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Vortex fluctuations in $YBa_2Cu_3O_{6.5}$ single crystal: Evidence for 2D→3D crossover

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The reversible magnetization M is measured in an $YBa_2Cu_3O_{6.5}$ crystal (T_c=45.2 K) as a function of temperature T for various fields H between 0.2 and 3.5 T. All isochamps for H > 1 T intersect at $T^*_{2D} \approx 42.8$ K and collapse into a single curve when $m = M(H \cdot T)^{(D-1)/D}$ is plotted as a function of $t=(T-T_c(H))/(H \cdot T)^{(D-1)/D}$ where the dimension D=2 ("2D scaling"). Surprisingly, the low field curves also intersect, but at a different temperature $T^*_{3D} \approx 43.4$ K, and they obey a 3D scaling.

1. INTRODUCTION

Thermal fluctuations of vortices in high- T_c superconductors (HTS) has attracted a great interest (see, e.g., [1-4] and references therein). The temperature range where fluctuations are important is proportional to the Ginzburg number: $Gi^{3D} = T_c / \left(2\sqrt{2}\varepsilon\varepsilon_0(0)\xi(0)\right)^2$ or $Gi^{2D} = T_c / \left(2\sqrt{2}\varepsilon\varepsilon_0(0)s\right)^2$ for a 3D and a 2D vortex system, respectively. Here ξ is the correlation length, s is the interlayer distance and ε is the anisotropy. Therefore, experimental study of materials with different anisotropy can provide new information about the physics of vortex fluctuations. A 3D behavior was observed in a fully oxygenated $YBa_2Cu_3O_7$ single crystal $YBa_2Cu_3O_7$ single crystal [5], but a 2D scaling was demonstrated [6] in $YBa_2Cu_3O_{6.6}$.

In the present work we show evidence for a 2D to 3D crossover in the nature of vortex fluctuations in the same $YBa_2Cu_3O_{6.5}$ single crystal (T_c = 45.2 K).

2. RESULTS

Details of sample preparation are given in [7]. The magnetization of our 2.45 x 3.85 x 0.8 mm^3 crystal was measured by a Quantum Design SQUID magnetometer. The high temperature paramagnetic part of the magnetization (46-200 K) was fitted to a Curie law, $M=(\chi_0+C/T)H$, and subtracted from the raw data measured below T_c. In Fig. 1 we show the temperature dependence of the magnetization for various magnetic fields H> 1 T. All these curves intersect at T^*_{2D}= 42.8 K, indicating vortex-fluctuations contribution to the magnetization [1-3]. Low-field measurements (H<1 T) are shown in Fig. 2. Another inter-

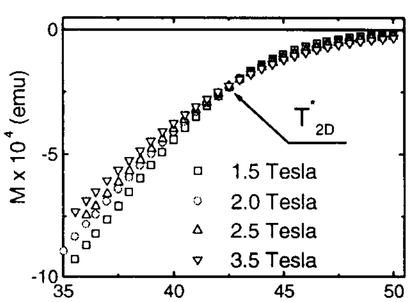

Figure 1. M vs. H for fields > 1 T

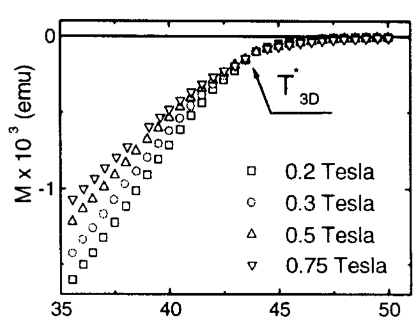

Figure 2. M vs. H for fields < 1 T

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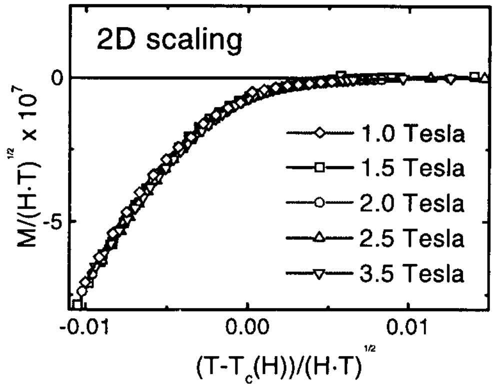

Figure 3. 2D scaling for fields > 1 T

section point, at T^*_{3D}= 43.4 K, is found in this field range. Each group of curves can be scaled by using 2D (H> 1 T) or 3D (H<1 T) scaling, respectively as shown in Figs. 3 and 4. These observations imply a 2D→3D cross over in the vortex fluctuation regime in our sample.

3. DISCUSSION

We presume a 2D→3D crossover [4] due to an increase of the longitudinal correlation length $R_c(T,H)=\xi_{c0}/\sqrt{|\tau_H|}$ with the increase of T or H. Here $\tau_H=(T-T_c(H))/T_c(H)$, $T_c(H)=T_c(0)=(1-H/H^0_{c2})$. When $R_c < s$, the sample is in 2D regime. The condition $R_c(T,H)=s$ defines a 2D→3D crossover line $H_D(T)$. In the vicinity of the transition line $H_{c2}(T)$ there is a region of

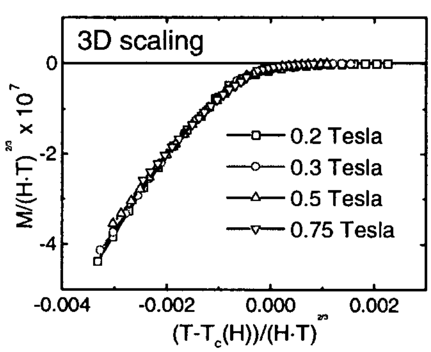

Figure 4. 3D scaling for fields < 1 T

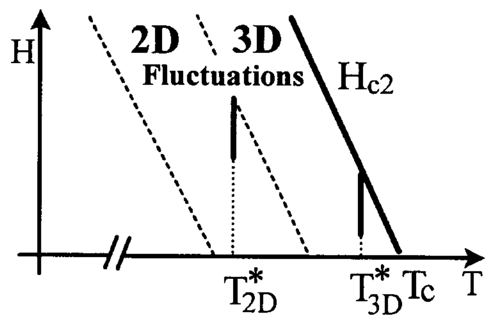

Figure 5. Schematic phase diagram of vortex fluctuations

strong fluctuations, where scaling behavior is expected [1,2]. The 'width' of such a strip depends strongly on the dimensionality of the system - it is wider for the 2D case. It may happen that the 2D→3D crossover line appears inside the 2D strong fluctuation region. Such a situation is described schematically in the field-temperature phase diagram of Fig. 5 in which the fluctuating region is shadowed. (The low field Josephson fluctuations region is not shown).

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