TWO-DIMENSIONAL VORTEX MELTING IN $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$

Bo Chen, W. P. Halperin (Northwestern U., Physics); Prasenjit Guptasarma (U. of Wisconsin-Milwaukee, Physics); D. G. Hinks (Argonne National Laboratory); V. F. Mitrovic (Brown U., Physics); Arneil P. Reyes and P. L. Kuhns (NHMFL)

Introduction

Understanding the vortex state in type-II superconductors has both fundamental value regarding their basic physical properties as well as for possible applications of the superconductive materials. The unique two-dimensional vortex states in layered superconductors with high anisotropy has been predicted by theory many years ago, where the vortex melting temperature is expected to be weakly field dependent at high magnetic field. However, a direct experimental realization has not been demonstrated. $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ (Bi-2212), a high temperature superconductor with extremely high anisotropy, is a good candidate to check the existence of such unique two-dimensional vortex states. Here we report the $^{17}\text{O}$ nuclear magnetic resonance (NMR) investigation of a Bi-2212 single crystal, that provides the first experimental demonstration of the two-dimensional vortex melting at high magnetic field.

Experimental

An overdoped Bi-2212 single crystal with $T_c = 75$ K was obtained by annealing in $^{17}\text{O}$, giving a ~ 60% exchange for $^{16}\text{O}$. NMR spectra of the central transition for $^{17}\text{O}(1)$, the oxygen in the CuO$_2$ plane, were measured in different magnetic fields, from 3 T to 29 T, with c-axis of the crystal parallel to the magnetic field, as a function of temperature from ~ 4 K to 200 K. The data at 18, 22, 27, and 29 T were taken in cell 6 and cell 7, resistive magnets at NHMFL, and low fields at Northwestern University. The freezing of vortices is manifested by a sharp increase of the NMR linewidth in the superconductive state with decreasing temperature, at the temperatures plotted in the figure.

Results and Discussion

The measured central transition of $^{17}\text{O}(1)$ exhibits a temperature dependent linewidth in the superconductive state; the linewidth decreases with decreasing temperature and then increases abruptly as vortices solidify. The data for the onset is fit by the theoretical prediction very well:

$$T_m(H) = T_m^{2D} \left(1 + \frac{1}{\ln^{1/0.37} \left(\frac{H}{H_{c2}}\right)}\right)$$

$T_m^{2D}$ is the limiting melting temperature for two-dimensional vortices at high field, and $H_{c2}$ is the crossover field beyond which vortices in the system decouple into two-dimensional pancakes. Our results indicate this transition from the three-dimensional region at low fields, to the two-dimensional region, where the vortex melting temperatures at high fields approach its field independent limit, $T_m^{2D} = 12 \pm 1$ K.

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References