OSCILLATION OF THE SUPERCONDUCTING CRITICAL TEMPERATURE IN SUPERCONDUCTOR/FERROMAGNET BILAYERS

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Present work reports the results of proximity effect investigation for superconducting Nb-Cu/Ni bilayers with the thickness of the ferromagnetic layer (Cu_xNi_{1-x}) being in sub-nanometer scale. It was found a non-monotonic behavior of the critical temperature, T_c , i.e. its growth with the ferromagnetic layer thickness increasing , d_F , for series of samples with constant thicknesses of Nb layer, d_{Nb} = const. The possible reasons of the T_c non-monotonic behavior at the sub-nanometer range of d_F variation are discussed.

Investigation of proximity effect in superconductor–ferromagnet (SF) layered systems are of interest both from the viewpoint of implementing inhomogeneous pairing of the Larkin–Ovchinnikov–Fulde–Ferrel type [1,2] as well as from practical reason: SF layered materials are promising for constructing π-junctions [3] and superconducting logical networks on their base [4, 5]. There exist up to now a lack of experimental study of layered systems with ultra thin ferromagnetic layers with the thickness $dF \ll \xi_F$ (ξ_F – the coherence length of superconducting pair in ferromagnetic). The theory predicts the possibility of observation of mixed vortex-LOFF state in parallel magnetic field for the 2D layered superconductors [6]. In present work we investigated layered SF samples Nb-Cu/Ni ultra thin ferromagnet Cu/Ni films. Oscillating dependence of superconducting critical temperature, Tc , on parallel external magnetic field was found.

SAMPLES PREPARATION AND CHARACTERIZATION

Investigated SF samples were deposited on Si substrates using Z-400 Leibold AG sputtering system. First was formed Nb layer by DC-magnetron sputtering then Cu/Ni layer by RF-cathode sputtering. The series of samples with equal Nb layer thickness and various thicknesses of Cu/Ni were formed at one run using wedge method [9]. Tc measurements were performed immediately after the sample preparation to avoid the oxidation influence. The Rutherford Back Scattering (RBS) technique was used for Cu/Ni layer thickness calibration and Cu/Ni ratio determination. The thickness calibration was calculated separately for Ni, Cu and Cu+Ni composition for the series of the samples, deposited at the same conditions as for measured ones. The Cu/Ni composition for the marked by arrow in fig.2 sample is 0.46/0.54. This value corresponds to $T_{Curie} \approx 110$ K for bulk samples [8].

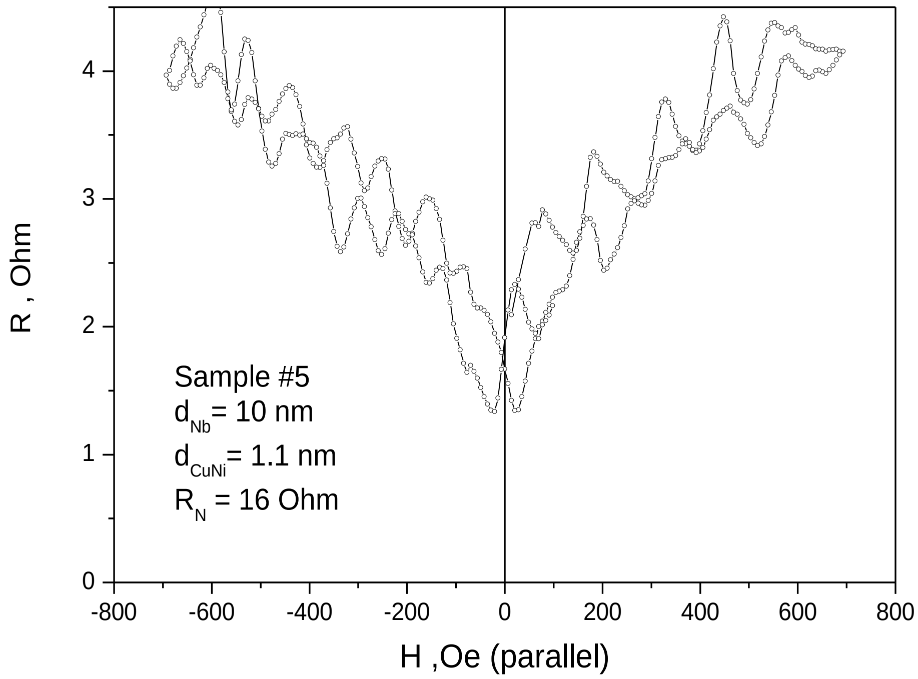

Fig.1. The data of resistivity measurements in the vicinity of superconducting transition with applied parallel to the layers magnetic field. The thickness of Nb layer is 10 nm. The thickness of CuNi layer is about 1.1 nm. The resistivity of the sample in normal state is 16 Ohm. These data concern to the same sample as marked by arrow on fig. 4 and 2. The line is only the guide for eyes.

RESULTS AND DISCUSSION

The results of resistivity measurements in applied parallel to the layers external magnetic field in the vicinity of superconducting transition are presented in fig.1. The line is guide for the eyes. The presented results concern to the marked by arrow in fig.2 data points. The results of measurements of critical superconducting temperature T_c and Ni ratio in Cu/Ni composition on thickness of Cu/Ni ferromagnet layer, dF , are presented in fig.2. Tc was determined as a middle point of transitions, the width of transition did not exceed 0.1 K (0.1-0.9Rn - criteria) for data in fig.2. It was found the maximum of Tc in the sub-nanometer range of dF in spite of increasing of the Ni ratio with increasing dF. The sufficiently strong spin-orbit scattering which suppress the Exchange field may be the possible explanation of this maximum [7].

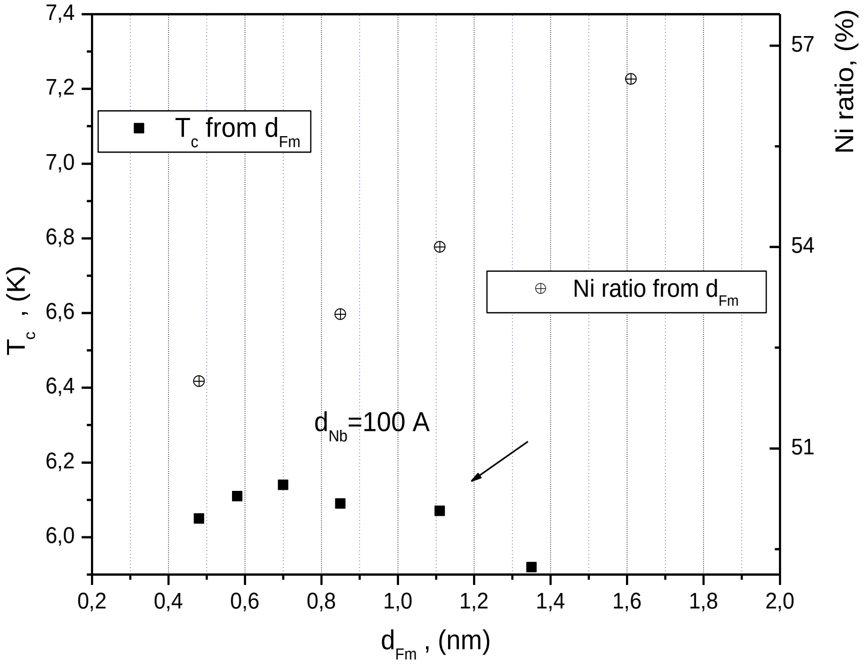

Fig.2. The dependence of critical superconducting temperature Tc (left axis) and Ni ratio in CuNi layer – (right axis) from ferromagnet CuNi layer thickness in ultra-thin range. The thickness of Nb layer dNb is constant and dNb= 10 nm. The R(H) measurements (fig.3) were performed on the marked by arrow sample.

The normal resistance of the bilayer, marked by arrow in fig.2 , is 16 Ohm just above the superconducting transition. The measurements in magnetic field applied parallel to the layers were performed for low parts of superconducting transition (few Ohms). The temperature was stabilized by means of the stabilization of the heating power, which was applied to the sample. One can see the oscillations of the bilayer resistance, which means the oscillations of superconducting critical temperature, besides the obvious monotonic R(T)-behavior with variation of the external magnetic field. The origin of these oscillations is not sufficiently clear. One of the possible reasons can be dealt with mixed vortex-LOFF state [6] as with the oscillation of the magneto-resistance of the ultra-thin ferromagnetic layer due to its magnetic domain structure or with the change of magnetic flow which can occurs when magnetic domain walls move in ferromagnetic layer.

CONCLUSION

Oscillating dependence of the resistivity on parallel external magnetic field in the vicinity of superconducting transition for Nb-Cu/Ni bilayers was found, which means the oscillations of superconducting critical temperature. The maximum of Tc in the sub-nanometer range of dF in spite of increasing the Ni ratio with dF increasing has been observed. The sufficiently strong spin-orbit scattering [7], the mixed LOFF-vortex state [6], or the influence of magnetic domain structure may be the possible explanation of observed phenomena.

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REFERENCES

1. A. I. Larkin and Yu. N. Ovchinnikov, Zh. Éksp. Teor. Fiz. **47**, 1136 (1964) [Sov. Phys. JETP **20**, 762 (1964)]
2. P. Fulde and R. A. Ferrel, Phys. Rev. **135**, 1550 (1964)
3. Z. Radovic, M. Ledvij, L. Dobrosavljevic-Grujic, *et al.*, Phys. Rev. B **44**, 759 (1991)
4. L. R. Tagirov, Phys. Rev. Lett. **83**, 2058 (1999)
5. V. V. Ryazanov, V. A. Oboznov, A. V. Veretennikov, and A. Yu. Rusanov, Phys. Rev. B **65**, R020 501 (2001)
6. U. Klein Phys. Rev. B **69**, 134518 (2004)
7. E.A. Demler, G.B. Arnold and M.R. Beasley Phys. Rev. B **55**, 15174 (1997)
8. C. Liu and S. D. Bader, J. Appl. Phys. **67** (9), 5758 (1990)
9. A. S. Sidorenko, V. I. Zdravkov et.al. Ann. Der Phys.(Leipzig) 12, 37 (2003)