High quality Nb and Nb/CuNi nanolayers for superconducting spintronics

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Abstract — **Advanced technological process for preparation of high quality superconducting Nb and ferromagnetic CuNi -alloy nanolayers of large area (~200 mm^2) is developed based on DC-magnetron sputtering. Homogeneity and proper thickness of the layers were proved by the target-holder movement during the DC sputtering. Rutherford backscattering spectrometry used for precise thickness measurements. The proposed technology serves as a base for development of superconducting spintronic devices.**

The developed technology is patented and merited by the silver medal on the international exhibition "INFOINVENT-2007"

Index Terms — **nanotechnology, superconductivity, microelectronics.**

I. INTRODUCTION

Superconducting hybrids based on thin films are the object for intense investigations for recent decades as a base element for superconducting electronics [1]. The investigations of proximity effect at Superconductor/Normal metal (S/N) and Superconductor/Ferromagnet (S/F) interfaces require technological approach yields high quality superconducting films with constant thicknesses and enhanced superconducting properties. Niobium is the common material for superconducting electronics. Unfortunately, Nb has a high getter capacity whereas adsorbed gases which intensively affects the superconducting properties especially for nanoscale thick films. On the other hand, S/F superconducting structures with Nb layers of this range of thicknesses demonstrate main interesting physical phenomena based on space oscillation of order parameter due to proximity effect [2, 3, 4]. Reliable producing of the most interesting range of superconducting Nb layer thicknesses of $d_{Nb} \sim$ 5-15 nm (keeping $d_{Nb} \approx \xi_{Sc}$ – superconducting coherence length) with reproducible high quality and with critical temperature T_c close to its bulk material value, using a method compatible with multilayered structures production, is a challenge for constructing of superconducting devices based on proximity effect [2, 3]. The efficient technological approach for producing of leered samples with equal superconducting layers was demonstrated in [5]. The disadvantage of this approach is relatively low T_c of Nb layer (6.4 K for single Nb layer with d_{Nb}=31 nm).

The protection cup and buffer layers from neutral material (Al_2O_3 or Si for example) could be useful to avoid impurity penetration in Nb layer and protection again oxidation.

II. EXPERIMENTAL DETAILS

Nb samples were prepared by magnetron sputtering on commercial (111) silicon substrates kept at room temperature. The base pressure in the "Leybold Z400" vacuum system was about 2×10^{-6} mbar; pure argon (99,999%, "Messer Griesheim") at pressures of 8×10^{-3} mbar used as a sputter gas. Targets of 75 mm in diameter, from Nb and Si were pre-sputtered for 3-5 minutes to remove contaminations as well as to reduce the residual gas pressure in the chamber during the pre-sputtering of Nb. As a next step, we deposited silicon buffer layer with RF magnetron to obtain clean interface for the subsequent niobium layer. To provide homogeneity and proper thickness of the Nb layer the target-holder was moved during the DC sputtering using specially constructed arrangement based on controllable DC motor with a gear. Using this setup could achieve the average growth rate of the Nb layer ~ 1.3 nm/sec (the steady-state deposition rate would be about 4 nm/sec). To prevent the deposited samples against degradation in an ambient atmosphere as well as from influence of contaminated Si surface we protected them with ~5-7 nm silicon cap and buffer layers. The Rutherford backscattering spectrometry (RBS) lets the possibility to determine the absolute thickness of the layers at the level of 1 nm with an accuracy of 0.03 nm. Details of the RBS measurements are described in [4].

III. RESULTS AND DISCUSSION

The thickness measurements and the elementary analysis were performed by RBS after T_c detection by resistive measurements. Fig.1 demonstrates one of the samples with 7 nm Nb layer, 14 nm CuNi layer deposited on a single crystalline Si-substrate with a 7 nm buffer Si layer. The thickness of the layers was measured on RBS spectrometer, the accuracy of RBS method for such range of thicknesses is 0.4-0.5 nm.

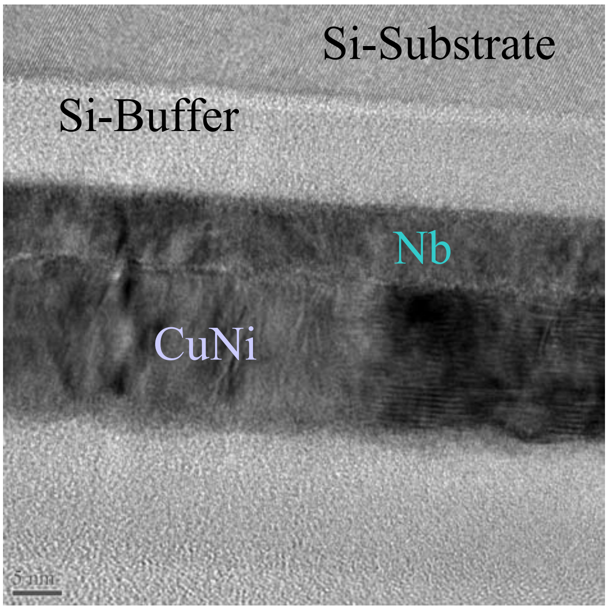

Fig.1. TEM image of the Nb-CuNi sample, deposited on Si substrate with a amorphous Si-buffer layer.

The residual resistance (ρ_N) of Nb films was: 16.5; 12.6; 8.9 µΩcm for $d_{Nb} \approx 7$ nm; 9 nm; 13 nm respectively. The critical temperatures of the samples with Nb thicknesses from about 5.5 to 100 nm are presented on Fig.2. The Nb critical temperatures for films with thickness 5.5-10 nm (5.6 – 7.5 K) are close to ones detected for the best of the Nb thin films in the same thickness range [6] but was formed in much simpler equipment and relatively rough vacuum conditions (~$2*10^{-6}$ mbar). It is worth to mention the other important advantage of presented technique is the possibility to form the large area film in single run and to combine it with other layer(s) without the vacuum interruption.

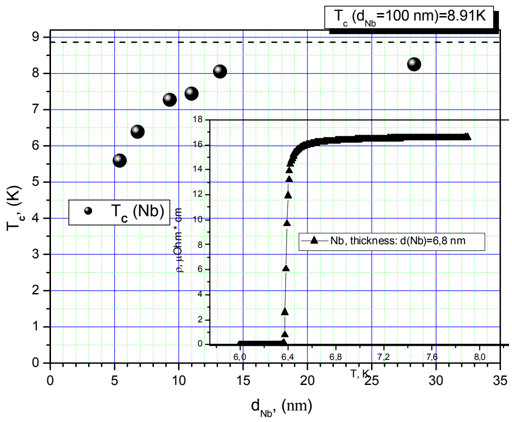

Fig. 2. Critical temperature of the samples with Nb thickness 5.5 - 100 nm. Insert: Typical superconducting transition for Nb film. The critical temperature for Nb film with thickness 6.8 nm is 6.37 K (criteria 0.5R_N).

The shape of typical superconducting transition is presented on the insert in Fig.2. Critical temperature (at 0.5 R_N) of the sample with Nb thickness of 6.8 nm is 6.37 K. The width of transition (criteria 0.9 R_N-0.1 R_N, R_N is resistance in normal state before transition) is 0.05 K. These characteristic values have advantage in comparison with Nb films with similar T_c but thickness of 31 nm deposited by common technique in [5].

IV. CONCLUSION

The presented technological approach yields significant improvement in superconducting properties of large area nanoscale Nb films in comparison with common method of DC- magnetron deposition [5]. The thickness deviation of Nb layer along the sample with length 80 mm does not exceed 5-6% for all strips and 3-4 % from strip to strip. This value is in general within the accuracy of the thickness determination method (RBS). The increase of superconducting critical temperature (>1.5 K for films with comparable thickness) and superconducting coherent length (30-35 %) opens the possibility of proximity effect investigation and spintronic devices construction based on large area superconducting films with thicknesses of a few nanometers.

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REFERENCES

[1] A. I. BUZDIN, Rev. Mod.Phys. 77, 935 (2005).
[2] L. R. TAGIROV, "Proximity effect and superconducting transition temperature in superconductor/ferromagnet sandwiches", *Physica* C 307, 145-163.
[3] V. ZDRAVKOV, A. SIDORENKO, G. OBERMEIER, S. GSELL, M. SCHRECK, C. MÜLLER, S. HORN, R. TIDECKS, L. R. TAGIROV . "Re-entrant superconductivity in Nb/Cu_{1-x} Ni_x bilayers". Phys. Rev. Lett. 97, 057004 (2006).
[4] V. V. RYAZANOV, V. A. OBOZHOV, A. Yu. RUSANOV, V. A. VERETENNIKOV, A. A. GOLUBOV, J. AARTS, Phys. Rev. Lett. 86 (2001) 2427.
[5] A. S. SIDORENKO, V. I. ZDRAVKOV, A. PREPELITSA, C. HELBIG, Y. LUO, S. GSELL, M. SCHRECK, S. KLIMM, S. HORN, L. R. TAGIROV, and R. TIDECKS, Annalen der Physik (Leipzig-Berlin) 12, 37 (2003).