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VORTEX DEPINNING IN $YBa_2Cu_3O_7$: RESISTIVE TRANSITION IDENTIFICATION OF THE CROSSOVER FROM FLUX-CREEP TO FLUX-FLOW BEHAVIOR

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Analysis of resistive transitions of $YBa_2Cu_3O_7$ crystals reveals a scaling behavior which identifies the vortex-depinning critical field H_{cp}, hence the crossover in behavior from flux creep to flux flow. The inferred H_{cp} for $YBa_2Cu_3O_7$ crystals closely approximates the magnitude and temperature dependence of H_{cp} derived from penetration length measurements of thin films.

1. INTRODUCTION

A complete characterization of the resistive transitions of high-T_c materials necessitates an understanding of the temperature and field dependence of the energy barriers U(T,H) which impede flux motion. Resistance measurements[1] at different fields H show clearly the importance of thermal activation over energy barriers (i.e., flux creep) where the resistance is proportional to $\exp(-U(T,H)/k_BT)$. In a complementary way, measurements of the penetration length λ at different H probe directly the curvature of these wells for small vortex displacements.[2]

Most importantly, both the resistance and the penetration length measurements share a common aspect by pointing to a field-dependent critical temperature $T_c(H)$ where U(T,H) becomes negligible. In the resistance measurements[3] this temperature is inferred by extrapolating the logarithmic slope $d(\ell nR)/d(\ell nT^{-1})$ to zero whereas in the penetration length measurements[2] this temperature is defined by extrapolating λ^{-1} to zero. Separately, the penetration length measurements show that in the field range $1\,T \leq H \leq 14\,T$ the linear dependence $H_{cp}^{1/2} \propto T$ is obeyed. We demonstrate here using a scaling argument that this same functional form for H_{cp} is manifest in the resistance transitions, shown in Fig. 1, of a $YBa_2Cu_3O_7$ crystal. Consequently, both measurements are consistent with the notion of a vortex-depinning critical field $H_{cp}(T)$ which delineates the crossover from flux-creep to flux-flow behavior.

2. THE SCALING MODEL

The central assumption of our model is that there is a well-defined temperature $T_c(H)$ below which vortex motion is dominated by the presence of non-zero barriers and above which the vortices are free to flow unimpeded. At $H = H_{cp}$ where $U \sim k_BT$ there is no creep contribution to the resistivity ρ which can therefore be written in the

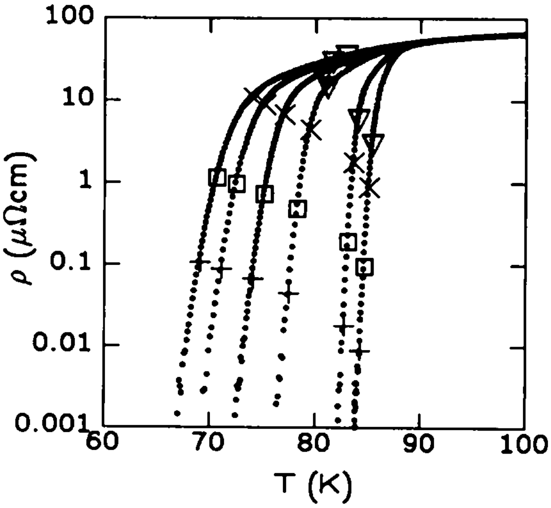

FIGURE 1
Resistive transitions at fields (H parallel to c-axis) of 1, 2, 5, 7.5, 10, and 12 T of a $YBa_2Cu_3O_7$ crystal.

form $\rho = H_{cp}\Phi_0/c^2\eta$, where Φ_0 is the flux quantum and η the vortex flow viscosity, assumed to be a constant.

With these assumptions, it is straightforward to analyze a family of $\rho(T)$ curves[1] taken at different fields such as shown in Fig. 1. We begin by choosing an arbitrary resistivity threshold, say $1.0\,\mu\Omega$ cm for the 1 T curve, and marking it with an identifier $\times$. In the flux flow regime the linear dependence of ρ on H_{cp} implies a linear scaling with H of the 1 T resistivity threshold. Thus $T_c(H)$ on the higher field curves can be identified and the locus of points ($\times$) plotted as shown in Fig. 1. Similar loci are shown for 1 T resistivity thresholds of $0.01\,\mu\Omega$ cm (+), $0.1\,\mu\Omega$ cm (□) and $3.0\,\mu\Omega$ cm (∇).

3. RESULTS AND CONCLUSIONS

Having determined possible trajectories for $H_{cp}(T)$ in Fig. 1 which depend only on the initial guess of a threshold resistivity, we can now directly interpolate to find the dependence of H_{cp} on temperature. The resulting dependences for resistivity thresholds of $0.01\,\mu\Omega$ cm (+), $0.1\,\mu\Omega$ cm (□), $1.0\,\mu\Omega$ cm ($\times$) and $3.0\,\mu\Omega$ cm (∇) are shown in the $H^{1/2}$ versus T plot of Fig. 2(a). For resistivity thresholds of $1.0\,\mu\Omega$ cm and smaller the agreement with the aforementioned $H_{cp}^{1/2} \propto T$ dependence found in penetration length measurements [see Fig. 2(a)] is excellent. We note that a higher resistivity threshold of $3.0\,\mu\Omega$ cm (∇) exhibits a pronounced deviation with positive curvature whereas lower resistivity thresholds (+ and □) exhibit less pronounced deviations with increasing negative curvature.

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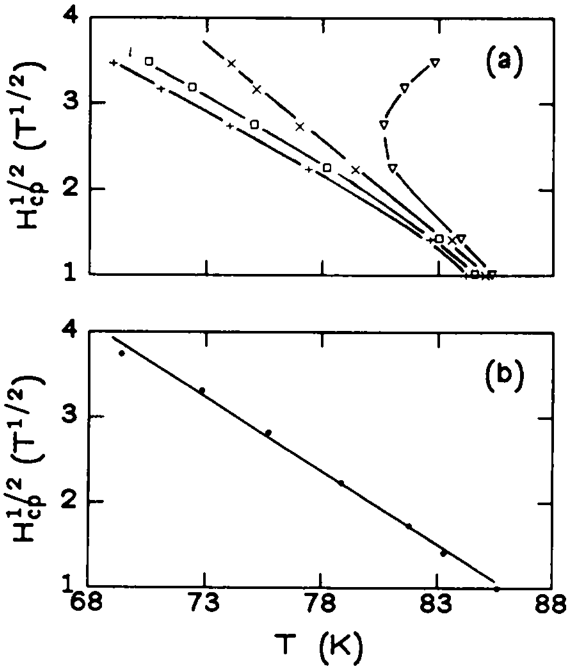

FIGURE 2
Plots of $H_{cp}^{1/2}$ vs T for (a) interpolated temperature dependences using the trajectories in Fig. 1 defined by the symbols (+,□,$\times$,∇) common to both figures and for (b) the penetration depth measurements.