

TEMPERATURE AND FIELD DEPENDENCE OF THE MAGNETIC PENETRATION LENGTH OF C-AXIS ORIENTED $\text{YBa}_2\text{Cu}_3\text{O}_7$ FILMS

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The penetration depth λ of c-axis oriented thin films of $\text{YBa}_2\text{Cu}_3\text{O}_7$ in perpendicular magnetic fields up to 14T is determined from complex impedance measurements at 1.25kHz. Vortex core pinning dominates over the condensate term and determines the functional form of $\lambda(T,H)$. The critical field $H_{cp}(T)$ identified by $\lambda \rightarrow \infty$ is associated with the vanishing of the curvature of harmonic pinning potentials. The critical temperature at which the pinning potentials vanish is field dependent, in contrast with assumptions elsewhere in the literature.

1. INTRODUCTION

The penetration depth λ defines the length scale over which magnetic fields and currents vary. Knowledge of λ and its temperature dependence provides fundamental information on the strength and nature of the superconductive coupling. A critical temperature may be determined from the point $\lambda \rightarrow \infty$. In the thin-film experiments presented here, a complex impedance is extracted from ac screening measurements and λ is calculated from the inductive component.¹ While λ is directly related to the condensate fraction in zero applied field, in a high magnetic field, the response of pinned vortices will dominate the complex impedance² and hence determine λ . In this regime, the temperature dependence of λ reflects the pinning potential. Further, λ will diverge when pinning, rather than the condensate, vanishes, analogous to the crossover from flux-creep to flux-flow in resistivity measurements.

2. MEASUREMENTS

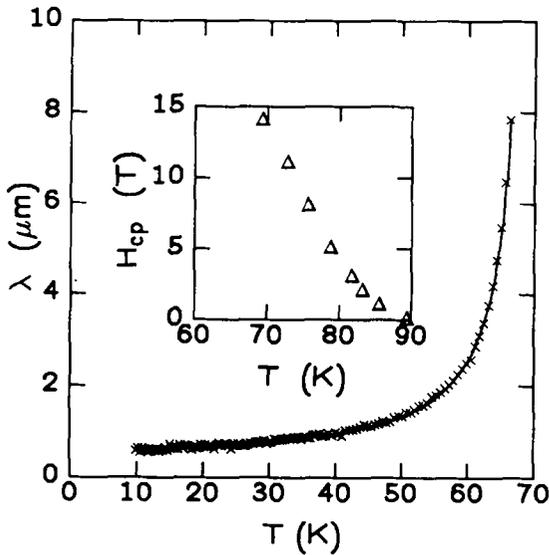
The c-axis oriented 2400Å thick film used for these measurements was grown³ on a (100)SrTiO₃ substrate. Leads were attached in a van der Pauw configuration to a piece approximately 4mm in diameter. This sample was placed between two 1mm diameter coils. The mutual inductance of the

coils is modified due to the complex impedance of the film, from which the screening is calculated¹ at a single frequency of 1.25kHz. Data on the resistance and screening were acquired simultaneously. A static field of up to 14T could be applied perpendicular to the plane of the sample. The sample had a room temperature resistivity of 270μΩ-cm and a critical current density at 77K of 1.8x10⁸A/cm². This, a sharp transition, and the absence of any tail in the transition indicated a high quality sample.

The figure shows the temperature dependence of λ deduced from measurements at 14T. The data diverge at a temperature, $T_c = 69.43\text{K}$ which is well into the tail of the resistive transition ($R/R_N < .01$).

3. MODEL

Since the high field data are dominated by pinned vortices, λ may be calculated from the complex impedance Z_ν arising from uncorrelated motion in harmonic pinning potentials.² Each vortex is pinned with a restoring force κ and damping coefficient η . In the low-frequency (relative to the characteristic response time $\tau = \eta/\kappa$), strong pinning limit $Z_\nu = i\omega L_p$, where $L_p = \Phi_0 H / c^2 \kappa$ is the pinning inductance. The penetration depth in this limit is $\lambda^2 = d\Phi_0 \frac{H}{4\pi\kappa}$ where d is the film thickness.⁴



The pinning force for pinning which occurs on length scales comparable to the superconducting coherence length ξ can be estimated by equating the product of the energy density $H_c^2/8\pi$ and the effective core volume $\pi\xi^2d$ to the stored energy $\kappa\xi^2/2$, giving $\kappa=H_c^2d/4$. Approximating the thermodynamic critical field by $H_c(t)=H_c(0)(1-t^2)$ gives

$$\lambda(t,H)=\frac{(\Phi_0H)^{1/2}}{\pi^{1/2}H_c(0)(1-t^2)}.$$

The solid line in the figure is a fit to this expression with $\lambda(0,14T)=0.63\mu\text{m}$. Similar fits⁵ with the applied field between 1T and 14T confirm the $H^{1/2}$ dependence and give $H_c(0)=.17T$ in agreement with thermodynamic estimates⁶ and thus implies strong vortex pinning.

The locus of points defined by $\lambda\rightarrow\infty$ is shown as a function of field in the inset. This line defines the critical depinning field at which vortex core pinning becomes negligible.

4. CONCLUSIONS

The temperature and field dependence of the

magnetic penetration depth λ is well described by a model of uncorrelated harmonic pinning at high fields. The critical temperature, defined by $\lambda\rightarrow\infty$ is associated with the disappearance of pinning and thus marks the crossover from flux-creep to flux-flow behavior. Although a detailed comparison is not yet available, it appears that the resistance deviates from its low temperature, activated form near this temperature⁷. Certainly, this point is well into the tail of the resistance transition. Central to our analysis is a field dependence to this critical temperature, a dependence previously neglected⁸.

The questions of frequency dependence and possible distributions of pinning strengths are not addressed within the context of the present measurement.

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