORE project organized by the Science and Technology Agency in Japan.

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