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PROXIMITY EFFECTS IN $CeCu_6$/Nb BILAYERS*

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We studied the proximity effect in order to probe the response of the heavy-fermion metal $CeCu_6$ to induced superconductivity. High-quality $CeCu_6$ films were grown by sputter deposition. Resistivity measurements show that the correlated electron state is formed. Bilayers were prepared of $CeCu_6$(75 nm)/Nb(d_{Nb}), with the Nb thickness d_{Nb} between 10 nm and 50 nm. Measured were the superconducting transition temperature T_{c} and the parallel critical fields $H_{\mathrm{c2}}^{||}$. We find that the interface transparency is high, indicating that Fermi-velocity mismatch effects are not significant, but the coherence length of the induced superconductivity is small, which is probably due to the very low Fermi-velocity in the heavy fermion metal.

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1. Introduction

In simple normal metals such as Au or Pd, questions about their ability to sustain superconducting correlations or unbalanced spins are of much interest. Similar questions can be raised about a metallic ground state with strong intrinsic correlations such as in heavy fermion (HF) systems. Specifically, if a metal is in contact with a superconductor, it can be asked what the mechanism is for pair breaking of Cooper pairs diffusing out of the superconductor. For normal metals (N) the mechanism is dephasing due to a finite temperature; for ferromagnets (F) it is the effect of the exchange field; for a HF ground state the answer is not known, and could involve *e.g.* spin fluctuations. An intrinsic problem for such studies is that the material has to be available in thin film form. Here we present the first results of a

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study of the proximity effect in a system consisting of thin films of the HF material $\mathrm{CeCu_6}$ combined with thin films of a superconductor (S), in this case Nb. Among the different HF systems, $\mathrm{CeCu_6}$ is of particular interest since it does not order magnetically down to mK temperatures [1,2].

2. Sample preparation

Sets of $\mathrm{CeCu_6}$ films and bilayers of $\mathrm{CeCu_6}$/Nb were made by DC-magnetron sputtering. We used an ultra high vacuum system with a background pressure of the order of 5×10^{-10} mbar, and an Ar sputtering pressure of 2.5×10^{-3} mbar. Crystalline $\mathrm{CeCu_6}$ was grown as reported before [3], at a temperature of 350° C using Si-substrates with amorphous $\mathrm{Si_3N_4}$ buffer layers to prevent Cu diffusion at those temperatures.

The Nb was deposited on top of the $\mathrm{CeCu_6}$ after cooling the substrate holder with cold nitrogen gas to close to room temperature. Composition, thickness and crystallinity of the films were determined by Rutherford backscattering (RBS) measurements together with X-ray diffraction measurements at low and high angles. The RBS measurements show good agreement with the expected stoichiometry for $\mathrm{CeCu_6}$ and no diffusion is found either of Ce or Cu into the substrate or of Nb into the $\mathrm{CeCu_6}$. Fig. 1 shows part of the RBS spectrum for $\mathrm{CeCu_6}$(75 nm)/Nb(15 nm) on a $\mathrm{Si/Si_3N_4}$ substrate and a fit of the data without taking any diffusion into account.

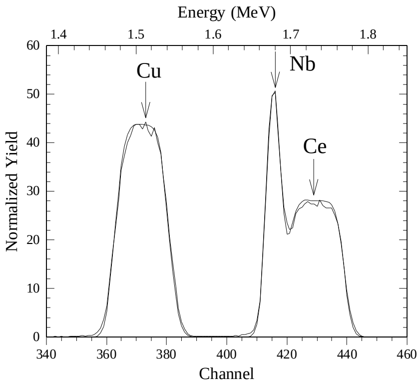

Fig. 1. RBS measurement using ^{4}He-ions of 2 MeV on a sample $\mathrm{Si/Si_3N_4/CeCu_6}$(75 nm)/Nb(15 nm). The different elements are indicated. The thin smooth line is a fit to the measured curve.

Fig. 2(a) shows the electrical resistivity ρ as a function of temperature T for two single films of $\mathrm{CeCu_6}$ with different thickness. A clear maximum in $\rho(T)$ is observed at $T_{\mathrm{max}} \approx 5$ K, similar to what is found for bulk material [4] and in previous investigations on sputtered $CeCu_6$ films [3]. We decided to use 75 nm thick $CeCu_6$ layer, which with $T_{\max} = 4$ K suggest only little deviation from the bulk properties.

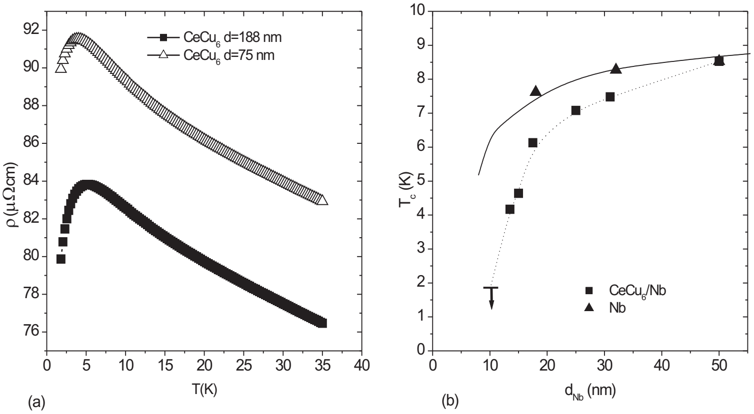

Fig. 2. (a) Resistivity as a function of temperature for $CeCu_6$ films of 75 nm and 188 nm. (b) Critical temperature as a function of Nb thickness d_{Nb} for bilayers $CeCu_6$/Nb and single Nb films. The solid line represents the typical behavior for Nb single films from different deposition systems, triangles show values for Nb films made in the same system as the $CeCu_6$/Nb bilayers, the dotted line is a guide to the eye.

3. $CeCu_6$/Nb bilayers; results and discussion

The superconducting transition temperature T_c was determined from resistivity measurements on a set of $CeCu_6$(75 nm)/Nb(d_{Nb}) with variable Nb thickness d_{Nb} in the range 10 nm to 50 nm. As seen in Fig. 2(b), T_c shows a strong suppression, with a critical thickness d_{cr} for onset of superconductivity reached around 12 nm. This would be equivalent to 24 nm in a trilayer configuration, and of a similar magnitude as found in Fe/Nb/Fe trilayers [5]. It has to be kept in mind however that single thin Nb films also show a decrease of T_c at small thickness (see Fig. 2(b)), which makes the correct determination of d_{cr} more difficult. The result shows, however, that the interface does allow particle exchange, opposite to what might be expected from the huge Fermi velocity mismatch in the system of order 10^3.

Also the parallel critical field $H_{c2}^{||}$ behaves differently than expected for simple N/S systems; as shown in Fig. 3(a) no dimensional crossover (DCO) is found at any Nb thickness, in contrast to the behavior of *e.g.* Cu/Nb, as witnessed by a sample Cu(75 nm)/Nb(15 nm) prepared for comparison (Fig. 3(b)).

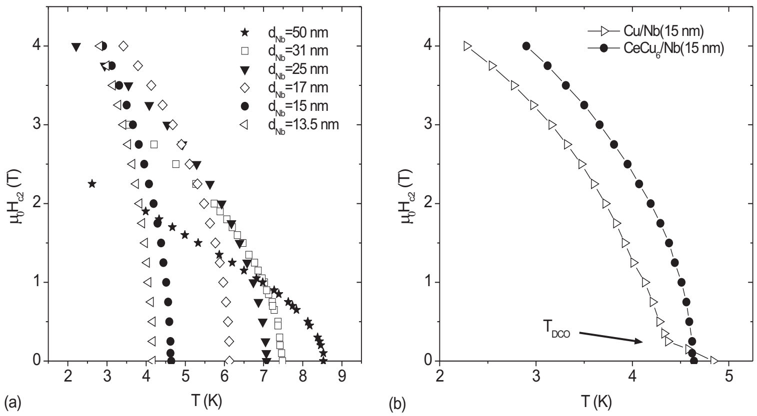

Fig. 3. Upper parallel critical field as a function of temperature for: (a) bilayers $CeCu_6$(75 nm)/Nb, $d_{\rm Nb}$ as indicated; (b) bilayers of $CeCu_6$(75 nm)/Nb(15 nm) and Cu(75 nm)/Nb(15 nm) with $T_{\rm DCO}$ indicated.

Absence of the DCO means that no appreciable amount of superconductivity leaks into the HF metal; together with the finite transparency this means either appreciable pair breaking by the HF metal, or a very small diffusivity due to the low Fermi velocity $v_{\rm F}$. Whether a small $v_{\rm F}$ alone is able to explain the experiments is presently under investigation.

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