Flux-Pinning Energies in High-T_c Superconductors

Using two independent analyses, we definitively rule out the possibility that the dissipation mechanism in $YBa_2Cu_3O_{7-\delta}$ epitaxial films is governed by a peak at 0.07 eV in the pinning-energy distribution, as recently deduced by Ferrari *et al.*[1] from their flux-noise measurements.

(1) Resistive-transition broadening.—A straightforward and widely accepted approach for observing thermally activated flux motion and for estimating the activation energy U derives from the exponential broadening of the resistive transition [Fig. 1(a)]. Since U is temperature dependent, the logarithmic slope of the curves is given by

$$-k\frac{d(\ln\rho)}{d(1/T)}\equiv U_{\text{eff}}=U(T)-T\frac{dU(T)}{dT}.$$

The effective activation energy U_{eff} in Fig. 1(b) is in excess of 7 eV at low current densities and decreases with increasing currents and magnetic fields.[2] Ferrari *et al.*[1] analyze their data with the temperature-dependent $U(t)=U_0(1-t^4)$, which leads to $U_{\text{eff}}=U_0(1+3t^4)\le 4U_0$ and hence $U_0>1.75$ eV ($t=T/T_c\le 1$). An even more conservative lower-bound estimate of U_0 is as follows: $U(T)$ is expected to be a monotonically decreasing function of T with a maximum value of U_0 at $T=0$ K. Assuming an extremely rapid drop of $U(T)$ within 10 K of $T_c=90$ K, the second term in U_{eff} is at most $9U_0$ so that $U_{\text{eff}}<10U_0$. Thus, the resistive data imply $U_0>0.7$ eV which is *10 times larger* than the 0.07-eV value of Ferrari *et al.*[1] They argue that this low value reflects the pinning energy of uncorrelated vortices since their experiment was carried out in low field and in the absence of driving current. However, the resistive transition becomes sharper and shows an *increase* in U as both the field and current are decreased,[2] a result that leads to an even *larger* discrepancy between the resistive data and those reported in Ref. 1.

(2) Flux-creep resistivity.—At low current densities the flux-creep-induced resistivity is given by $\rho=(2\nu_0B^2L^2V_c/kT)\exp(-U/kT)$, with ν_0 the attempt frequency of a flux bundle of volume V_c to hop a distance L. In Ref. 1, a value of $10^{11}\ \text{sec}^{-1}$ was used for ν_0 and $U=23kT$ at 35 K was reported. By taking an average length scale of 1000 Å for V_c and L, ρ at 35 K and 1 T field is $4\times10^{-5}\ \mu\Omega\,\text{cm}$. This implies that one could easily measure a *linear* resistivity in $YBa_2Cu_3O_{7-\delta}$ almost *at any temperature*. However, it is well established that the resistivity of good-quality $YBa_2Cu_3O_{7-\delta}$ films at 35 K and 1 T is practically immeasurable as can be seen from the extrapolation of the low-current curves in Fig. 1(a) to 35 K.

Clearly then, the 0.07 eV is not the relevant pinning energy in the *electrical transport* dissipation mechanism. The low U derived in Ref. 1 may reflect the hopping of flux lines between some adjacent local minima, or alternatively, flux motion in some defected areas of the sample. The fact that the noise level and the density of the activation energies in the lower-quality film of Ref. 1 are an order of magnitude higher than in their epitaxial film may support this hypothesis. Furthermore, in another collaboration[3] using a much higher-quality laser-ablated epitaxial film, the authors do not detect $1/f$ noise at lower temperatures. Hence the physics of the intrinsic *macroscopic* motion of the vortices lies in the very large noise peak near T_c rather than in the sample-dependent residual noise at lower temperatures. Finally, the low U values derived from the magnetic-relaxation and critical-current experiments may be of a completely different nature due to the nonlinear current dependence of the activation energy.[2,4]

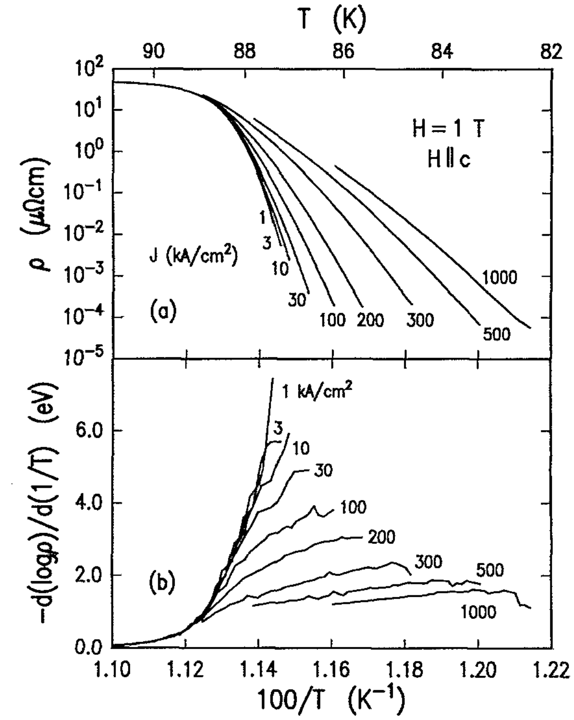

FIG. 1. (a) Arrhenius plot of the resistivity and (b) the logarithmic derivative of the resistivity of $YBa_2Cu_3O_{7-\delta}$ epitaxial film at $H=1$ T and various current densities up to 10^6 A/cm^2.

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