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Persistence of the intrinsic transition in the vortex matter of disordered BSCCO:2212 crystals

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Abstract

The first order melting transition (FOT) in vortex matter of clean $Bi_2Sr_2CaCu_2O_8$ crystals, is identified by a discontinuity in the reversible magnetization, which extends to the low temperature (irreversible) regime in the form of a jump in the energy barrier vs. current, $U(J)$, variation. Heavy ion irradiation disorders the vortex lattice, enhances flux pinning, and is believed to suppress the FOT. However, in underdoped samples, detailed measurements of magnetic relaxation by the Hall-array technique reveal the existence of a discontinuous jump in the $U(J)$ curve precisely at the location of FOT of pristine crystals.

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The introduction of crystalline defects into high-T_c superconductors by irradiation is a unique means to investigate the evolution of the first order transition (FOT) of the vortex lattice [1] as function of varying degrees of controlled disorder. In particular, bombardment of $Bi_2Sr_2CaCu_2O_8$ crystals with swift heavy ions leads to the creation of a random distribution of columnar defects, with a well-defined density. The localization of vortex lines on the defects destroys the vortex lattice order and leads to the Bose-glass phase [2]; the latter is presumed to undergo a second order transition to the vortex liquid. Pioneering work on the evolution of the phase diagram with density of columnar defect [3] has shown that the signature of the FOT line is progressively suppressed, and that the irreversibility line (IRL) splits away from the FOT and moves up in the (B, T) phase diagram. At high defect densities, a universal IRL is reached, limited by the unbinding of vortex lattice defects, while vortices are still pinned by the columnar defects [4].

We demonstrate here that in disordered samples, within the localized Bose-glass phase, vortex matter exhibits a transformation *precisely at the location of the FOT* in pristine samples. The fingerprint of this transformation is a jump from one to another current–voltage characteristic, very similar to that observed in clean $Bi_2Sr_2CaCu_2O_8$ in the vicinity of the second magnetization peak feature [5].

We have used underdoped $Bi_2Sr_2CaCu_2O_8$ crystals ($T_c = 76$ K) grown by the traveling solvent floating zone technique [6]. Rectangles of dimensions 0.2×0.7 mm^2 have been cut from a bigger crystal after imaging of the flux penetration by magneto-optics and elimination of defective regions. The crystals were irradiated with 5.8 GeV Pb^{56+} ions at GANIL (Caen). Different samples were exposed to different fluences in the range 10^8–10^{11} ions/cm^2, yielding columnar defect densities n that, expressed in matching field $B_\Phi = n\Phi_0$, range from 20 G to 2 T. For the magnetic measurements, a Hall sensor-array of 11 sensors of area 10×10 μm^2 separated by

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10 μm, was centered on top of the rectangular crystal, parallel to its shorter side. All experiments were carried out with the dc magnetic field H_a applied perpendicularly to the surface (i.e. parallel to the crystal *c*-axis).

The pristine sample exhibits, above 30 K, a very well-defined FOT on the background of surface barrier irreversibility. At lower temperatures, the second magnetization peak feature (SMP) is also observed. Because of the high anisotropy ($\gamma = 600$) those features are observed at much lower values of the magnetic induction than in optimally doped samples, e.g. SMP occurs at 80 Oe.

A typical magnetic hysteresis curve shows strong enhancement of pinning in irradiated samples (Fig. 1). The use of the Hall-array allows one to plot it as the gradient of the local magnetic induction $\partial B/\partial x \propto J$ vs. the local induction B, instead of the more usual M vs. H_a. In the irradiated samples, we observed a novel feature; an abrupt decrease of the gradient $\partial B/\partial x$ when the magnetic induction is close to the location of the FOT of the pristine sample. The same break is observed in all explored samples that had B_Φ in the range 100 G–1 T.

In order to elucidate the origin of the anomaly in the magnetic hysteresis curve, we have performed relaxation measurements in its vicinity. Magnetic decay in the flux exit mode was triggered by a fast ramp of the applied field to its target value from a starting point far above the irreversibility field. The magnetic relaxation was recorded for 350 s at each target field. We have used the procedure introduced in Ref. [7] to convert the spatially resolved relaxation of the induction to the variation of the flux creep energy barrier U as function of J. The time derivatives $\partial B_z/\partial t$ are numerically calculated for each of the Hall sensors, and the local electric field E was approximated by the sum of the $\partial B_z/\partial t$ values from the five sensors from the center outwards.

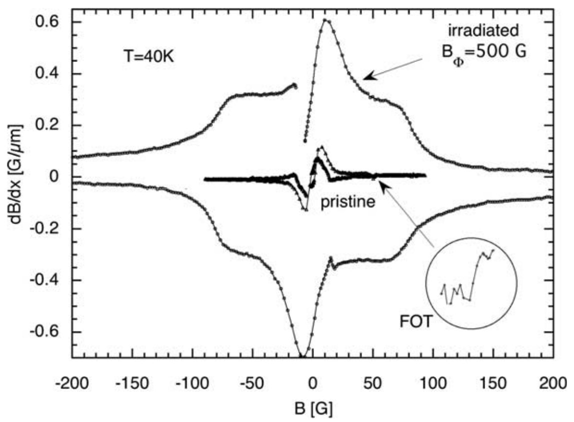

Fig. 1. Magnetic hysteresis loop recorded at 40 K on the pristine and heavy ion irradiated sample ($B_\Phi = 500$ G).

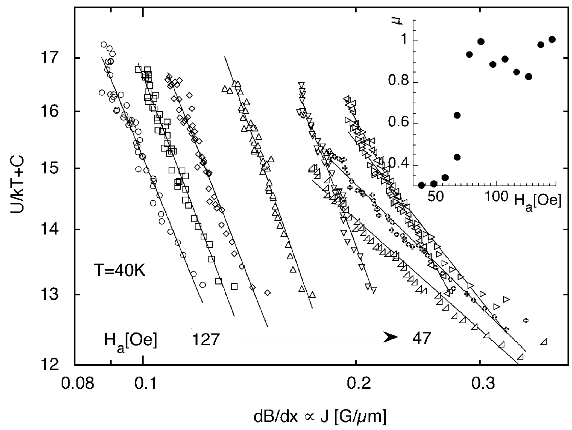

Fig. 2. Energy barrier for flux creep vs. current variations extracted from decays of magnetic induction profiles in columnar defect containing BSCCO crystal ($B_\Phi = 500$ G) at 40 K at various target fields. Inset: Magnetic field dependence of the exponent μ in power law approximation of energy barrier vs. current variation ($U \propto J^{-\mu}$) extracted from data of Fig. 2. The sum of the $\partial B_z/\partial t$ values from the five sensors from the center outwards.

Assuming that the electrical field arises from thermally activated flux creep ($E \propto B^* \partial B/\partial x^* \exp(-U/kT)$) and taking $\partial B/\partial x$ as proportional to the current we may draw $U \propto kB^*T \ln(E/B/J)$ vs. J at various applied fields (Fig. 2). It is clear that the abrupt drop of magnetic hysteresis has a dynamic character and results from the variation of the electrodynamic response of the vortex lattice, namely its $U(J)$ characteristic. The fact that this change occurs precisely at the same value of the magnetic induction as the FOT of the pristine sample leads us to believe that the driving mechanism is the same for both phenomena. A possible explanation is the depression of Josephson coupling at FOT which in the irradiated sample allows the decomposition of the vortex line occupying a single column to a stack of pancakes spread over many columns [8].

References

[1] E. Zeldov et al., Nature 375 (1995) 373.
[2] D.R. Nelson, V.M. Vinokur, Phys. Rev. B 48 (1993) 13060.
[3] B. Khaykovich et al., Phys. Rev. B 57 (1998) R14088.
[4] C.J. van der Beek et al., Phys. Rev. Lett. 86 (2001) 5136.
[5] M. Konczykowski et al., Physica C 332 (2000) 219.
[6] Ming Li et al., Phys. Rev. B 66 (2002) 024502.
[7] Y. Abulafia et al., Phys. Rev. Lett. 77 (1996) 1596.
[8] S. Colson et al., Phys. Rev Lett. 90 (2003) 137002.