Effects of electron irradiation on the vortex order-disorder transition in $La_{2-x}Sr_xCuO_4$ crystals

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Abstract

The vortex order-disorder phase transition line in $(La_{0.937}Sr_{0.063})_2CuO_4$ exhibits a steep concave decrease throughout the whole temperature range. This unusual behavior is explained postulating that in $(La_{0.937}Sr_{0.063})_2CuO_4$, both thermal and disorder-induced fluctuations take part in destabilizing the vortex lattice. Irradiation of the samples with electrons causes a significant decrease in both the magnitude of the transition field and the curvature of the transition line. These results are interpreted as caused by the enhanced role of disorder-induced fluctuations as compared with thermal fluctuations.

Key words: High-temperature superconductors; vortex matter; vortex phase transitions; electron irradiation; $La_{2-x}Sr_xCuO_4$

The vortex phase transition line from an ordered-solid to disordered-solid in $La_{2-x}Sr_xCuO_4$ (LSCO) exhibits a steep decrease throughout the whole temperature range [1] similar to the melting line [2,3], suggesting that thermal fluctuations play a role in driving the transition. On the other hand, manifestation of the transition as a fishtail hints at the importance of disorder-induced fluctuations. In order to reconcile these two observations, we proposed [1,4] that *both* kinds of fluctuations contribute to the destruction of the vortex ordered phase in LSCO. Numerical calculations, based on the Lindemann criterion [2,3] showed that a spectrum of transition lines - ranging from the concave melting line to the convex solid-solid transition line - can be obtained by tuning the relative contributions of thermal and disorder-induced fluctuations. When both contributions are significant we reproduce a line similar to that measured in LSCO. Our analysis predicts that an increased disorder causes a decrease in both the magnitude of the transition field and the curvature of the transition line. In order to test these predictions we measured the transition line in a LSCO sample before and after electron irradiation.

A single $(La_{0.937}Sr_{0.063})_2CuO_4$ crystal ($0.35 \times 0.8 \times 2.5$ mm^3, $T_c = 32$ K) [5] was irradiated twice, each time with a relatively low dose ($1 \times 10^{18} e/cm^2$) of 2.5 MeV electrons. Such low doses of irradiation do not affect the superconducting transition temperature T_c of our LSCO sample, but significantly affect the position and shape of the transition line. Measurements were performed using an MPMS-5S magnetometer.

As depicted in Fig. 1 the width of the magnetization loop, which is proportional to the persistent current, increases with irradiation dose. The onset field, H_{onset}, and kink field, H_{kink}, on both the ascending (+) and descending (−) branches of the loop [1], are preserved despite irradiation. However, the location of these features depends strongly on irradiation dose, so that the features appear at lower fields with an increase of the irradiation dose.

Relaxation measurements, performed on the pristine sample [1] and on the irradiated sample showed that the locations of both H^+_{kink} and H^-_{kink} do not change with time, and the positions of both H^+_{onset} and H^-_{onset}

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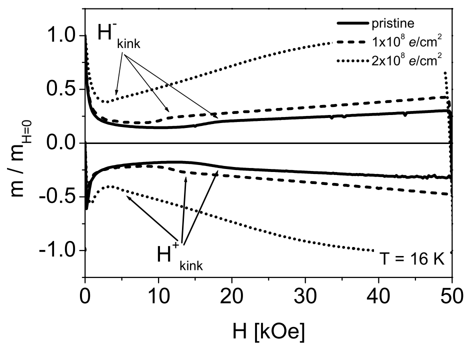

Fig. 1. Magnetization loops at 16 K measured on pristine sample (solid line), after one dose of irradiation (dashed line), after two doses of irradiation (dotted line), normalized to the magnetization of the remanent state.

shift to lower fields with time. The field dependence of the relaxation rate depicts (see Fig. 2) a sharp change of the slope at a position corresponding to the kink on the descending branch (H^-_{kink}), even when the measurements were performed on the ascending branch of the loop. This implies that the feature signifying the transition field is H^-_{kink}, in all three samples.

Fig. 3 demonstrates that irradiation affects the order-disorder transition line in two ways: Both the location of the transition line and its curvature are changed. The transition line appears at lower fields for the same temperature as the irradiation dose increases [6]. Furthermore, as pinning increases, the transition line becomes less steep.

Both effects of irradiation - the depression of the transition line and its change of curvature - are consistent with the predictions in Ref. [1,4]. The induction at the transition decreases with irradiation, since pinning energy is enhanced, and the transition may be induced

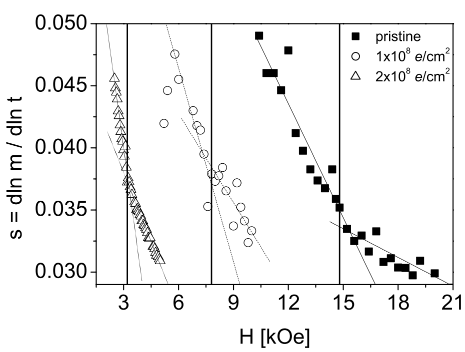

Fig. 2. Field dependence of the relxation rate s, for the pristine sample (squares), after one dose of irradiation (circles), after two doses of irradiation (triangles). Sharp changes occur at fields corresponding to the kink on the descending branch.

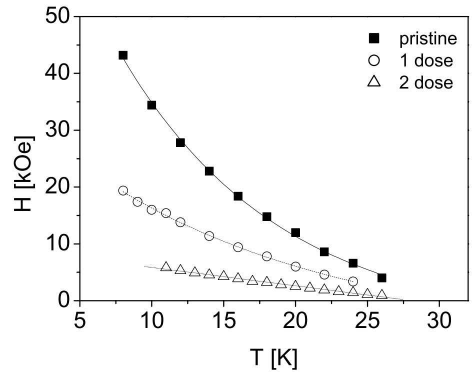

Fig. 3. Order-disorder transition line, for the pristine sample (squares), after one dose of irradiation (circles), after two doses of irradiation (triangles). Lines are guides to the eye.

at lower fields. The curvature of the line is affected by the relative sizes of the pinning and thermal energy; As pinning grows, thermal fluctuations have a relatively smaller effect on the transition. It is expected that as pinning further increases, the transition will ultimately approach a behavior observed in NCCO [7], i.e. temperature independent transition line at low temperatures.

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