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Superconductivity in Thin Films of UBe_{13}

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Films of the heavy fermion compound UBe_{13} have been prepared by dc sputtering from a compound target. The transition temperatures of 3000 Å thick films deposited onto single-crystal sapphire substrates approach those of bulk material. Temperature dependences of the parallel and perpendicular critical fields of UBe_{13} were determined resistively. The ratio $H_{c\parallel}/H_{c\perp}$ was found to be 1.25, a value which suggests the partial rather than complete suppression of the surface superconductivity of the films. This result implies that the pairing configuration in UBe_{13}, at least near the surface, cannot be pure triplet, or any other pure state with $L\neq0$.

1. INTRODUCTION

The nature of superconducting pairing in heavy fermion metals has been the subject of extensive investigation[1,2] because the results of experimental studies deviated significantly from the predictions of BCS theory for superconductors with s-wave pairing. A widely held view is that the pairing is not s-wave. Symmetry analyses of the order parameter have identified possible pairing configurations consistent with the underlying crystalline symmetry,[3] and indicate that it is appropriate to classify states according to whether they have even or odd parity.

The above classification appears to argue against a single experiment determining the symmetry of the pairing. In this context there have been discussions relating to the observability of Josephson effects between conventional spin-singlet superconductors and postulated anisotropic superconductors[4] and to the character of the proximity effect between such systems[5]. Both of these phenomena are sensitive to the nature of the surface boundary conditions on the order parameter which are specific to the nature of the pairing.

An alternative to the above, in characterizing pairing near a surface is the study of surface superconductivity. As was shown by Saint-James and de Gennes many years ago, the nucleation of the order parameter can occur at a surface in a field higher than the bulk nucleation field H_{c2}[6]. For a film, H_{c2} is the perpendicular critical field and H_{c3}, the surface critical field, is the parallel critical field. For s-wave pairing the ratio H_{c3}/H_{c2} is 1.695 even for a strong-coupled superconductor.[7] Coating of a surface with a normal metal layer, which is a pair-breaker, reduces the ratio of the critical fields to unity. The observation of a ratio less than 1.695, at least for s-wave superconductors, could be evidence of pair breaking at the surface or of an effect due to sample inhomogeneity. For a pure triplet pairing state or any other pairing state with $L\neq0$, as we will argue below, the free surface itself is pair-breaking, and the critical field ratio should be unity.

2. SAMPLE PREPARATION

UBe_{13} films were fabricated in a dc sputtering system. The system was first pumped down to the 10^{-9} Torr range and baked out. It was then back-filled with research grade Ar gas and sputtering was carried out at 1.5 kV in a pressure of 50 μ of Ar. Films were formed at the rate of 15-20 Å/minute on sapphire substrates which were heated to 800°C during the deposition. The UBe_{13} phase was identified from X-ray diffraction data, which also indicated that the samples were random and polycrystalline. The surfaces of the films were highly reflective.

3. EXPERIMENTAL TECHNIQUES

Electrical resistance measurements were carried out using a standard four-terminal arrangement. Large magnetic fields were generated using a Bitter solenoid. The samples were cooled using a top-loading dilution refrigerator. A calibrated resistance thermometer was used to determine temperatures.

4. RESULTS

Figure 1 shows a plot of R(T) for a 3000 Å thick UBe_{13} film in zero magnetic field. The superconducting transition is comparable to that found in bulk material.[8] However, the sharp rise in resistivity at 2K observed in bulk material was not found in these films. The relatively broad extremum in the normal-state resistivity found near 20K was observed.

The magnetoresistance of the films was measured in both the parallel and the perpendicular orientations. Data were taken at fixed T by sweeping the field. The shift of the data in parallel fields relative to that in perpendicular fields was more substantial than that reported in

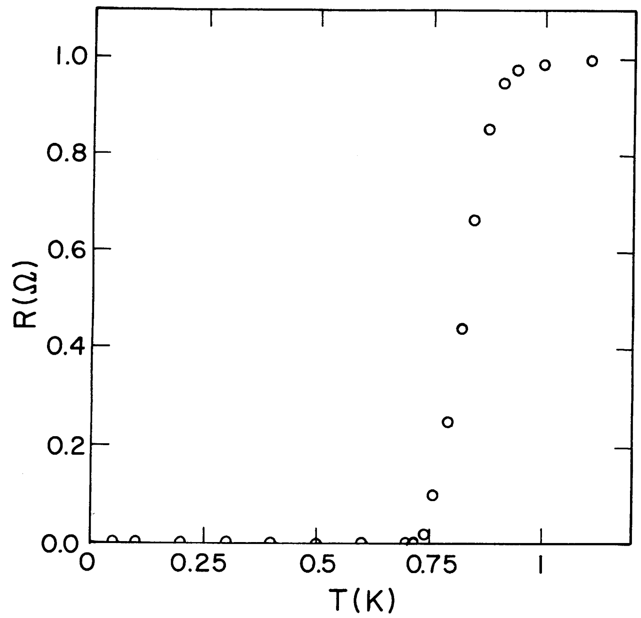

Fig. 1. Temperature dependence of R(T) of a 3000 Å thick UBe_{13} film.

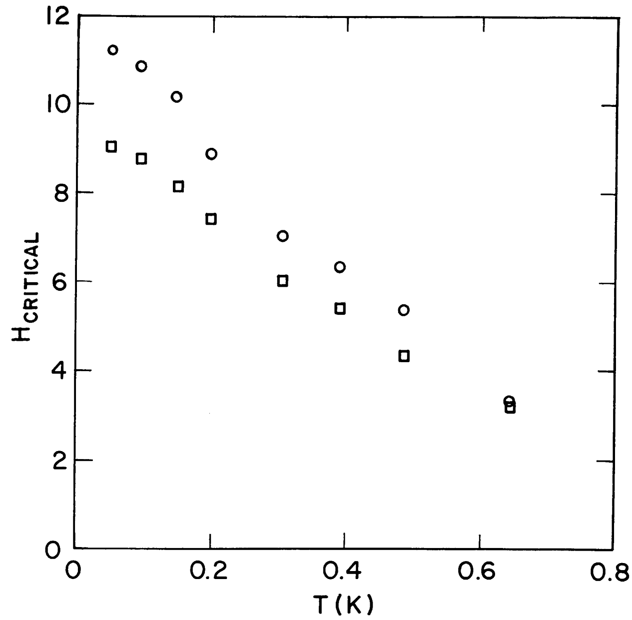

Fig. 2. Parallel (circles) and perpendicular (squares) critical field ($H_{critical}$) in Tesla of a UBe_{13} film as a function of temperature (T).

previous studies of UBe_{13} films.[9]

Because of the strong negative magnetoresistance in the normal state, there is ambiguity as to the definition of the critical fields H_{c2} or H_{c3}. We have taken as the critical fields the values of field at which the resistance is 1/2 of the peak resistance in the normal state. The resultant curves are shown in Fig. 2.

5. DISCUSSION

The main feature of Fig. 2 is the observation that $H_{c3}/H_{c2} \sim 1.25$. If 1.695 had been found, triplet or any other $L \neq 0$ pairing configuration could have been ruled out. The ratio being less than 1.695 does not in itself preclude pure s-wave superconductivity because of the possibility of either pair-breaking or inhomogeneity effects that could even reduce the critical field ratio to unity. The latter value would actually be expected for pure triplet pairing configuration or other pure $L \neq 0$ pairing configuration. The reason for this is that these do not obey Anderson's theorem.[10] As a consequence both nonmagnetic scattering centers and surfaces are pair-breakers. The critical field ratio would be reduced to unity because of surface pair-breaking.

In summary, the result $H_{c3}/H_{c2}=1.25$, although ambiguous with regard to ruling out s-wave pairing in UBe_{13}, does preclude the possibility of pure states with any $L \neq 0$ pairing at least at the surface. Because surface scattering may modify the pairing, it may be unwise to draw conclusions about the interior of a material from the measurement of a surface property such as H_{c3}. A similar caveat would apply to the study of superconducting tunneling and the proximity effect.

6. ACKNOWLEDGEMENTS

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REFERENCES

1) G.R. Stewart: Rev. Mod. Phys. 56(1984) 755.
2) P.A. Lee et al., Comments on Solid State Phys. XII(1986) 99.
3) G.E. Volovik and L.P. Gor'kov: Sov. Phys. JETP 66(1985) 843; E. Blount: Phys. Rev. B 32(1985) 2935.
4) E.W. Fenton: Solid State Commun., 60(1986) 347.
5) Siyuan Han et al.: Phys. Rev. Lett. 57(1986) 238.
6) D. Saint-James and P.G. De Gennes: Phys. Lett. 7(1963) 306.
7) Gert Eilenberger and Vinay Ambegaokar: Phys. Rev. 158(1967) 332.
8) H.R. Ott, H. Rudiger, Z. Fisk and J.L. Smith: Phys. Rev. Lett. 50(1983) 1595.
9) P.M. Tedrow and J.H. Quateman: Phys. Rev. B 34(1986) 4595.
10) R. Balian and N.R. Werthamer: Phys. Rev. 131(1963) 1553.