THE ANALYSIS OF Nb AND $Cu_{41}Ni_{59}$ - ALLOY THIN FILMS BY ATOMIC FORCE MICROSCOPY

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Abstract. *This work is one part of a whole project for elaboration of a superconducting spin-switch. At a certain stage there was the need to develop technologies of magnetron sputtering of mirror-smooth film structures. AFM microscope acted as feedback for controlling the quality of the surface of films and for correction of deposition regimes. The paper is a detailed review of the deposition regimes of each layer (superconducting Nb and ferromagnetic alloy $Cu_{41}Ni_{59}$), and also the basic description of the work on the AFM microscope.*

Key-words: *AFM, spintronics, magnetron sputtering, surface topographic model, thin film.*

I. Introduction

Everyone is well known Moore's law – the numbers of transistors on a chip will double every 18-24 months, it took more than 35 years, and this rule still holds. Observance of this rule is due, mainly, with the development of technology production of chips and integral circuit boards, employment of new elements from the periodic table and also their compounds. But all the innovations do not change the essence of the p-n junction. All this gives the physical volume reduction of components and increase their density on a chip. Currently, the development of semiconductor electronics goes to some kind of plateau – the further reducing the size of the components leads to a significant increase the heat transfer problems, now the sizeable chip area occupied by heat sink channels and the volume of them cannot be reduced in the silicon electronics. Moreover, in the nanometer range "size effects" are present, i.e. physical phenomena which completely disrupting the operation of traditional silicon devices. Currently some interesting solutions exist for overcoming of the impending crisis: transition to three-dimensional architecture of chips [1], molecular electronics [2] and superconducting spintronics [3]. Three-dimensional architecture and molecular electronics circuits partially resolve the question of further size reduction, but the problem of heat transfer remains open. The solution may be the transition to the superconducting spintronics, it is the electronics, where in functioning process involved not only the particle charge, but also its spin. Superconducting spintronics is becoming more attractive due to the fact that heat generation is not possible; all its elements operate in the superconducting state without heat emission. But for creation of a spin-switch is necessary to solve some technological problems, one of which - the growing of a mirror-smooth boundary between the superconductor and ferromagnet.

As previously reported [4] for quick and unambiguous switching of the superconducting spin-switch (according Tagirov's model [5]) the conditions of Fabry-Perot resonator for the wave function of Cooper pairs in the ferromagnetic layer must be strict observed. The essence of the resonator is as follows: superconducting wave function of Cooper pairs is generated in a layer of superconductor, penetrates into the ferromagnetic film, passes through it, is reflected from the outer boundary and interferes with the again penetrating from the superconductor layer. And as in the case of classical Fabry-Perot resonator there is necessity in a parallel layer boundaries of the ferromagnet.

The main purpose of this study was analysis of film surface of separated layers structure based on the superconductor and ferromagnet using Atomic Force Microscopy (AFM) for determining surface roughness. These analyzes had served as a kind of feedback for correcting of the magnetron sputtering process in a vacuum, and development of technology for growing F/S/F structures with a high quality.

Here we study samples consisting of individual films of ferromagnetic alloy CuNi and superconducting niobium, the roughness of the layers is analyzed. The process of deposition of individual layers is no different from the process of growing the whole structure – the same modes are kept, the same isolation films techniques are used from contamination and adhesion of substrate.

II. Sample preparation

As noted above, the deposition process of separate films is the same as in the case of growing the whole multi-layered structure. A separate deposition allowed us to analyze the surface topography of each layer, thus we were able to correct the growing process of film, and easily recreate it in deposition process of the whole F/S/F structure [6].

The samples were grown on (1 1 1) Si substrates with size of 80 × 10 mm, in the magnetron sputtering system of Leyboldt Company mod. Z-400. The deposition process occurred in an argon atmosphere (99,999%) at a pressure of 8×10^{-3} mBar at room temperature. This method was chosen due to the following advantages: for magnetrons sputtering the next strict requirements are not significant – consistency of the lattice parameters of deposited material and the substrate and superficial defects of the substrate; this method make possible the control deposition rate in a sufficiently large range, it enables to find optimal conditions for the deposition of alloys (CuNi).

It should be mentioned here, for our research there is a necessity for a set of samples with the same thickness of niobium and different thickness of the ferromagnet layers, for this the sputtering technology was developed for obtain the whole series of samples in a single cycle of vacuum deposition.

Immediately before the sputtering process the targets were etched for 5 minutes. The size of all targets is Ø 75 mm.

The sputtering of superconducting niobium films:

Sputtering occurred on a silicon substrate during the motion target with constant velocity. Due to this method the homogeneity of thickness of the superconducting layers was increased. By varying the speed of motion of the target the growing thickness can be controlled.

The magnetron operated in a DC mode, at a fixed power of 380 W, the average speed of growing of Nb layers was about 1.3 nm/s, and time of deposition was 5 sec.

The sputtering of ferromagnetic $Cu_{41}Ni_{59}$ alloy films:

For the sputtering the varied Copper-Nickel layers there was used a method of wedge-shaped profile of the film growth. During sputtering the target was located asymmetrically relative to the center of the substrate; therefore there is a native concentration gradient of sputtered elements and there was growth a wedge-like ferromagnetic layer.

For the accurate transmission of the concentration of nickel in the alloy, the magnetron system operated in the AC mode at a fixed voltage 1, 35 kV and a current of 310 mA. The average speed of growing of CuNi layers was about 3-4 nm/s. According to RBS analysis [7], the CuNi film thickness decreases linearly from 40 nm to about 1 nm along the whole length (80mm).

III. Surface analysis of films via AFM.

The main advantage of an atomic force microscope is the possibility to obtain images of the sample surface at a very high resolution without any complicated preparatory operations [8]. The software makes possible to form an exact three-dimensional topographical model of the scanned area, a vertical resolution below the sub nanometer area. It should be noted, due to many modes of operation AFM enables to obtain topographical information from virtually every surface and it not depending on its density, hardness, conductivity and magnetic properties of the sample. The scanning samples not require expensive special preliminary processing.

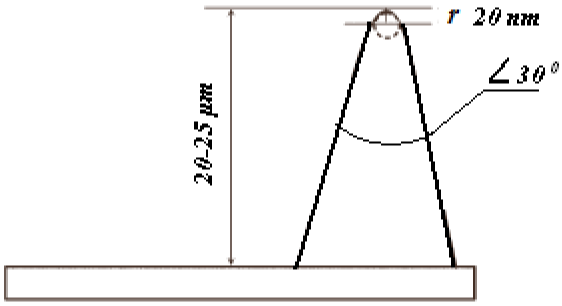

Fig. 1 schematic image of Si_3N_4 tip. The cantilever is of Anfotec Instruments Company, mod μMarsch, the stiffness is 0.03 N/m

AFM was used of Park Scientific Instruments Company, model SFM-BD2, it refers to the microscopes of Scanned-Sample type. This type of microscope has a higher accuracy in all three coordinates (absolute error of the order of pikometers in Z-direction) [9]. All samples were scanned in a clean room at 22 ^{0}C on dry area. The contact mode was chosen for scanning regime, it reduces an error and draws topographical model with a best quality of image. It should be clarified here: the cantilever was chosen and calibrated taking into account the stiffness and viscosity of the film samples (the size and main parameters see on Fig. 1 and subscribe of it). Scanning processes had undergone in a closed room isolated from outside sounds and sharp pushes. The design of the microscope provides for a natural swings of the building to 5 Hz and is able to extinguish it.

Scanning was carried out at six areas of the every sample; the size of segments was 10×10 μm. The topographic images of each type of sample were identical, so there is given only one picture from each material (Nb-layer and CuNi-alloy layer), for better visibility the areas were zoomed to size about 1 μm^2.

Figure 2 shows the result of a ferromagnetic scanned film. As can be clearly seen, CuNi film is virtually smooth, roughness is less than 1.2 nm. For a definite reflection of Cooper pairs of electrons there is a next need – the surface roughness must be less than the coherence length of the pair. The coherence length of the pair is 8-10 nm [10], the ferromagnetic film answers this condition. It should be noted, the CuNi thin film is easily oxidized in the atmosphere, and slightly changes its surface; therefore, the authors are confident that before the contact with oxygen, surface roughness had been less than 1 nm. This fact is confirmed by TEM analysis of cross-sectional structure with a passivate silicon-layer, which prevents oxidation of the samples [11].

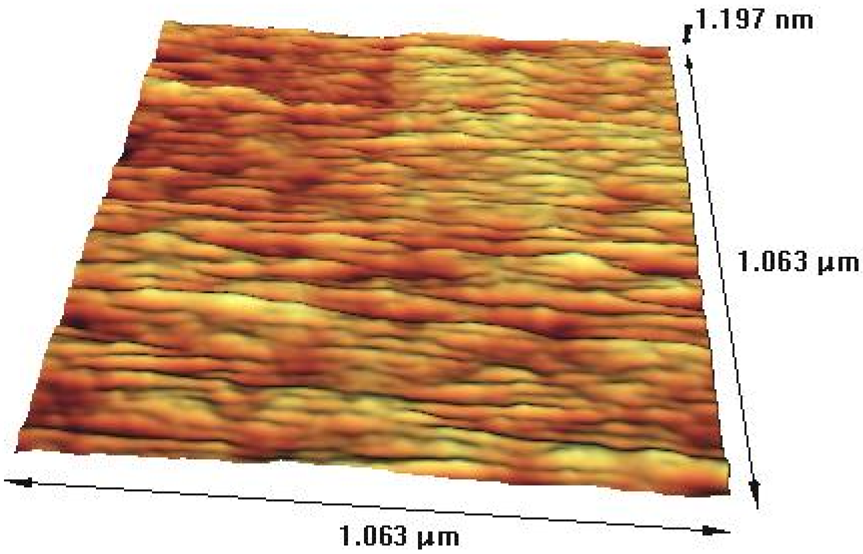

Fig. 2 The topographic model of the surface of a ferromagnetic alloy CuNi layer.

Figure 3 shows the result of the surface analysis of niobium film. How clearly seen the surface roughness is more than 4 nm, it is not a bad result. In Contact Mode the AFM scans the surface without directly touching of tip with the area of the sample; on the scanned surface a thin film of moisture rises, it prevents for touching the tip with the sample [13]. The film of niobium is a strong absorber, which good attracts water and various gases. Therefore, we believe the properties of niobium to attract water distorted the results, and increased it. This is clearly seen in the TEM cross-sectional analysis of the F/S/F structure, the cleanness of thin films is safeguarding by coating protective layer of Si and Vacuum airproofing in magnetron sputtering process [11].

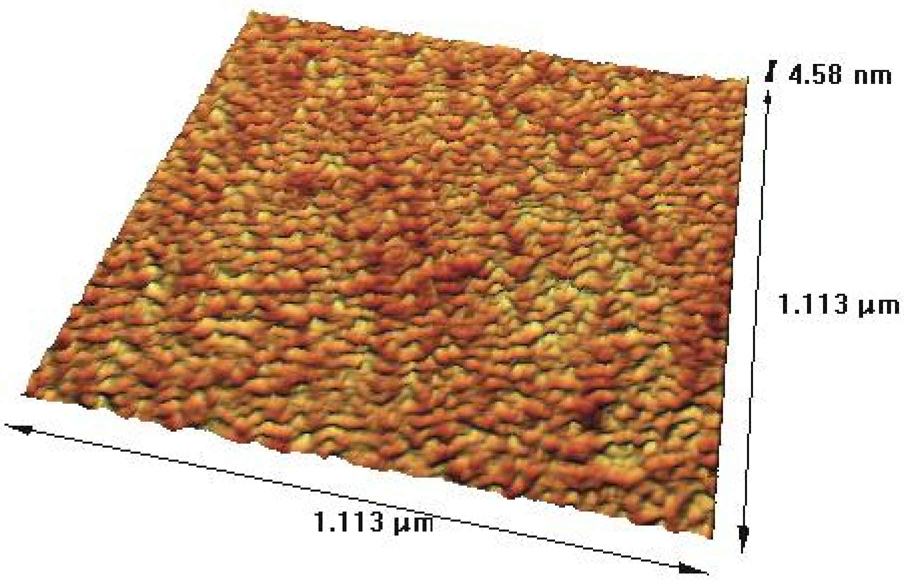

Fig. 3 The topographic model of the surface of a superconducting Nb layer.

IV. Conclusions

In this work the surfaces of the individual layers of ferromagnetic alloy of niobium and copper-nickel were studied using AFM. The main question was - is there possible to obtain the structure consisting of a mirror-smooth S/F and F/S interface by magnetron sputtering?

Via the AFM analysis, the imaging of surface topography was quickly gotten from individual films of niobium and copper-nickel alloy, without complicated preliminary operations. As shown by AFM analysis, the developed magnetron sputtering technology of structures satisfies the requirements of the boundaries of layers – the external sides of the films are homogeneous and mirror-smooth.

These research formed the basis for the development of sputtering technology of structures consisting of the layers of superconducting and ferromagnetic nickel-copper-nickel alloy [12].

The developed technology [12] of the controlled and reproducible preparation of superconductor-ferromagnet nanostructures can be used in superconducting spintronics to produce high-speed quantum logical elements and high-speed superconducting computer.

The advantages of using a computer based on the superconducting logic elements such as "spin valve" and "π-contact", as well as memory cells based on them in comparison to similar devices based on semiconductors, are: higher speed of operation, up to 100-1000 GHz, and the absence of the heat dissipation.

V. Acknowledgments

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