Decay Rate Measurement of Magnetization and Transport Properties in Bi-2212 Single Crystal

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ABSTRACT

Measurement of decay rate of magnetization was performed as a function of temperature for Bi-2212 single crystal which was grown by TSFZ method. Normalized decay rate increases monotonically with increasing temperature, and does not have such plateau region as reported for YBCO. According to the Hagen and Griessen's inversion scheme, we calculated the distribution of pinning potential, and obtained a narrow distribution centered around 40 meV. This result can explain consistently other properties of Bi-2212 single crystal.

KEY WORDS: Bi-2212 single crystal, decay rate of magnetization, pinning potential, distribution of pinning energy

INTRODUCTION

Extensive efforts have been concentrated on the study of critical current density (Jc) of the high-temperature superconductors (HTSCs) because of the technological and scientific importance. Because of the extremely short coherence length in HTSCs, weak-link has been the major obstacle for increasing Jc in HTSC-materials.[1] In fact, higher Jc has been achieved at 4.2K for the samples which have better crystallographic quality.[2,3,4] However, Jc decreased rapidly with increasing temperature in these materials. It is now of common knowledge that it is necessary to introduce artificial pinning centers to make possible applications at 77K.

Many researchers are continuing to make their effort to find out available pinning centers. Murakami et al. succeeded in introducing artificial pinning center in YBCO by the MPMG process.[5] Pinning energy can be estimated by the measurement of magnetization decay. The literature on magnetic relaxation of high-temperature superconductors is extensive, and most of all these experiments were done for YBCO materials.[6,7,8] According to the normalized decay rate analysis, Malozemoff asserted that the flux-creep relaxation-rate data could be classified into four temperature regimes.[7]

In case of Bi-based materials, report on magnetic relaxation is not so extensive as compared to Y-based materials. Present authors observed very high critical current density at 4.2K and obtained small pinning potential about 10 meV for Bi-2212 single crystal.[9] Based upon the flux-annealing method experiment, small distribution of pinning potential was infered. Introduction of artificial pinning centers to Bi-based materials will be the important subject for the future investigation. Therefore, it is important to investigate pinning characteristics for bare materials which have no intentional pinning. In the present paper, we report on the measurement of magnetization-decay, and discuss the distribution of pinning potential in Bi-2212 single crystal.

EXPERIMENTAL PROCEDURES

The Bi-2212 single crystal were grown by the travelling solvent floating zone (TSFZ) method which is described in Ref.10 in details.[10] The sample is a plane with thickness about 30μm along the c-axis and area about 2.4mm x 4.6mm parallel to the a-b plane that was cut off from the bulk crystal. The critical temperature of this sample was 86K.

Magnetization was measured using a vibrating sample magnetometer (VSM). In this apparatus, maximum magnetic field 6T is applicable, and temperature can be changed from 4.2K to room temperature. In case of the present measurement, temperature was changed from 4.2K to about 30K within the accuracy of 0.1K. Since the Jc decreases rapidly with increasing temperature and then temperature-instability affects very much to the decay rate, this temperature stability during the measurement is very important condition. Although the angle between magnetic field and sample can be changed in our system, magnetic field was applied perpendicular to a-b plane of the crystal. The angle can be controlled within the accuracy of 1 degree. Two types of measurements were performed as; decay rate measurement at various temperatures and so-called flux annealing experiment.

RESULTS AND DISCUSSION

Results of decay of magnetization at several different temperatures are shown in Fig.1. These measurements were performed as follows. After stabilizing temperature to desired value, we applied magnetic field higher than the twice of saturation field, then decreased to zero field. Just after the magnetic field decreased to zero, decay of the magnetization started to measure. These procedures assure that the present decay corresponds the decay exactly from the critical state. As shown in this figure, decay rate increases with increasing temperature. The almost linear dependence of normalized magnetization on to logarithm of time suggests the activation of flux lines from pinning sites.

Figure 2 shows the normalized decay rate at t=100s as a function of temperature. As shown in this figure, there is no plateau region that was reported for YBCO as suggesting vortex glass state. And whole picture can be interpreted as shifted to lower temperatues compared to YBCO.[7] If we assume that each pinning center has the same pinning energy U(T) and flux moves by thermal activation, normalized decay rate S is given by,

$$S = \frac{d\ln M}{d\ln t} = \frac{dM}{M d\ln t} = -\left[\frac{U(T)}{kT} - \ln\left(\frac{t}{t_{eff}}\right)\right]^{-1}$$

where t is the observation time and t_{eff} is a effective attempt time for flux movement.[7] Though this equation well explains time dependence of magnetization decay, it does not follow the expected temperature dependence.

Figure 3 shows the result of flux annealing measurement. In this case, measurement was performed as follows; the sample was cooled to 5.8K in zero magnetic field, then magnetic field was increased to 2T, decay measurement was started right after magnetic field reached to maximum. Continuing decay measurement, sample was quenched to 4.2K at t=550s. It took about 30s for quenching. As seen in the figure, slope of magnetization decay rapidly changes. This is based on the idea as follows. If the distribution of pinning potential exists, decay after the quench will be different from that of without quench. Because, in case of quench from higher temperature to 4.2K, weak pinning will be already relaxed before the quench due to higher thermal activation, and on the other hand, weak pinning will remain in case of the temperature fixed at 4.2K.

Figure 4 is the expanded graph of Fig.3, where time scale is transfered as t'=t+7050, and normalized magnetization was multiplied by 0.897 taking into account the temperature dependence and time dependence of magnetization.[9] As shown in Fig. 4, Quenched datum shows somewhat smaller slope than continued decay-line of 4.2K without quench (denoted by broken line). This result suggests the presence of distribution of pinning potential.

Hagen and Griessen have given the expression of magnetization for a superconductor consisting of a collection of regions with different activation energies as follows.[8]

$$M(t,T)=M_0\frac{b(T)}{a(T)}\int_{Eo^*(t,T)}^{\infty} m(E^*)\left[1-\frac{kT}{E^*b(T)}\ln\left(1+\frac{t}{t_{eff}}\right)\right]dE^*$$

Inverting this equation, the distribution function m(E) is expressed as follows.

$$m(E_0^*(t_b,T))=\left[\frac{d}{dT}\left\{\frac{a(T)}{M_0b(T)}\left[\ln\left[\frac{t_b}{t_{eff}}\right]\left[\frac{dM}{d\ln t}\right]-M\right]\right\}\right]\left[\ln\left[\frac{t_b}{t_{eff}}\right]\frac{d}{dT}\left[\frac{kT}{b(T)}\right]\right]^{-1}$$

Since our experiment was done far below the Tc, we can take a(T) and b(T) to be unity in good approximation.[8] The calculated distribution is shown in Fig.5 by solid curve. For the comparison, the data for YBCO single crystal which is the quotation from Hagen and Griessen's paper is also shown by broken line. The prominent features in Bi-2212 single crystal are the facts that pinning energies are concentrated to low energy and have narrow distribution. It has a non-negligible weight at low energies and has no weight at higher energies than 80 meV. This is probably due to the extremely small coherence length and quasi two-dimensional character of Bi-2212 single crystal. This distribution can consistently explain such experimental results as; rapid decrease of Jc with increasing temperature, behaviour of the normalized decay rate as a function of temperature, temperature dependence of pinning potential. This distribution will also be able to explain very high transport critical current density and its temperature dependence.[9,11]

In conclusion, we have measured the decay of magnetization for Bi-2212 single crystal at various temperatures. According to the inversion scheme proposed by Hagen and Griessen, we deduced the distribution of activation energy. Obtained result showed narrow distribution centered around 40 meV. This distribution is consistent with other experimental results reported before.

REFERENCES

1. Gao L, Meng R.L, Xue Y.Y, Hor and Chu C.W, (1991) Appl. Phys. Lett. 58: 92.
2. Dinger T.R, Worthington T.K, Gallagher W.J, and Sandstrom R.L, (1987) Phys. Rev. Lett. 58: 2687.
3. van Dover R.B, Schneemeyer L.F, Gyorgy E.M, and Waszczak J.V, (1988) Appl. Phys. Lett. 52: 1910.
4. Hayashi S, Shibutani K, Shigaki I, Ogawa R, Kawate Y, Maret V, Kitahama K, and Kawai S, (1991) Physica C 174: 329.
5. Murakami M, Oyama T, Fujimoto H, Taguchi T, Gotoh S, Shiohara Y, Koshizuka N and Tanaka S, (1990) Jpn. J. Appl. Phys. 29: L1991.
6. Yeshuran Y and Malozemoff A.P, (1988) Phys. Rev. Lett. 60: 2202.
7. Malozemoff A.P, (1990) Proc. A.I.P.Conf. ed. Y.H.Kas et al. p89.
8. Hagen C.W and Griessen R, (1989) Phys. Rev. Lett. 62: 2857.
9. Shibutani K, Hayashi S, Egi T, Shigaki I, Ogawa R, Kawate Y, Kitahama K and Kawai S, (1991) Proceedings of ICMC'91.
10. Shigaki I, Kitahama K, Shibutani K, Hayashi S, Ogawa R, Kawate Y, Kawai T, Kawai S, Matsumoto M and Shirafuji J, (1990) Jpn. J. Appl. Phys. 29: L2013.
11. Shibutani K, Hayashi S, Egi T, Shigaki I, Ogawa R, Kawate Y, Kitahama K and Kawai S, (1991) Proc. M2S-HTSC3.

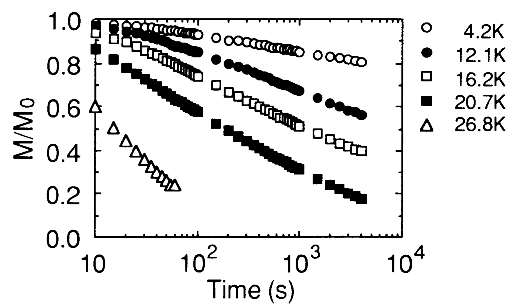

Fig.1 Relaxation of the normalized magnetization at various temperatures. Magnetic fluxes which are perpendicular to a-b plane of the crystal are trapped.

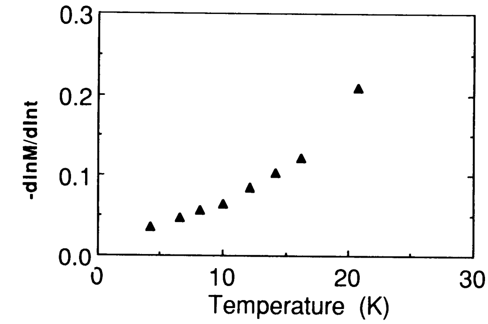

Fig.2 Normalized decay rate at t=100s. The decay rate monotonically increases with temperature and does not have plateau region.

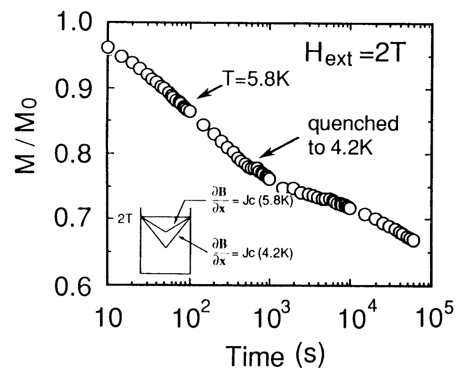

Fig.3 Decay of the magnetization. The sample was quenched from 5.8K to 4.2K at t=550s. By quenching, decay rate rapidly changes.
Inset shows the induction profile at t=0s for T=5.8K and T=4.2K.

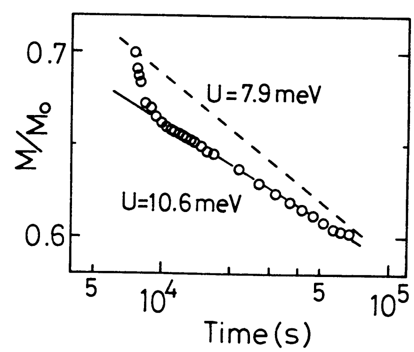

Fig.4 Expansion of the datum which corresponds to t>550s in Fig.3. Time scale is added 7050s and magnetization is multiplied by 0.897 compared to Fig.3. Broken line corresponds to the continued decay at 4.2K without quench.

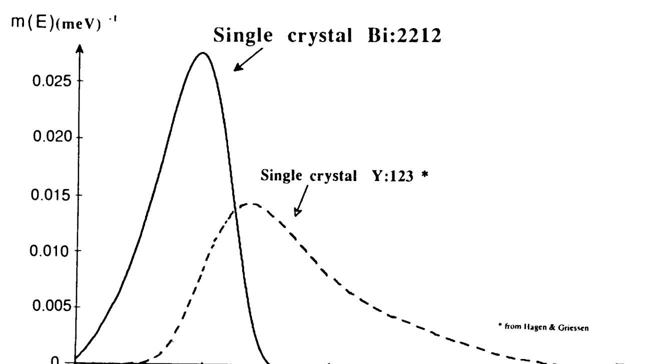

Fig.5 Distribution of pinning potential. Solid curve corresponds to the Bi-2212 single crystal. The data for YBCO single crystal which is the quotation from Hagen and Griessen's paper are also shown by the broken line for the comparison.