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Influence of magnetic order in the superconducting properties of Nb/Fe/Cu multilayers

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Abstract

The superconducting properties of a Nb film can be strongly affected by a ferromagnetic layer in contact with it due to the magnetic proximity effect. In order to study the efficiency of this pair-breaking effect as a function of the magnetic order present in the ferromagnetic layer, [Fe/Cu]/Nb multilayers have been grown by DC sputtering and MBE. As the Fe layer thickness is varied in the range 0–20 Å, a phase transition is induced from FCC γ-Fe to BCC α-Fe so that the Fe Curie temperature is abruptly increased. An enhancement in the superconducting transition temperature of the Nb film is found for the samples with BCC α-Fe in comparison with those with FCC γ-Fe. These results imply a more efficient proximity effect for the material with the lower Curie temperature.

Keywords: Proximity effect; Multilayers; Pair breaking

Superconductivity and magnetism are generally two competing forms of order, since magnetic atoms act as strong breakers of the Cooper pairs. Interaction between superconductivity and magnetism can result in a rich variety of phenomena such as mutual exclusion in reentrant compounds [1] or coexistence of superconductivity and GMR in high-temperature superconducting superlattices [2].

In particular, superconductor/ferromagnetic (SC/F) multilayers can be very useful model system in order to analyze this interaction [3]. Experimental studies in metallic SC/F multilayers have shown different qualitative behaviours that range from a fast suppression of superconductivity [4] to an oscillatory dependence of the superconducting transition as a function of the ferromagnetic layer thickness [5]. Different approaches have been used to explain this anomalous behaviour, mainly the possible existence of an exotic kind of coupling between the superconducting layers (π-coupling) [5] or changes in the magnetic order in the ferromagnetic layers [6].

In order to clarify the role of magnetic order in the proximity effect between superconducting and magnetic layers, we have studied the superconducting properties of SC/F bilayers, where the superconductor is a 200 Å Nb film and ferromagnet is an Fe/Cu superlattice (see the sketch in Fig. 1). In this geometry any effects coming from (π-coupling) can be excluded since there is only one superconducting layer. On the other hand, the ferromagnetic layer has been chosen to be an Fe/Cu superlattice because a controllable magnetic transition can be induced in it by changing the Fe layer thickness [7]. Then, the behaviour of the superconducting properties of the Nb film can be simply correlated with the changes in magnetic order of the Fe/Cu superlattice.

The [Fe/Cu]/Nb samples have been deposited on Si (1 0 0) substrates at room temperature by DC sputtering and MBE. The magnetic and structural transition in the Fe/Cu superlattice has been characterized by X-ray diffraction and with a SQUID magnetometer. Fig. 2 shows the X-ray θ–2θ scans for a series of $[\mathrm{Fe(t)}/\mathrm{Cu(3t)}]_8$ superlattices with different Fe layer thickness (t). The position of the high-angle peak shifts to the right when t is increased above 10 Å, indicating a structural transition in the superlattices. When $t \leqslant 10$ Å. The strain due to the FCC Cu layers induces the growth of FCC

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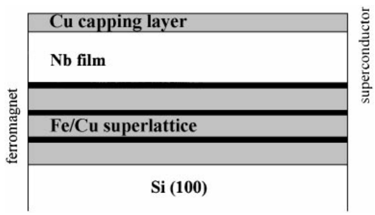

Fig. 1. Sketch of the Nb/Fe/Cu multilayer structure used in the study of the ferromagnetic proximity effect. Superconducting layer: 200 Å Nb film; Ferromagnetic layer: $[Fe(t)/Cu(42\ Å]_8$ superlattice with $t = 0$–25 Å where a magnetic transition from α-Fe to γ-Fe can be induced as a function of the Fe layer thickness (see text).

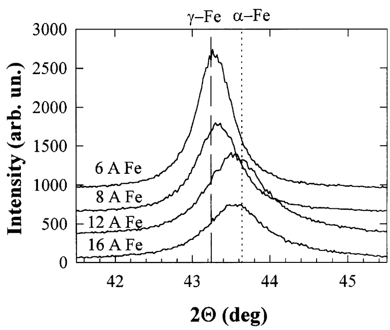

Fig. 2. θ–2θ X-ray diffraction scans for several $[Fe(t)/Cu(3t)]_8$ superlattices with different Fe layer thickness. Dashed lines indicate the calculated spacings for a superlattice with α-Fe (d_{110}(α-Fe) = 2.02 Å) and a superlattice with ferromagnetic γ-Fe (d_{111}(α-Fe) = 2.102 Å).

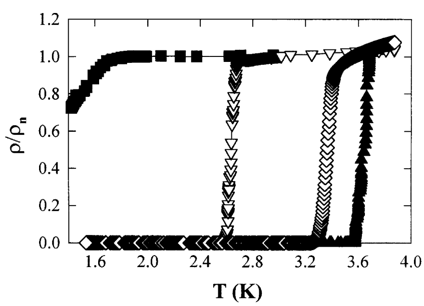

Fig. 3. Resistivity vs. temperature curves for several $[Fe(t)/Cu(42\ Å)]_8$/200 Å Nb multilayers: filled squares, $t = 5$ Å; hollow triangles $t = 7$ Å; filled triangles, $t = 11$ Å; hollow rhomboids, $t = 20$ Å. Each curve has been normalized by the normal state value of the resistivity ρ_n just above the transition.

γ-Fe. On the other hand, for the samples with larger Fe thickness the Fe layers present the usual BCC structure of the α-Fe phase. This phase transition implies an increase in the Curie temperature of the superlattice from $T_{Curie} \approx 210$ K for ferromagnetic γ-Fe [8] to $T_{Curie} =$ 1043 K of α-Fe.

The proximity effect of the Fe/Cu superlattice in contact with the Nb thin film has a clear influence on its superconducting transition. Fig. 3 shows the resistivity vs. temperature curves for several [Fe/Cu]/Nb multilayers with different Fe layer thicknesses, grown in the same run. In all the cases the superconducting transition temperature (T_C) is strongly suppressed in comparison with that of a single Nb film grown in the same conditions, T_C(film) = 6.04 K. The lowest value of $T_C = 1.6$ K is found for the sample with thinner Fe layers ($t = 5$ Å). Then, T_C goes up as the Fe layer thickness is increased up to the phase transition thickness from γ-Fe to α-Fe and has a maximum value of $T_C = 3.6$ K for $t = 11$ Å. Finally, T_C decreases again for the multilayer with thicker Fe layers ($t = 20$ Å). Therefore, this experimental behaviour implies a more efficient magnetic proximity effect for the samples with γ-Fe than those with α-Fe, i.e. the pairbreaking by the magnetic atoms is stronger for the material with lower T_{Curie}. These results would suggest a dominant pair breaking mechanism by spin-flip scattering processes that can be hindered by the stronger magnetic order [9].

In summary, the superconducting properties of [Fe/Cu]/Nb multilayers have been studied as a function of the magnetic order present in the Fe layers. An enhancement in the superconducting transition temperature is found as the Fe layers change from the FCC γ-Fe with $T_{Curie} \approx 210$ K to BCC α-Fe with $T_{Curie} = 1043$ K, i.e. the magnetic proximity effect is weakened by the stronger magnetic order.

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