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Giant Flux Creep Through the Surface Barriers and the
Irreversibility Line in High- T_c Superconductors

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GIANT FLUX CREEP THROUGH THE SURFACE BARRIERS AND THE IRREVERSIBILITY LINE IN HIGH- T_c SUPERCONDUCTORS

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Magnetic flux relaxation over the surface barrier in high temperature superconductors are investigated. Vortex dynamics controlled by the penetration both of pancake vortices and vortex lines are discussed. The penetration field H_p for pancakes decays exponentially with temperature. The size of the magnetization loop is determined by the decay of H_p during the process of relaxation, but its shape remains unchanged. The irreversibility line associated with the pancake penetration is given by $H_{irr} \propto \exp(-2T/T_0)$, and may lie both above and below the melting line.

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Bean-Livingston surface barriers play an important role in vortex dynamics in high temperature superconductors (HTS) [1-3]. In case of weak bulk pinning the surface barriers control the penetration field H_p [1,2] and may determine the position of the irreversibility line [4]. The penetration field for the ideal surface had been found to be of the order of the thermodynamic critical field $H_p \simeq H_c$ and the surface barrier had been shown to disappear at fields $H \approx H_{c2}$ [5,6,3]. However experiments in HTS revealed a strong (exponential) temperature dependence of H_p and the irreversibility field due to surface barriers was found to lie well below H_{c2} [1,2,4]. We show that the observed effects can be explained by thermal fluctuations and find the temperature dependence of the whole magnetization loop including that of the irreversibility field for both 2d and 3d cases.

In strongly layered superconductors flux penetration is governed by the single pancake creep over the surface barrier which is determined by the interaction of pancake with its image. Following [1] one finds the creep activation energy for the pancake resulting from as $U_0 = \epsilon_0 d \ln(H_c/H)$, where $\epsilon_0 = (\Phi_0/4\pi\lambda)^2$, with λ being the penetration depth (magnetic field $\mathbf{H} \parallel \mathbf{c}$) The probability per unit time for the thermally activated jump over surface barrier is $\propto \exp(-U_0/T)$, and the penetration field H_p follows from the equation $U(H_p) = T \ln(t/t_0)$ [7], where

t and t_0 are the time scale of the experiment and some microscopic time scale respectively[1]:

$$H_p \simeq H_c \exp[-(T/T_0)] \propto H_c (t/t_0)^{-T/\epsilon_0 d}, \quad (1)$$

with $T_0 = \epsilon_0 d / \ln(t/t_0)$, d being the interlayer spacing. This result holds until the energy of the Josephson coupling with the image is small compared to U_0 i.e. in the field range $H > H_c \epsilon / d \simeq \epsilon H_c$ in HTS materials, where $\epsilon = \sqrt{m/M} < 1$ is the anisotropy parameter. In layered superconductors $\epsilon_0 d \simeq 700K$ ($\lambda \simeq 2000\text{\AA}$ [9], $d = 15\text{\AA}$, $\epsilon \sim 10^{-2}$ for BSCCO). Taking the typical value of the $\ln(t/t_0) = 30$ one obtains $T_0 = 23K$ in a reasonable agreement with the experiment [1,2,4].

The model by [5,6] (see also [3]) predicts the existence of the vortex free region of the width x_f near the surface of the sample and the constant vortex density B for $x > x_f$. The distribution of the field in the vortex-free region ($x < x_f$) is given by $h(x) = B \cosh((x - x_f)/\lambda)$ with the current density at the surface $j = (c/4\pi)B \sinh(x_f/\lambda)$. The current relaxation due to vortex creep over the barrier is determined by the condition $U(j) = \epsilon_0 d \ln(3\sqrt{6}j_0/4j) = T \ln(t/t_0)$. This gives: $B \sinh(x_f/\lambda) = H_p(T)$ with $H_p(T)$ from the Eq. (1). Making use of the boundary conditions $H = B \cosh(x_f/\lambda)$ one obtains straightforwardly $B = \sqrt{H^2 - H_p^2}$, and for $H \gg H_p$ the magnetization is

$$-4\pi M \approx H_p^2/2H \propto \exp(-2T/T_0) \quad (2)$$

The magnetization loops preserve their shape during the relaxation process, and creep results only in the thermal renormalization of the penetration field $H_p(T, t)$.

The pancake penetration becomes reversible when the hopping distance r_0 becomes of order of x_f which corresponds to $-4\pi M \simeq H_p^2/2H \simeq M_{e1} \simeq \Phi_0/8\pi\lambda^2 \ln(\eta H_{c2}/H)$, where $\eta \approx 0.35$. The irreversibility line at high enough temperatures $T > T_0$ is then given by

$$H_{irr} \approx H_{c2}(T_0/2T) \exp(-2T/T_0). \quad (3)$$

In agreement with experimental data [8-10].

For less anisotropic HTS materials (such as YBCO) or for Bi and Tl based compound at high temperatures where $H_p(T)$ drops below ϵH_c the thermal activation over the surface barrier occurs via the creation and the further expansion of the half loop excitation [3,11]. The activation energy as a function of current is given by

$$U(j) = \frac{\pi \epsilon \epsilon_0^2 c \ln^2(j_0/j)}{2\Phi_0 j}.$$

Proceeding further analogously to 2D case one easily finds

$$H_p \approx H_c \frac{\pi}{2\sqrt{2}} \frac{\epsilon \epsilon_0 \xi}{T \ln(t/t_0)} \ln^2(H_c/H_p), \quad (4)$$

providing that the creep is strong enough and H_p is smaller than H_c , and

$$H_{irr} \simeq \frac{\pi}{256} \frac{\epsilon \epsilon_0^2 \Phi_0 \ln^3(H_{c2}/H_{irr})}{T^2 \ln^2(t/t_0)} \quad (5)$$

This expression differs from the conventional expression for the melting line $B_m \simeq 8\epsilon_0^2 c_L^4 \Phi_0/T^2$ by the factor of $\ln^{3/2}(H_{c2}/H)/24 \ln(t/t_0)$ instead of the Lindemann factor c_L^2 . This implies that in YBCO the irreversibility line as defined by Eq. (7) lies below the melting line since the usual observation fields are about $0.1H_{c2}$, and as a result the surface barrier is suppressed near the melting. On the contrary in much more anisotropic BSCCO materials the melting line at high temperatures may be close to H_{c1} and the irreversibility line from Eq. (7) can be located above the melting line. Therefore in BSCCO the

irreversibility line may arise from the surface pinning rather than from the freezing of the vortex liquid into a vortex solid.

We discuss briefly the finite size effect [12]. The penetration field for the rectangular sample with the thickness $h \ll w$, w being the transverse size is $\sqrt{d/w}H_p$ (note the distinction from the commonly used demagnetization factor of d/w for the sample of the ellipsoidal shape). The slope of the magnetization curve in the Meissner state below H_p is equal to $(H/4\pi)(w/d)$. In the field much bigger than the penetration field $\sqrt{d/w}H_p$ the magnetization is $M \simeq H_p^2/2H$ and does not depend on the demagnetization factor.

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REFERENCES

1. V. N. Kopylov, *et al*, Physica C 170, 291 (1990).
2. M. Konczykowski *et al*, Phys. Rev. B 43, 13707 (1991).
3. L. Burlachkov, Phys. Rev. B 47, 8056 (1993).
4. E. Zeldov *et al*, to be published.
5. F. F. Ternovskii and L. N. Shekata, JETP 35, 1202 (1972).
6. J. R. Clem, in *Proceedings of the 13th Conference on Low Temperature Physics* (LT 13), ed. by K. D. Timmerhaus *et al*, (Plenum, New York, 1974), Vol. 3, p.102.
7. G. Blatter *et al*, Rev. Mod. Phys. (in press).
8. A. Schilling *et al*, Phys. Rev. Lett. 71, 1899 (1993).
9. J. Yazui *et al*, Physica C 184, 254 (1991).
10. C. J. van der Beek and P. H. Kes, Phys. Rev. B 43, 13032 (1991).
11. A. E. Koshelev, Physica C 191, 219 (1992).
12. E. Zeldov *et al*, Phys. Rev. Lett., submitted (1994).

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