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Molecular dynamics modeling of the influence forming process parameters on the structure and morphology of a superconducting spin valve

Alexander Vakhrushev*[1,2,3], Aleksey Fedotov[1,2,3], Vladimir Boian[3,4], Roman Morari[4,5] and Anatolie Sidorenko[3,4,6]

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Address:
[1]Modeling and Synthesis of Technological Structures Department, Institute of Mechanics, Udmurt Federal Research Center, Ural Division, Russian Academy of Sciences, Baramzinoy 34, Izhevsk 426067, Russia, [2]Nanotechnology and Microsystems Department, Kalashnikov Izhevsk State Technical University, Studencheskaya 7, Izhevsk 426069, Russia, [3]Orel State University named after I.S. Turgenev, Komsomolskaya Str. 95, 302026, Orel, Russia, [4]Ghitu Institute of Electronic Engineering and Nanotechnologies, Academiei Str. 3/3, MD-2028, Chisinau, Republic of Moldova, [5]Laboratory of Topological Quantum Phenomena in Superconducting Systems (TQPSS), MIPT, Institutskiy Per. 9, 141701, Dolgoprudny, Russia and [6]Technical University of Moldova, 168 Stefan cel Mare Avenue, MD-2004, Chisinau, Republic of Moldova

Email:
Alexander Vakhrushev* - Vakhrushev-a@yandex.ru

* Corresponding author

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Abstract

This work is a study of the formation processes and the effect of related process parameters of multilayer nanosystems and devices for spintronics. The model system is a superconducting spin valve, which is a multilayer structure consisting of ferromagnetic cobalt nanolayers separated by niobium superconductor nanolayers. The aim was to study the influence of the main technological parameters including temperature, concentration and spatial distribution of deposited atoms over the nanosystem surface on the atomic structure and morphology of the nanosystem. The studies were carried out using the molecular dynamics method using the many-particle potential of the modified embedded-atom method. In the calculation process the temperature was controlled using the Nose–Hoover thermostat. The simulation of the atomic nanolayer formation was performed by alternating the directional deposition of different composition layers under high vacuum and stationary temperature conditions. The structure and thickness of the formed nanolayers and the distribution of elements at their interfaces were studied. The alternating layers of the formed nanosystem and their interfaces are shown to have significantly different atomic structures depending on the main parameters of the deposition process.

Introduction

Multilayer superconductor/ferromagnetic (S/F) hybrid nanostructures are a new type of quantum electronics elements based on electron spin transport. Unlike conventional electronics, spintronics uses not only charge transfer, but also the electron spin in solids, solving the problem of transport and recording of information [1-7]. Based on the basic nondissipative elements of spintronics, it is possible to create new superconducting nanoelectronics devices that consume minimum energy and have a high operation speed [8-13].

One type of magnetic nanostructure with wide potential use is the spin valve [14,15], consisting of several magnetic films separated by a magneto-resistive layer. Due to the exchange interaction with the adjacent antiferromagnetic nanofilm, one of the layers has constant magnetization. For the adjacent nanofilm, the direction of magnetization can be controlled by an external magnetic field. The weak link of the ferromagnetic layers causes a restructuring of the magnetic moment configuration under low-power magnetic fields and switches the spin valve from a high to a low resistance state. When a superconducting film is used as a magneto-resistive interlayer, a superconducting spin valve is obtained. Furthermore, these structures are highly sensitivity to magnetic field switching and energy consumption is significantly reduced due to the absence of dissipation in such a valve in the ground (superconducting) state.

Practice shows that the creation of multilayer S/F nanostructures with the required properties is an extraordinarily complex process. Figure 1 and Figure 2 show actual spin-valve multilayer nanosystems formed from various materials [9]. As demonstrated in the figures, the structure of real nanosystems is far from ideal. In particular, it can be noted that the surface separating the various nanolayers of the system is not perfectly flat. The surface has noticeable irregularities that penetrate into adjacent layers. The figures also show that there is a mutual penetration of one contact layer into another. Therefore, the layer interface has a certain quantifiable thickness. It should be noted that the atomic structure of each layer does not form an

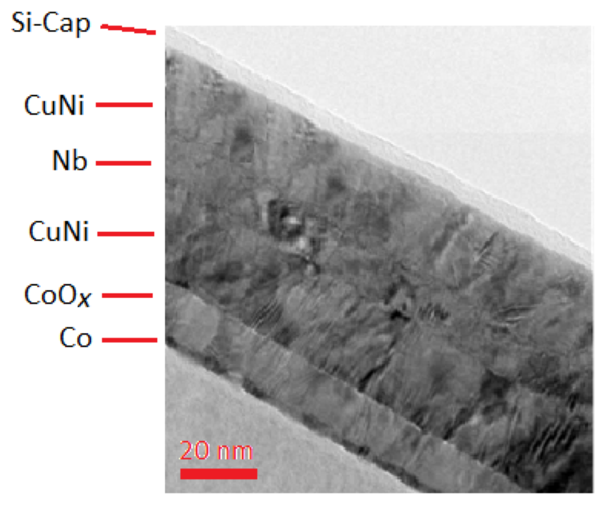

Figure 1: Transmission electron microscopy (TEM) image of a layered nanostructure consisting of Nb, CuNi, CoO_x and Co layers, prepared by magnetron sputtering.

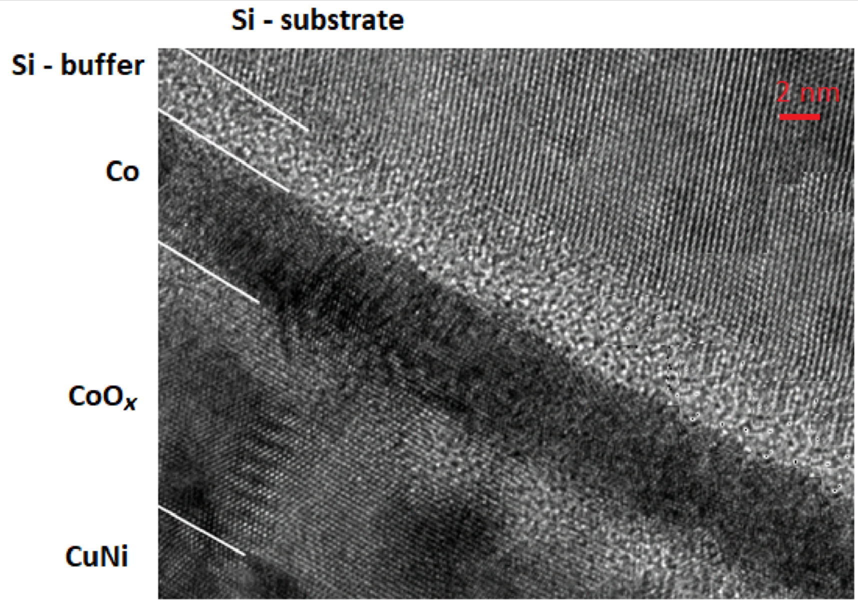

Figure 2: High-resolution transmission electron microscopy (HR-TEM) image of a layered Co, CoO_x and CuNi nanostructure prepared by magnetron sputtering.