FUNCTIONAL SUPERCONDUCTOR-FERROMAGNET NANOSTRUCTURES FOR SUPERCONDUCTING ELECTRONICS

A. S. Sidorenko[1,a], V. Boian[1,b], E.I. Antropov[1,c], Yu. B. Savva[2,d], A.A. Lomakin[2,e], A.V. Vakhrushev[3,f]

[1]*Institute of Electronic Engineering and Nanotechnologies named after D. Ghitu, Moldova, MD-2028, Chisinau, Academiei 3/3,* [a]sidorenko.anatoli@gmail.com, [b]boianvladimir@gmail.com, [c] aidjek@gmail.com

[2]*Orel State University named after I.S. Turgenev, Russia, 302026, Orel, Komsomolskaya, 95,* [d]su_fio@mail.ru, [e] lomakin@gmail.com

[3]*Udmurt Federal Research Center, Ural Branch of the Russian Academy of Sciences, ul. T. Baramzina, 34* [f]vakhrushev-a@yandex.ru

Abstract. The work is devoted to the study of the processes of formation and analysis of the parameters of a functional nanostructure - a superconducting spin valve, which is a multilayer structure consisting of ferromagnetic cobalt nanofilms separated by niobium superconductor films. The studies were carried out using molecular dynamics simulations and vacuum deposition of the modelled nanostructures. The atomic structure of individual nanolayers of the system is considered. Particular attention is paid to the analysis of the atomic structure of the contact regions, since the quality of the interface between the layers plays a decisive role in creating of a microelectronic devices. The obtained results can be used both in the development and optimization of technologies for the formation of spin valves and other functional elements of spintronics.

1. Introduction

The development of nanotechnologies led to the emergence of a special section of quantum electronics - spintronics [1]. The systems in spintronics are based on heterostructures consisting of ferromagnets, superconductors and normal metals [2], which implies the creation of multilayer nanocomposites formed by nanofilms. The aim of this study is to analyze the processes of formation and microstructure of a multilayer nanostructure: superconductor (niobium)-ferromagnet (cobalt).

2. Experimental procedure and sample preparation

The samples are fabricated by vacuum deposition in the magnetron sputtering system LEYBOLD Z400 of the film material on Si (111) substrates. In the general case, the nanosystem contains more than 20 layers, but the processes of their formation, as well as their structural features, are similar.

3. Mathematical model and problem statement

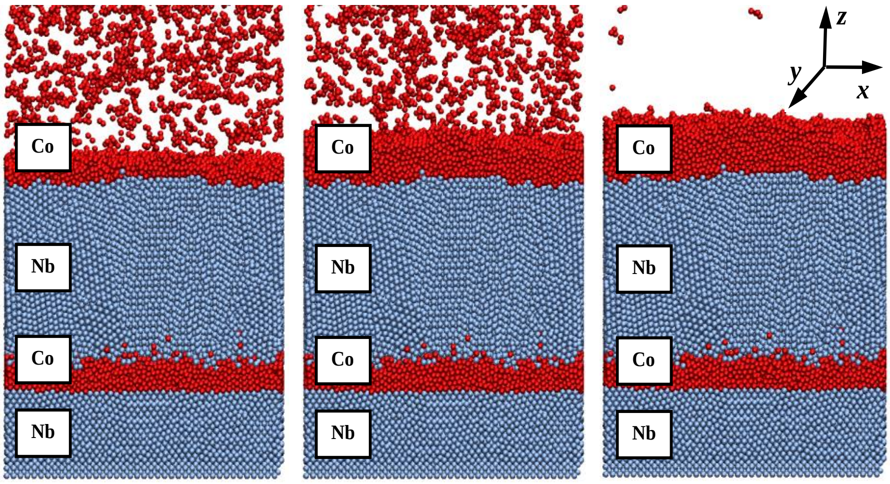
The study of the contact layer between superconducting and ferromagnetic materials was carried out by the method of molecular dynamics, while considering both the process of formation of nanolayers and the resulting structure formed by atoms inside a multilayer nanocomposite. The basis of the method of molecular dynamics is Newton's equation of motion, which is solved for each elementary particle:

$$m_i \frac{d^2\vec{r}}{dt^2} = -\frac{\partial U(\vec{r})}{\partial \vec{r}_i} + \vec{F}_{ex}, \vec{r}_i(t_0) = \vec{r}_{i0}, \frac{dr_i(t_0)}{dt} = \vec{V}_{i0}, i = 1, \dots N \quad (1)$$

where N is the total number of atoms in the nanosystem; m_i is the mass of the i-th atom; $\vec{r}_{i0}, \vec{r}_i(t)$ are the initial and current radius vectors of the i-th atom, respectively; $U(\vec{r})$ - potential energy or potential of the system, depends on the relative position of all particles; $\vec{V}_{i0}, \vec{V}_i(t)$ are the velocity vectors at the initial and current moment; $\vec{r}(t) = \{\vec{r}_1(t), \vec{r}_2(t), .., \vec{r}_K(t)\}$ - generalizing variable, indicates dependence on all coordinates of atoms; $\vec{F}_{ex}$ - the strength of the external environment, it also serves to maintain a constant temperature. For the definiteness of the solution of the equation of molecular dynamics, it is necessary to have clarifying conditions, which in (1) are the indication of the initial coordinates and velocities for all atoms.

4. Results and their analysis

Figure 1 illustrates the layer-by-layer analysis of the Nb/Co heterostructures composition.



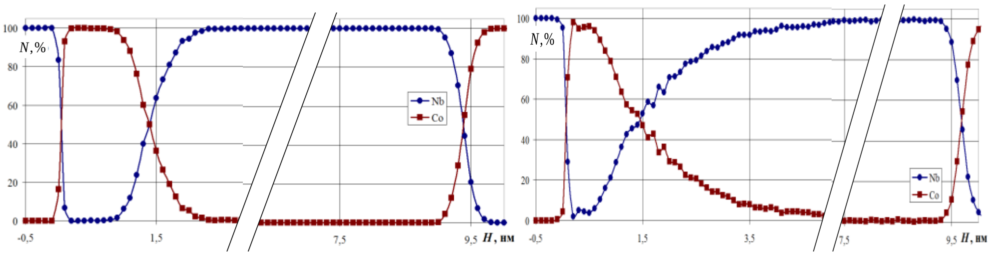


Fig.1. Deposition of a heterostructure from niobium and cobalt (upper panel) at temperature of 300 K, deposition time a) 0.1 ns, b) 0.2 ns and c) 0.4 ns (top panel). Percentage composition of a multilayer Nb/Co nanocomposite formed at 300 K (bottom panel, left) and at 800 K (bottom panel, right)

The deposition of layers corresponding to alternating elements, Nb and Co, led to the formation of contact layers in the niobium/cobalt interfaces. The contact areas are characterized by a change in the structure and the presence of a mixed composition (bottom panels in Fig1). An analysis of the structure of these layers also shows that niobium is formed by crystalline regions of different directions. Cobalt nanofilms are characterized by a structure close to amorphous one.

Conclusions:

Several series of computational and vacuum deposition experiments were carried out in the work, in which the formation of heterostructures at high temperatures (300, 500 and 800 K) were studied. The results obtained indicate a significant dependence of the processes of formation of multilayer nanocomposites, their contact areas, as well as the composition and structure of the layers on the temperature at which the formation of a multilayer nanosystem occurs.

This work was done in frame of the project Nr. 20.80009.5007.11 of the Moldova State Program (samples fabrication and investigation) and the grant RSF No. 20-62-47009 (theory development, nanostructures modelling).

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