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High temporal resolution magneto-optical study of the vortex solid–solid transition in $Bi_2Sr_2CaCu_2O_8$ crystal

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Abstract

A high temporal resolution magneto-optical system is employed to observe the time evolution of the vortex structure in a $Bi_2Sr_2CaCu_2O_8$ crystal after a sudden application of a magnetic field H_a in the range around the vortex solid–solid transition field. For low applied fields, initially Bean-type profiles are observed, rapidly relaxing into the equilibrium state of the quasi-ordered phase. For high fields, a boundary between two distinct vortex solid phases coexisting in the sample is clearly observed. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Bi-2212; Magneto-optic imaging; Vortex dynamics; Vortex states

Recent studies of $Bi_2Sr_2CaCu_2O_8$ (BSCCO) crystals [1], indicated the existence of two distinct vortex solid phases: a quasi-ordered lattice below a transition field B_{ss} (≈ 400 G [2]), and a highly disordered solid above B_{ss}. A problem of fundamental importance is the process of formation of these two distinct phases after a sudden application of an external field. Utilizing a high temporal resolution magneto-optical method for direct flux visualization, we followed the time evolution of the vortex structure in a $0.66 \times 0.24 \times 0.03$ mm^3 BSCCO single crystal immediately after a step increase (rise time < 50 ms) in the applied magnetic field from 0 to H_a, in the range around B_{ss}. Magnetic induction was detected on the sample surface employing magneto-optically active iron–garnet film with in-plane anisotropy [3]. For each applied field images were captured during 6 s at time intervals of 40 ms.

Fig. 1 shows the time evolution of the induction profiles for $H_a = 350$ Oe. Profiles describe the induction across the width of the sample in the middle of the strip. (Data points are shown across half of the sample, where domain structure in the indicator does not interfere.)

Initially, Bean-type profiles are observed, gradually evolving into a dome-shaped profile, characteristic of Bean–Livingston and geometrical barriers. The solid lines are theoretical fits utilizing two parameters – surface current j_s and bulk current j_b. As shown in the inset, j_b decays rapidly (with an exponential tail) and after several seconds the profile is mainly due to j_s [4].

Fig. 2 presents the induction profiles for $H_a = 510$ Oe. The profiles exhibit a sharp change in the slope at a distance $|x| = x_p$ from the center. The solid lines in Fig. 2 are theoretical fits with surface current j_s and *two* bulk-currents j_l ($|x| < x_p$) and j_h ($|x| > x_p$). The lower inset to Fig. 2 shows the time dependence of x_p (circles, left axis), j_h and j_l (triangles and squares, right axis). Bulk currents j_h and j_l exhibit power-law dependence in time with different exponents: -0.34 and -0.58, respectively. The results imply coexistence of high- and low-current phases, presumably disordered and quasi-ordered phases, respectively. The point x_p is the border between the two solid phases. Note the non-monotonic time dependence of x_p: Initially, the low-current quasi-ordered phase nucleates at the center and expands outwards. As the induction increases, the quasi-ordered phase retreats and the high-current phase pushes its way towards the center. The time dependence of the location x_p is determined by the competing effects of the increase in the induction and the decrease of the current. As the system approaches equilibrium the induction B_p at the boundary x_p, steadily increases, implying that B_p is smaller than the thermodynamic transition field B_{ss}.

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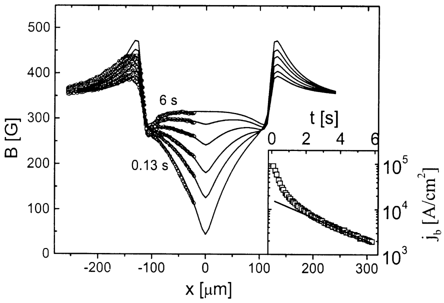

Fig. 1. Time evolution of the magnetic induction profiles for $H_a = 350$ Oe at $T = 23$ K for $t = 0.13$, 0.25, 0.41,0.81, 1.89, 5.85 s. Inset: time dependence of the bulk current. The solid line is guide to the eye for the exponential tail.

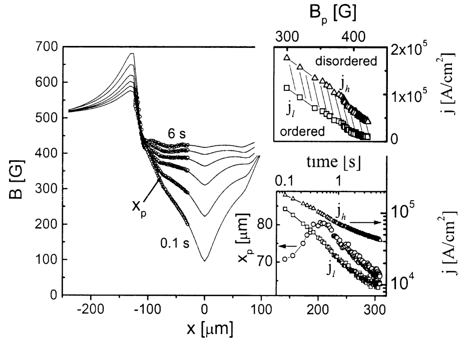

Fig. 2. Time evolution of the magnetic induction profiles for $H_a = 510$ Oe at $T = 23$ K for $t = 0.10$, 0.22, 0.46, 0.86, 1.94, 5.90 s. Upper inset: j_h and j_l versus B_p. Lower inset: Time dependence of x_p (linear-log scale), j_h, j_l (log–log scale).

The upper inset to Fig. 2 shows j_h and j_l versus B_p. This diagram can be viewed as a dynamic phase diagram: The region above $j_h(B_p)$ corresponds to the disordered phase, whereas the region below $j_l(B_p)$ corresponds to the quasi-ordered phase. The 'true' transition line between these two phases is presumably in the shaded area between $j_h(B_p)$ and $j_l(B_p)$.

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