Influence of the columnar defect densities on the current-voltage characteristics in high-T_c superconducters

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Abstract

We investigated the influence of columnar defect densities on the critical exponents estimated from the critical scaling analysis of the current-voltage characteristics in high-T_c superconductors. It was found that the dynamic critical exponent z increased with increasing columnar defect densities, systematically. The peak of z was observed near the magnetic field $B/B_\Phi = 1/3$. These results are explained by the depinning model considering the distribution of the pinning strength rather than the voltex glass model.

Key words: Columnar defects; Vortex glass; Critical exponents; Matching field

1. Introduction

The current-voltage characteristics in high-T_c superconductors are very important properties for both the physical interestings and the technological applications. Especially, it is well known that a set of isothermal current-voltage curves collapes on two master curves above and below the vortex-glass transition temperature T_g, when plotted as $(E/J)/|T-T_g|^{\nu(z-1)}$ versus $J/|T-T_g|^{2\nu}$, where z and ν are the dynamic and static critical exponents, respectively [1]. This fact has been explained by the vortex-glass model [2], in which the critical exponents estimated from the critical scaling analysis are interpreted as the universal behavior which does not depend on the pinning strength itself. On the other hand, the scaling collapse of current-voltage curves can be also described by the percoration model [3], in which the pinning strength distribution are taken into account. In this model, the critical exponents depend on the pinning properties. The experimental results to support this model have been reported, recently [4,5]. The main difference in the both models is the physical meanings of critical exponents. Therefore, the useful method to clarify the mechanism of the scaling collapse is to compare for the samples with each different pinning properties. Introduction of the columnar defects by the heavy-ion irradiation is the best way for the control of the pinning properties. In this study, we investigated the influence of the columnar defect densities on the critical exponents estimated from the current-volatge characteristics in $YBa_2Cu_3O_{7-\delta}$ thin films.

2. Experimental procedure

We prepared two $YBa_2Cu_3O_{7-\delta}$ thin films by a laser abration technique on $SrTiO_3$ substrates. On each thin film, two microbridges were defined by the chemical etching process in order to discuss the influence of columnar defect densities on scaling parameters without the consideration of background effect. Irradiation

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with 200MeV ^{197}Au ions were performed along their c-axis from a tandem accelerator at JAERI. We prepared two substrates that have two microbridges respectively. One substrate has unirradiated and irradiated (B_Φ=1.5T) microbridges, the other has two irradiated samples (B_Φ=0.4T and B_Φ=1T). The current-voltage characteristics were measured by the standard four probe method in which the current applied in the direction perpendicular to the applied magnetic field, the c-axis, and the columnar defects. The critical exponents were estimeted from the scaling analysis of the current-volatage characteristics under the magnetic field.

3. Results and discussion

In Fig.1, we compare the dynamic critical exponent z between unirradiated and B_Φ=1.5T irradiated samples, which are prepared on the same substrate. It is found that the values of z for the irradiated sample is larger than thoes of unirradiated one. Furthermore, it is interesting that the peak appears in the magnetic field dependencs of z near the field B/B_Φ=1/3 for irradiated sample, while the unirradiated one exhibits no peak. Fig. 2 shows the comparison of the values of z with two samples, which have different densities of columnar defects (B_Φ=0.4T and B_Φ=1T). These samples also lie on the same substrate. It is clarified that the values of z increase with increasing the densities of columnar defects. For the B_Φ=1T sample, the peak is also obserbed near B/B_Φ=1/3.

In the vortex glass model [2], the universality of the critical exponents is predicted. However, our results are incompatible to this prediction. Especially, the appearence of the peak of z near B/B_Φ=1/3 could not explained even by the shift from the Bose glass behavior [6] to vortex glass one with increasing magnetic field.

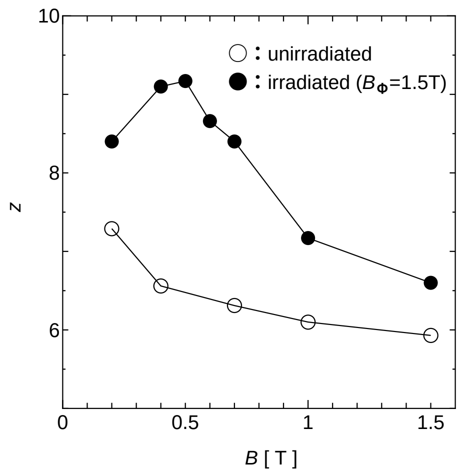

Fig. 1. Comparison of the dynamic critical exponet z between unirradiated (open square) and B_Φ=1.5T irradiated sample (closed one).

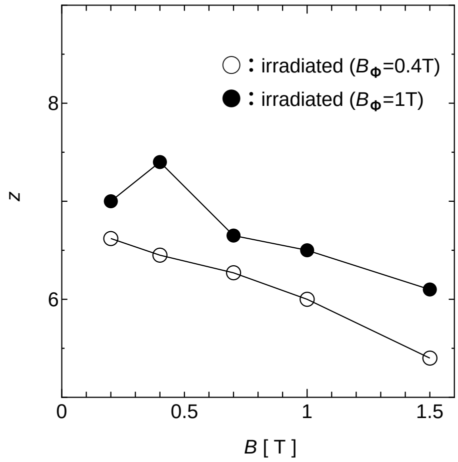

Fig. 2. Comparison of the dynamic critical exponet z between B_Φ=0.4T (open circle) and B_Φ=1T irradiated sample (closed one).

According to the percoration model [3], on the other hand, the dynamic critical exponent z is related to the parameter m determining the shape of the local critical current density ($J_{\rm cl}$) distribution. The parameter m increases with the weakening of the relative elastic correlation strength of vortices, which means that the shape of the distribution of $J_{\rm cl}$ tends to steep [7]. Therefore, one of our results, i.e. the increment of z is considered to arise from the variation of distribution of $J_{\rm cl}$ due to the introduction of each different density of the columnar defects. The peak of z near B/B_Φ=1/3 could be corresponding to uniforming the distribution of $J_{\rm cl}$ due to the matching effect. Therefore, the scaling collapse of the current-voltage characteristics in high-$T_{\rm c}$ superconductors could be originated from the percoration network of the unpinned domains in the presence of the pinning strength distribution.

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