ELSEVIER

Physica C 282-287 (1997) 2215-2216

PHYSICA C

Thickness dependence of the magnetic properties in $YBa_2Cu_3O_{7-\delta}$ thin films

R. Prozorov, E. Sheriff, Y. Yeshurun, and A. Shaulov

Institute of Superconductivity, Department of Physics, Bar Ilan University, Ramat - Gan, Israel.

We report on magnetization measurements in laser ablated $YBa_2Cu_3O_{7-\delta}$ films with thickness 800 - 3000 Å. The persistent current density j and the magnetic relaxation rate decrease with increase of the thickness. At certain conditions this leads to a crossing of the relaxation curves measured in films of different thickness. These results are explained considering surface effects which cause a non-homogeneous distribution of j along the film thickness.

1. INTRODUCTION

A number of publications dealt with the decrease of the persistent current density j with increase of the film thickness [1-2]. In this contribution we show complementary measurements of the magnetic relaxation in films of various thickness and find that the relaxation rate is larger in thinner films. Along with higher j this leads to a crossing of the relaxation curves.

2. RESULTS

2.1 Experimental

Four 5×5 mm² $YBa_2Cu_3O_{7-\delta}$ films of thickness d = 800, 1000, 2000 and 3000 Å have been prepared by the laser ablation technique on $SrTiO_3$ substrates. All samples had $T_c \approx 89$ K. The magnetization was measured as a function of field, temperature and time, using a Quantum Design SQUID.

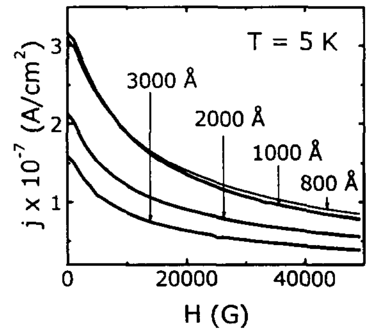

Figure 1. j vs. field at T = 5 K.

2.2 Persistent current density j

The current density was extracted from the magnetic hysteresis curves using the Bean model: $j=60M/da^3$, where M is the irreversible magnetization, d is the film thickness and a=0.5 cm is the lateral dimension. Fig. 1 shows the persistent current density j at T = 5 K as a function of the applied magnetic field H. Apparently, j is **larger** for the thinner films. The same trend is found at all temperatures.

2.3 Relaxation

Fig. 2 shows typical relaxation curves at H = 0.2 T (decreased from 1 T) measured in films of different thickness. The interesting and unexpected feature is that curves cross, i. e., the relaxation is faster for the thinner films. This is further illustrated in Fig. 3 where j vs. d is plotted at different times.

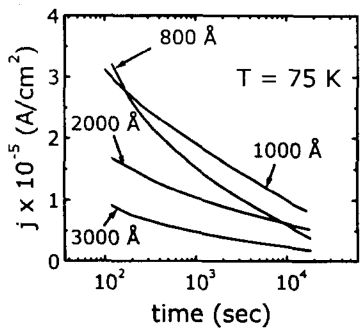

Figure 2. j vs. time at T = 75 K

PII S0921-4534(97)01174-X

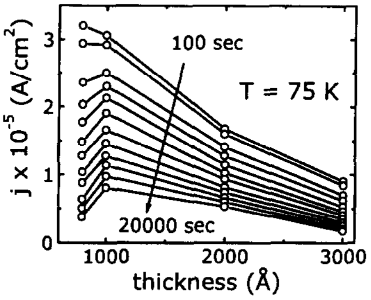

Figure 3. j vs. d at different times.

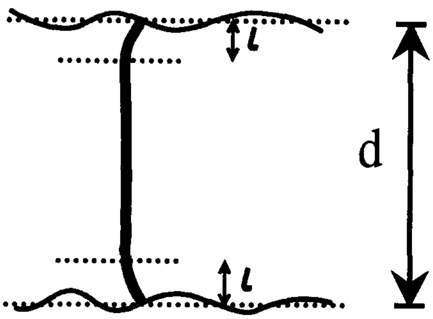

Figure 4. Vortex in thin film

3. DISCUSSION

A decrease in the measured critical current density j_c with the increase of the film thickness d has been explained as a result of surface pinning [1]. We extend this approach in order to interpret the observed thickness dependence of the persistent current j and the flux dynamics. In our model we take into account the important role played by the film surface in determining the *spatial distribution* of the persistent current, i. e., the effect of vortex bending near the surface due to a boundary condition that a vortex must be perpendicular to the surface. The schematic position of a vortex in thin film with rough surface is sketched in Fig. 4. As shown in Ref. [3] the vortex is bent on a length scale $l^2 = \lambda^2 H_{c1} / (H_{c1} + B_z)$ where λ is the London penetration length. One can further show that the current density is maximum near the surface, and it decreases towards its bulk value over the same characteristic length scale l [3]. In our case $H_{c1} \approx 100$ G and $B_z = 2000$ G and we find $l \approx 330$ Å. We recall that the current density, estimated from the magnetization loops, is the *average* current density

$$\bar{j} = \frac{2}{d}\int_0^{d/2} j(z)dz = \bar{j}_s \frac{l}{d} + j_b, \qquad (1)$$

where $\bar{j}_s$ is the average over the length l surface current density and j_b is the bulk current density. Apparently, $\bar{j}$ decreases with d. In contrast, one can show that the average barrier for flux creep $\overline{U}$ increases with thickness as long as $U(j)$ is a decreasing function of j. Thus, the relaxation in thinner samples is faster. To calculate the time t_c at which the relaxation curves of films of thickness d_1 and d_2 cross one should find the time dependence of $\bar{j}$ for each film. This can be done by equating the calculated $\overline{U}(\bar{j}, d)$ to the logarithmic solution of the flux creep equation: $\overline{U}(\bar{j}, d) = kT\ln(t/t_0)$. We then equate $j(t,d_1)$ with $j(t,d_2)$ and obtain the crossing time t_c. We find that for all the available models of $U(j)$ $t_c = t_0 exp(U_c/T)$ explaining the absence of crossing at low temperatures.

Acknowledgments: We are grateful to E. Sonin and V. Vinokur for useful discussions. This work was partially supported by The Israeli Science Foundations and the Heinrich Hertz Minerva Center for high - temperature superconductivity. Y. Y. acknowledges support from USA-Israel Binational Science Foundation. R. P. acknowledges support from the Clore Foundations.

REFERENCES

1. M. McElfresh *et al.*, J. Appl. Phys. **71**, 5099 (1992); C. Jooss *et al.*, Physica C **268**, 87 (1996).
2. A. Mogro-Campero *et al.*, Physica C **247**, 239 (1995); C. Jooss *et al.*, Physica C **266**, 235 (1996); E. Sheriff *et al.*, submitted.
3. E. Sonin and K. B. Traito, Phys. Rev. B **50**, 13547 (1994).