SCALING OF CURRENT-VOLTAGE CHARACTERISTICS IN SUPERCONDUCTING Bi-2212 SILVER-SHEATHED TAPE WIRES

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ABSTRACT

The scaling of current-voltage characteristics is investigated for a two-dimensional silver-sheathed Bi-2212 tape wire under the magnetic field parallel to the c-axis. It is found that the current-voltage curves are approximately scaled on two master curves by normalizing as predicted in the scaling theory. The results are compared with the theoretical analysis based on the flux creep-flow mechanism in which the distribution of flux pinning strength is taken into account. It is found that the theoretical result approximately explains the experimental result on the scaling behavior and the transition line. A discussion is given on the dynamic critical index.

KEYWORDS: scaling of current-voltage curve, vortex glass-liquid transition, critical index, flux creep, flux flow, Bi-2212 superconductor

INTRODUCTION

It is known that the current-voltage curves of high temperature superconductor meet on two master curves when those are normalized by a proper function of temperature [1, 2]. Such a scaling behavior is predicted by the vortex glass-liquid transition theory [3]. However, a similar scaling can also be derived from the mechanism of flux creep and flow [4-6]. In addition, the transition line and the two critical indices of a Bi-2223 tape wire were well explained by this mechanism in which the effect of distributed flux pinning strength was taken into account [7] However, the obtained dynamic critical index, z, was smaller than usual values of z for two-dimensional flux line systems. In this paper the scaling of current-voltage curves is investigated for a more two-dimensional Bi-2212 superconductor and a silver-sheathed tape wire is chosen for the specimen. The results are compared with the theoretical analysis based on the flux creep-flow model. The results are discussed with comparing the obtained critical indices with those of a dip-coated Bi-2212 tape wire [8].

EXPERIMENTS

The measured specimen was a Ag-sheathed Bi-2212 tape wire. Its size was about, 4.7 mm wide, 0.25 mm thick and 37 mm long and the thickness of the superconducting region was approximately 10 μm. The c-axis of the specimen was oriented normal to the flat surface of the tape. The critical temperature, T_c, was 90.0 K. The current-voltage curves were measured by the four probe method under the magnetic field parallel to the c-axis. The pulse transport current with the period of 3 s was applied to the specimen to reduce the joule heat at the current leads and the voltage was measured across the voltage terminals separated by 1.0 cm. After the measurement of the current-voltage curves of the specimen, the superconducting layer was broken and the resistivity of the silver layer only was measured. This was needed for the evaluation of the current-voltage characteristics only of the superconducting region. The critical current density at sufficiently low temperatures was also measured, since the information on the flux pinning strength is necessary for the theoretical analysis based on the flux creep-flow model. For this purpose a SQUID magnetometer was used.

Figure 1 shows the results of scaled current-voltage curves at B=0.5 T. Although only two curves were measured because of large transport current below T_g, a rather good scaling was obtained. The obtained scaling parameters are T_g=30 K, z=13.1 and ν=0.85. The transition line and the static and dynamic critical indices are represented in Figs. 2, 3 and 4, respectively. The

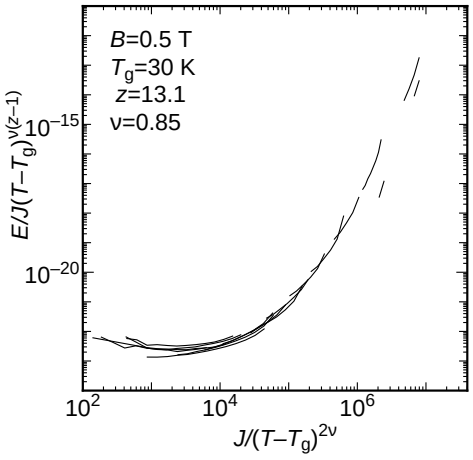

Fig. 1. Scaled current-voltage curves at $B = 0.5$T.

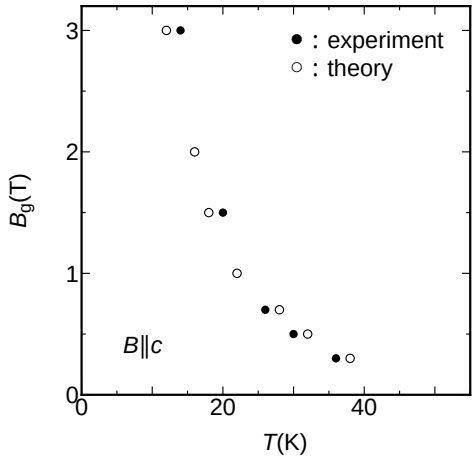

Fig. 2. Experimental(●) and theoretical(○) results of transition line.

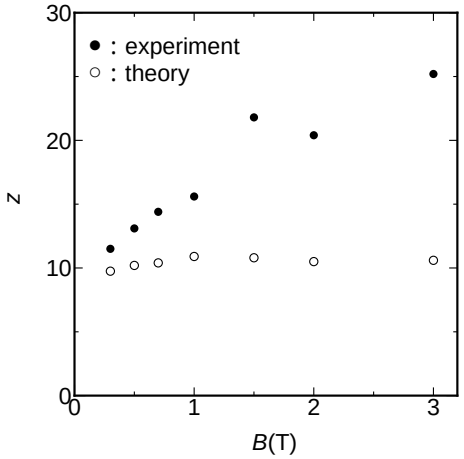

Fig. 3. Experimental(●) and theoretical(○) results of dynamic critical index, z.

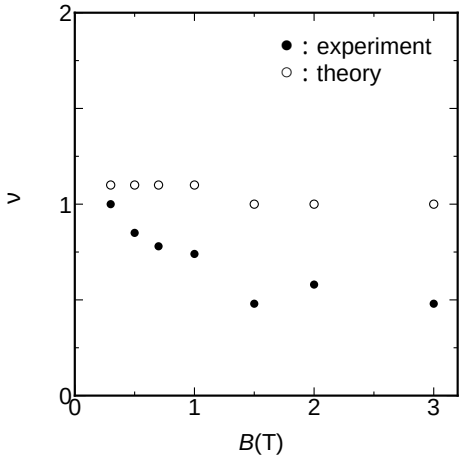

Fig. 4. Experimental(●) and theoretical(○) results of static critical index, ν.

two indices are found to vary with magnetic field. Figure 5 shows the critical current density determined using the electric field criterion of 1.0×10^{-4} V/m.

FLUX CREEP-FLOW MODEL

In the flux creep-flow model the current-voltage curves can be calculated using the pinning potential which is expressed using the virtual critical current density, J_{c0}, in the creep-free case. The detail of the analysis is described in [6]. We assume the following temperature and magnetic field dependences of J_{c0}:

$$J_{c0} = A\left[1 - \left(\frac{T}{T_c}\right)^2\right]^m B^{\gamma-1}\left(1 - \frac{B}{B_{c2}}\right)^\delta, \tag{1}$$

where A, m, γ and δ are the pinning parameters. It is considered that the flux pinning strength is distributed in practical superconductors [6]. For simplicity, we assume that only A in Eq. (1) is distributed in the form:

$$f(A) = K\exp\left[-\frac{(\log A - \log A_m)^2}{2\sigma^2}\right], \tag{2}$$

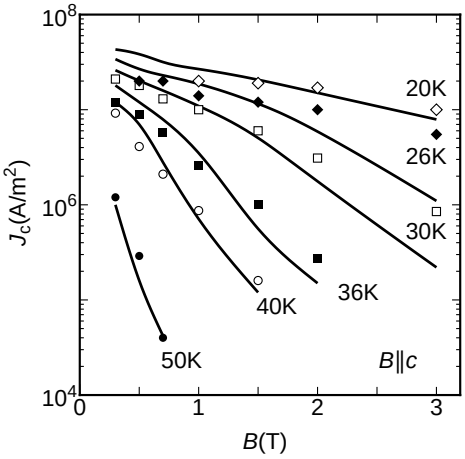

Fig. 5. Experimental(solid symbols) and theoretical(lines) results of critical current density.

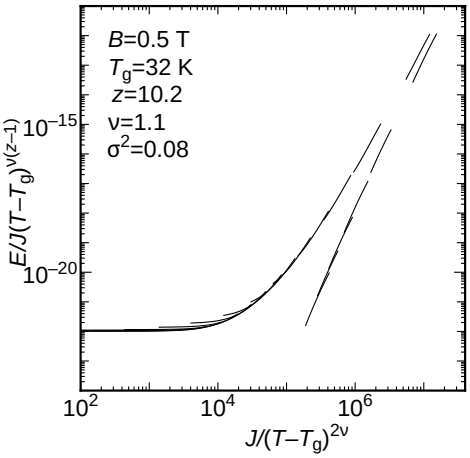

Fig. 6. Calculated scaled characteristics at $B = 0.5$T.

where $A_{\rm m}$ is the most probable value, K is a constant determined by the condition of normalization and σ^2 is a constant representing the degree of deviation.

The parameters used in the numerical calculation are; $B_{\rm c2\|}(0) = 34.5$ T, $\rho_{\rm n}(T_{\rm c}) = 100$ $\mu\Omega$m, $A_{\rm m} = 5.1 \times 10^8$, $m = 3.9$, $\gamma = 0.90$, $\delta = 2.0$, $g^2 = 1.0$ and $\sigma^2 = 0.08$. The above g^2 is estimated at 40 K and 1.5 T and this value is used within the entire region of temperature and magnetic field in the analysis. The pinning parameters and σ^2 are determined so that a good fit is obtained between the experimental and theoretical values of the critical current density. The experimental and theoretical $J_{\rm c}$ values are compared in Fig. 5. It is seen that agreement is fairly good. Hence, the numerical analysis is carried out using the above parameters.

DISCUSSION

Figure 6 shows the scaled results of numerical calculation. The obtained scaling parameters are $T_{\rm g} = 32$ K, $z = 10.2$ and $\nu = 1.1$. Comparing these results with the experimental results shown above, it is found that the scaling is similar although the scaling parameters are slightly different. The obtained transition line, dynamic and static critical indices are compared with the experimental results in Figs. 2, 3 and 4 respectively. The agreement is good for the transition line. Although the theoretical values of z and ν agree with the experimental values at low fields and explain the trend, the disagreement is enhanced with increasing field.

The numerical analysis [6] shows that z increases and ν decreases with decreasing deviation. If the deviation of the flux pinning strength becomes smaller at lower temperatures, the tendency of experimental results in Figs. 3 and 4 can be explained. The distribution of the pinning strength may be ascribed to the distribution of the critical temperature. Hence, the above speculation seems to be natural, since the temperature margin, i.e., the difference between the critical temperature and the ambient temperature becomes relatively smaller at lower temperatures. Thus, the disagreement seems to be ascribed to the assumption of the constant σ^2 in the analysis.

The values of z and ν for the silver-sheathed Bi-2212 tape wire are compared with those for a dip-coated Bi-2212 tape wire in Figs. 7 and 8, respectively. When we assume $d = 3$ for the dimensionality of the flux line system, the z value for Bi-based superconductors is reported to be in the range of 12-13. However, z in the silver-sheathed tape wire at high magnetic fields is much larger than this prediction, and z in the dip-coated tape wire is too small. Hence, z is not a quantity inherent to the superconductor, i.e., to the dimension of the flux line system. On the other hand, z is expected to be largely influenced by the inhomogeneity as abovementioned. In fact, $\sigma^2 = 0.08$ is used in the present analysis for the silver-sheathed tape wire and $\sigma^2 = 0.70$ was used for the dip-coated tape wire [8]. This suggests that the scaling of the current-voltage curves

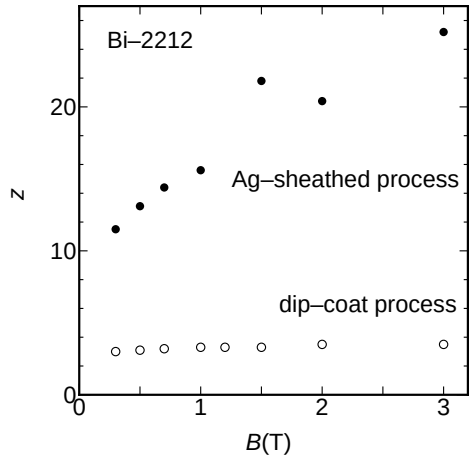

Fig. 7. Magnetic field dependence of dynamic critical index, z. Solid and open symbols represent the results of Ag-sheathed tape and dip-coated tape [8], respectively.

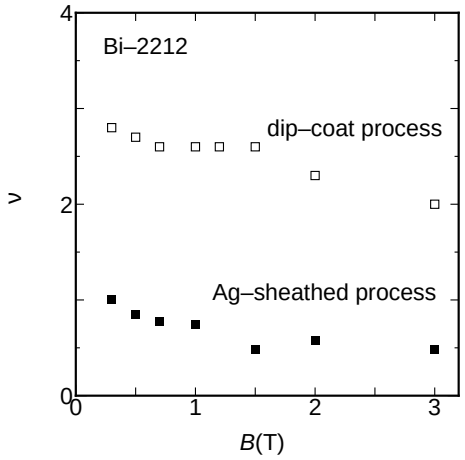

Fig. 8. Magnetic field dependence of static critical index, ν. Solid and open symbols represent the results of Ag-sheathed tape and dip-coated tape [8], respectively.

does not mean the occurrence of the vortex glass-liquid transition.

CONCLUSION

The scaling of the current-voltage curves is investigated for a Bi-2212 tape wire. The results are compared with the analysis based on the flux creep and flow model with taking account of the distributed pinning strength. The following results are obtained:

1. The scaling of the current-voltage curves and the transition line are well explained by the theoretical model of flux creep and flow.
2. Although the theoretical values of z and ν agree with the experimental values at low fields, the disagreement is enhanced with increasing field. This seems to be ascribed to be the distribution of the flux pinning strength.
3. The obtained z value exceeds 20 at high fields and is larger than the predicted value of the vortex glass-liquid transition theory, while the z value in the dip-coated tape wire is much lower than the prediction. This suggests that z is not a quantity inherent to the superconductor, i.e., to the dimension of the flux line system. It is expected that z is determined by the inhomogeneity.
4. It is considered from these points that the scaling of the current-voltage curves does not originate from the vortex glass-liquid transition.

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