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Inductive response of polished, single crystal of UPt₃

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Abstract

Our earlier work on the inductive response of single crystals of UPt₃ revealed a difference between the low frequency (31.7–317 Hz) and the radio frequency (RF) (3–16 MHz) temperature dependence of the susceptibility for $T/T_c < 0.5$. After carefully polishing the surface of the crystals (defect size ≤ 0.3 μm), RF measurements have been repeated, and the results are dependent on the surface conditions.

1. Introduction

Many experimental studies have raised interesting challenges about the nature of the superconducting state in the heavy-fermion system UPt₃ [1]. One of the important parameters that can be investigated is the magnetic field penetration depth, $\lambda(T)$, which provides information about the superconducting ground state. For example, a completely gapped Fermi surface would lead to the usual behavior where the change in $\lambda(T)$ is $\Delta\lambda(T) \sim \exp(-\Delta/T)$ in the low-temperature limit. Alternatively, a superconductor possessing nodes in the gap structure would have $\Delta\lambda(T) \sim T^n$, where n is a number of order unity that depends on the crystallographic direction being studied and the symmetry of the superconducting state [2].

Several groups have measured $\lambda(T)$ in UPt₃ using a variety of techniques and have obtained different results [3–6]. In our previous work [7], we measured $\lambda(T)$ over a broad frequency range (31 Hz 16 MHz) using

inductive methods for $H_{ac} \| c$. Briefly, the low-frequency response, obtained with a mutual inductive technique, showed a linear dependence of $\Delta\lambda(T)$ for $T/T_c < 0.5$. On the other hand, the RF response, obtained with a resonant tank circuit, gave a temperature dependence of $\Delta\lambda(T)$ close to T^2 for $T/T_c < 0.5$. The analysis of our RF data, along with resistivity measurements performed on our samples, allowed us to extract $\lambda(0) \cong 1$–2 μm.

We have extended this work by making similar measurements on polished single crystals, and in this paper, we report our preliminary RF measurements of $\Delta\lambda(T)$.

2. Sample preparation

Scanning electron microscope (SEM) pictures of our etched, but unpolished needles [7] indicated that surface roughness of the order of 2 μm was present. Since $\lambda(T \to 0)$ was also a few microns, we anticipated that surface quality was playing a role in our measurements for $T/T_c < 0.5$. With this in mind, we carefully polished our samples using very fine paper of 0.3 μm grating. The

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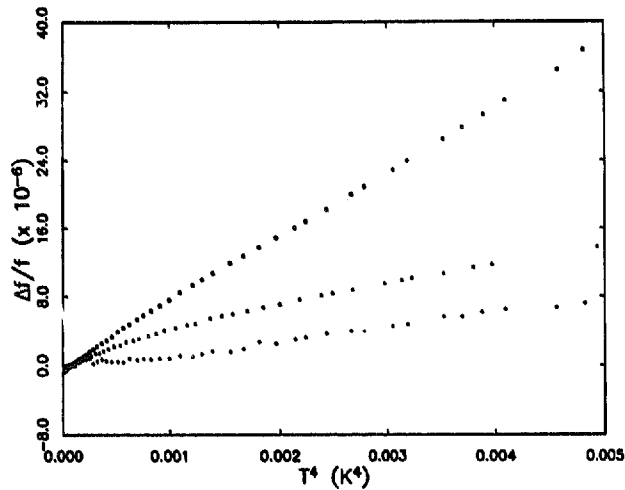Fig. 1. $\Delta f/f$ versus T^4 for $T/T^c < 0.5$ and $f = 1.9$ MHz (o), $f = 6.7$ MHz ($\triangle$) and $f = 34.4$ MHz (+).

samples were mounted on a brass holder and reoriented to polish each of the six facets independently. After polishing, SEM pictures confirmed a much improved surface smoothness, with defects less than 0.3 μm. It is important to note that the polishing did not affect T_c, contrary to other groups findings [2, 8].

3. RF measurements of $\Delta\lambda(T)$

The results of our RF measurements are shown i. Fig. 1 for the three different frequencies used, where $\Delta f/f \equiv \{f(0) - f(T)\}/f$. In all cases, the background temperature dependence, which was determined in the absence of the specimens, was small (< 10%) and subtracted from the data. After polishing, the temperature dependence of $\Delta\lambda(T)$, which is proportional to $\Delta f/f$ [7], is approximately T^4 for $f = 1.9$ MHz and $f = 34.3$ MHz, and closer to T^3 for $f = 6.7$ MHz. This differs from the T^2 dependence found prior to polishing for $f = 3$ MHz and $f = 16$ MHz [7].

4. Discussion

Investigating the frequency dependence of $\lambda(T)$ is motivated by the possible existance of an additional energy

scale which plays a role in the pair breaking of the quasiparticles. For a conventional BCS superconductor, the energy gap (Δ_0 or T_c) is the only relevent parameter. AC measurements, with frequencies lower than T_c (10 GHz for UPt$_3$) should give results similar to DC measurements. One expects this to hold true even for superconductors with gap nodes for temperatures such that $f \ll T \ll T_c$, where f is the measurement frequency (in our case $f \sim 10$ MHz ~ 0.5 mK) [9]. In this context, Putikka et al. [9] proposed a new energy scale responsible for a frequency dependence in our temperature regime. Their motavation was to reconcile the DC measurement of Ref. [3], which reported $\Delta\lambda(T) \sim T^2$, and the RF measurements of Ref. [4], which indicated $\Delta\lambda(T) \sim T^4$.

Our new results suggest a very strong surface quality dependence for $\lambda(T)$ inductive measurements. This observation motivates a more complete investigation especially at lower frequencies. Unfortunately, the polishing procedure reduced the cross-section area of the specimens and thereby reduced our signal to noise ratio. In the case of the mutual inductance experiment, this decrease was sufficient to keep us from extracting $\Delta\lambda(T)$ for $T/T_c < 0.5$. The recent installation of an RF SQUID on our dilution refrigerator should allow us to perform this experiment with high sensitivity. Consequently, we will present a complete picture when we conclude our low-frequency studies on these polished samples.

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