Nonmonotonic behaviour of superconducting critical temperature of Nb/CuNi bilayers with a nanometer range of layer thickness

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***Abstract* — Present work reports the result of the proximity effect investigation for superconducting Nb/CuNi-bilayers with the thickness of the ferromagnetic layer (Cu_xNi_{1-x}) being in the sub-nanometer range. It was found a non-monotonic behavior of the critical temperature, T_c , i.e. its growth with the increasing of the ferromagnetic layer thickness, dF , for the series of the samples with constant thicknesses of Nb layer, (d_{Nb} = const).**

***Index Terms* — superconducting critical temperature, nanolayers, inhomogeneous pairing.**

I. INTRODUCTION

The investigation of proximity effect in superconductor–ferromagnet layered systems are of interest both from the viewpoint of implementing inhomogeneous pairing of the Larkin–Ovchinnikov–Fulde–Ferrel type [1, 2] and as a main combination of materials in constructing π-junctions [3] and superconducting logical networks on their base [4, 5]. Are especially interesting and complicated for experimental study of layered systems with ultra thin ferromagnetic layers : $dF \ll \xi_F$ (ξ_F – the coherence length of superconducting pair in ferromagnetic). The theory predicts very unsimilar dependences of Tc from dF in this range of thicknesses for different ratios of many parameters. The thickness and critical temperature of superconductor, mean free path in superconductor and ferromagnetic, value of exchange field E_{ex} , interface parameters and the quantum-mechanical interface transparency T_m and other can affect on dependence Tc (dF). For sufficiently strong ferromagnetics usually one can expect fast suppression of T_c with dF increasing with a subsequent minimum, reentrance or stabilization [6]. On the other hand the presence of T_c maximum theoretically was predicted for the case of sufficiently strong spin-orbit scattering [7].

II. SAMPLES PREPARATION AND CHARACTERIZATION

The samples were deposited on oxidized Si substrates using system Z-400 (Leibold AG). The first was formed Nb layer by DC-magnetron sputtering then CuNi layer by RF-cathode sputtering. The diameter of the Nb and Cu/Ni targets was 75 mm. Two series of the samples with thicknesses of Nb layer 10 and 8.5 nm and equal CuNi layer were fabricated at one run by wedge method. The oxidized Si substrate with sizes 75*10 mm was placed radially with the shift of the edge at about 5 mm from the Cu/Ni target's center projection. This position was fixed during the sputtering of Cu/Ni layer , whereas the Nb target moved with linear speed to achieve the equal thickness of Nb layer at all area of the substrate. After sputtering the sample was cutted on the equal pieces with period 3 mm. The details of this method are subscribed in [8]. The measurements of T_c were performed by the four-probe technique immediately after the sample preparation to avoid the oxidation influence. The temperature of superconducting transition (T_c) was determined as a middle point of the transition. The width of the transition did not exceed 0.1 K for data on Fig.3 and 0.15 K for data on Fig.4.

The Retherford Back Sputtering (RBS) technique was used for Cu/Ni layer thickness calibration (Fig.1) and Cu/Ni ratio determination (Fig. 2). The thickness calibration was calculated separately for Ni, Cu and Cu+Ni composition for the sample, deposited by wedge method at the same conditions as for measured ones but with 10 Cu/Ni layers and without Nb layer. One can see the linear decreasing of the Cu/Ni layer's thickness and constant Cu/Ni ratio for pieces with thickness from 20 to 5 nm (1st region). Such thicknesses approximately correspond with the position on the wedge opposite to the Cu/Ni target. One can see the lowering of Ni concentration and the reduction of the thickness decreasing rate in the second region.

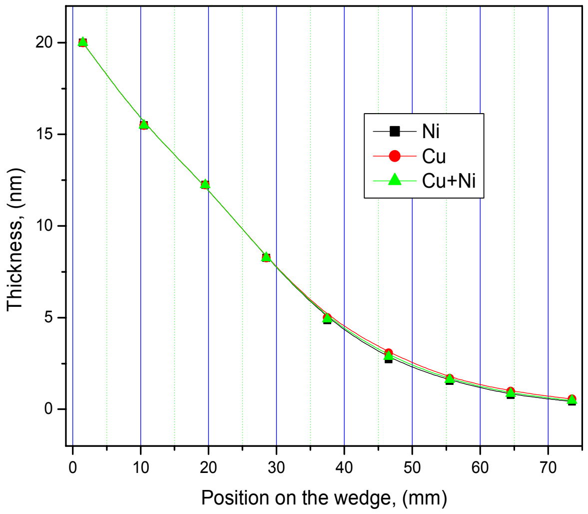

Fig.1. Calibration curve for the ferromagnet layer thickness determination using data for Cu, Ni and Cu+Ni composition (based on RBS data).

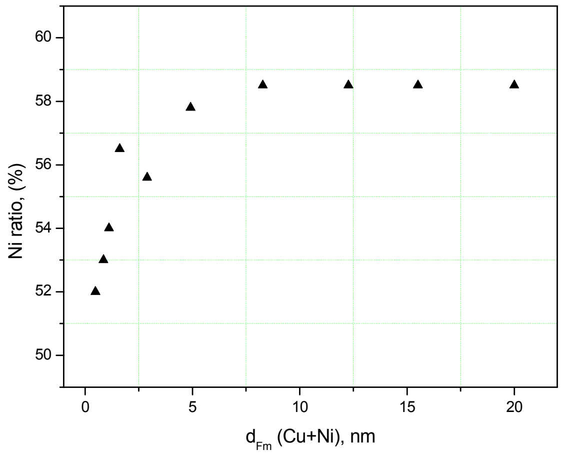

Fig. 2. The ratio of Ni in the Cu/Ni composition for various thicknesses of ferromagnetic layer.

III. THE RESULTS AND DISCUSSION.

The results of measurements of critical superconducting temperature T_c and Ni ratio in CuNi composition from thickness of CuNi ferromagnetic layer dFm are presented on Fig.3.

One can see the smooth depression of superconductivity at the high thicknesses of CuNi layer for series with d_{Nb} = 10 nm and full suppression of T_c for series with d_{Nb}= 8.4 nm. This result can be explained on the base of proximity effect for weak ferromagnets, when we consider the decreasing of T_c owing to the proximity effect in metals and strong dependence T_c from thickness for thin Nb films. The layer with weak ferromagnetic is able to suppress Tc only in the case of sufficiently depressed superconductivity.

The unusial effect of T_c growth with increasing of d_{Fm} and Ni ratio was found for bilayer with d_{Nb} = 10 nm for very small (near 1 nm) CuNi thicknesses. The base of the explanation of this phenomena can be the influence of spin-orbit scattering [7]. One can see the maximum of T_c in the range of small magnetic layer thicknesses from Fig. 5 in [7] for certain combination of magnetic and superconducting parameters. The $T_c(d_{Fm})$ maximum can be observable for sufficiently weak ferromagnetic with strong spin orbit scattering.

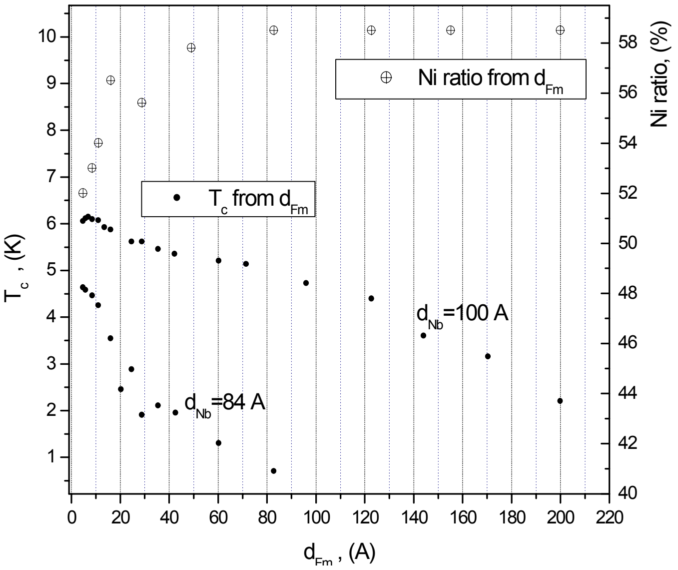

Fig. 3. The dependence of critical superconducting temperature Tc (left axis), Ni ratio in CuNi layer – (right axis) from ferromagnet CuNi layer thickness for 2 series of samples with different thicknesses of Nb layer. The thickness of Nb layer dNb is constant and dNb= 10 nm (the upper series of dark circles) and 8.4 nm (the lower series of dark circles.

IV. CONCLUSION

Different types of critical superconducting temperature Tc dependence from thickness of ferromagnetic layer dF were observed for 2 series of samples prepared at equal technological conditions but different thickness of superconducting layer (10 nm and 8.4 nm). The change of critical temperature of Nb layer Tc0 with decreasing of its thickness may be the reason of changing of the type of Tc(dF) dependences.

It was found the maximum of Tc in the sub-nanometer range of dF in spite of increasing the Ni ratio with dF. The sufficiently strong spin-orbit scattering may be the possible explanation [7].

This work was supported by RFBR-Moldova grants 08.820.05.28RF , 08.820.05.30RF , and 08.820.06.43RF.

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