Magnetic Relaxation in Y-Ba-Cu-O Thin Films

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Abstract

Distribution of a local field $B(x)$ on the surface of YBCO thin films in the mixed state and its time dependence is measured using a micro Hall-probe array. Analizing these data based on the flux diffusion equation, the model-independent activation energy U is obtained. Since the local current density J is defind to reproduce the field profile $B(x)$, $U(B, J)$ can be plotted in a 3-dimensional space. This 3-dimensional mapping gives us information on U as a function of B and J.

Key words: superconductivity; magnetic relaxation; YBCO; Hall probe; local field

Measuring magnetic relaxation is a popular method to study the activation energy U [1], but the spatial distribution of flux-density B in samples complicates the analysis of experimental results. Abulafia et al.[2] propose a method to determine the local flux current density D directly using Hall probe array. D is associated with U by the equation,

$$D = \frac{A\phi_0}{4\pi\eta} B \frac{\partial B}{\partial x} \exp\left(\frac{-U}{kT}\right).$$

Where η is the viscosity coefficient and A is a numerical facter. Using the Hall probe array, we get D, B and $\partial B/\partial x$ simultaneously. Thus, a model-independent U can be obtained.

In this work we use a c-axis oriented YBCO epitaxial film having a rectangular shape of size $890\times10000\times0.27\mu\mathrm{m}^3$. The micro Hall probe array [3] is made of GaAs doped with Si and has 7 elements. Each element has $10\times10\mu\mathrm{m}^2$ active area. The sample is laid on the Hall probe directly. Therefore a dc field measured by the probe is parallel to the c axis of the crystal. The sample is cooled to 20K at zero field and applied a dc field H. Fig.1 shows a result at $H = 400$ Oe and the inset does an arrangement of the sample on the Hall probe array. From the field profiles, the probe 4 is in the center of the sample. In Fig.1, the time dependence of B at each point is not logarithmic. Under several H's, the above measurements were performed.

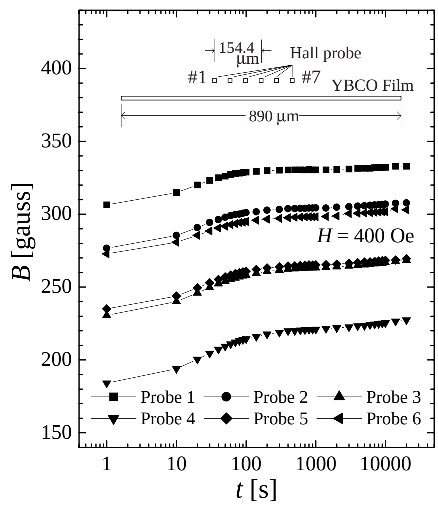

Fig. 1. A time dependence of local flux-density B measured at 20K and $H = 400$Oe.

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According to the method of Abulafia et al. [2], $D(x,t)$, B and $\partial B/\partial x$ are calculated in the middle between probe 1 and 2. But we use a different way to define the local current since we measure thin films. Assuming the screening current is uniform but it changes the sign at the center of the sample, we calculate the surface field and fit it to experimental results. These estimated local current differ from $(c/4\pi)\partial B/\partial x$ by 2 order of magnitude. Generally, fitting for high field measurements are better than for low field.

However, when flux penetrates partly in the sample, the uniform current can not reproduce the experimental results. Therefore we utilize a different model proposed E. H. Brandt et al.[4]. According to them, in case the sample has a width $2a$ along the x axis supposing the local sheet current $J(x)$ saturates at $x = b$, the profile of $J(x)$ is defined by

$$J(x) = \begin{cases} J_c. & (-a \le x \le -b) \\ (-2J_c/\pi)\arcsin(x/b). & (|x| < b) \\ -J_c. & (b \le x \le a) \end{cases}$$

Using b and J_c for parameters, the experimental data are fitted (Fig.2 and Fig.3). In Fig.3, full circles show the measured value and the solid curve does calculated B at 40μm distance from the sample surface. The dotted curve is a calculated internal B and fairly differs from B at 40μm. This suggests the strong dependence of B on the distance from the surface, especially at the center of the sample. From the calculation, internal B at the center of the sample is about 5 gauss and flux hardly penetrates yet there. Fig.3 shows the profile of calculated J and it's time dependence. Both J_c and b decrease monotonically with time. Since the reproduction of the field profile and the time dependences of J_c and b, this model is considered to be appropriate.

Using above estimated J, $U(B, J)$ can be plotted in a 3-dimensional space(Fig.4). According to Fig. 4, all data seem to fall on the same curved surface. The ultimate goal of this work is to get B and J dependences of U. For further analysis, Fig.4 does not have enough measuring points. But the nonlinearity of $U(J)$ can be pointed out and it probably coincides with the logarithmic barrier.

In conclusion, we get the logarithmic dependence $U(J)$. To determine it, it is important to define J precisely. For this purpose, Hall array technique is a very effective method.

We thank Keiji Enpuku for connecting lead wires to the Hall probe.

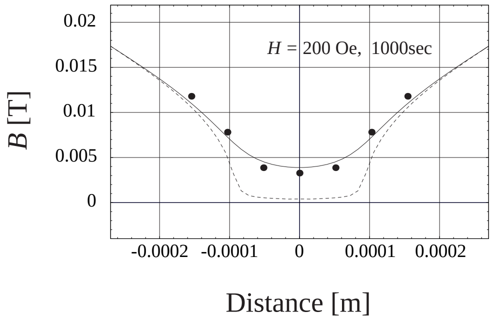

Fig. 2. The profile of flux-density B measured at T=20K, H=200Oe and at 1000 seconds. The solid curve shows calculated B at 40μm distance from the sample surface. The dotted curve shows calculated internal B.

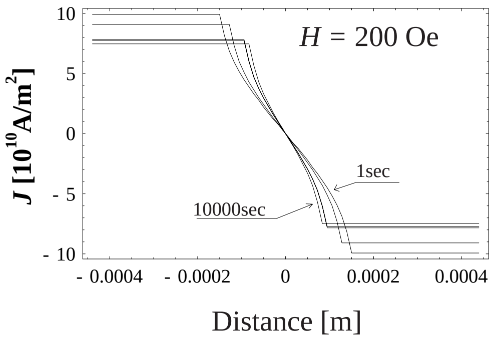

Fig. 3. The profile of calculated current density J at T=20K and H=200Oe for 1, 10, 100, 1000 and 10000 sec.

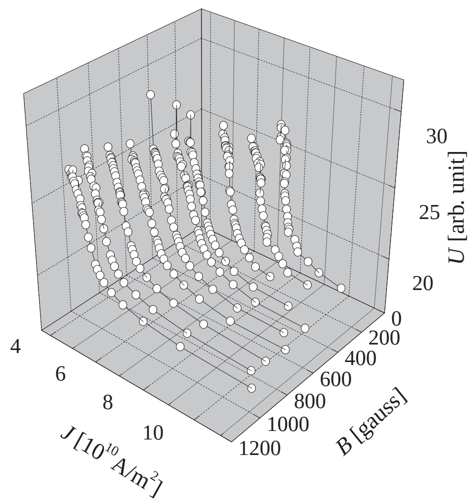

Fig. 4. 3-dimensional plot of activation energy U calculated in the middle between probe 1 and 2.

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