3) the coefficient of thermal emissivity of the coating under investigation directly characterizes the reflectivity of the screen in the infrared wavelength range.

Therefore, aluminum thin-film coatings with the addition of nickel nanoparticles have a low reflection coefficient (less than 7%) in the ultraviolet region in the case of the dominant (more than 50%) component in the screen-nickel content.

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PECULIARITIES OF MAGNETORESISTANCE OF THE SPIN VALVE WITH AN ANTIFERROMAGNETIC LAYER

G. B. Baiman[1], A. Bogutsky[2], A. Danilyuk[2]
[1]International Academy of Informatization, Almaty, Kazakhstan
[2]Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus

I. INRODUCTION

At the present time, nanostructures for spintronics elements containing ferromagnetic (FM) and antiferromagnetic (AFM) layers are being actively studied all over the world in leading scientific centers. Impressive advances have been already achieved in the technology of formation of nanoscale spin valves containing ferromagnetic films separated by metallic or dielectric nonmagnetic interlayers (NI) with high structural perfection. Their electrical and structural properties, magnetoresistance, and spin torque transfer effects at current passage were studied in detail. Part of the results obtained is successfully introduced into the industry and is used in the manufacture of magnetic field sensors and memory elements. To date, the main active components of spintronic elements are ferromagnetics. Their behavior is widely studied and described in detail in the literature. However, recently interest has also arisen to other magnetic materials, antiferromagnetics, as potential information carriers [1, 2]. From the point of application, they have a number of advantages over ferromagnetics. First, having a high susceptibility to external fields, antiferromagnetic materials have zero or small magnetization, it means, they do not create external magnetic fields and, as a result, interact weakly with each other. Second, the characteristic frequencies of such materials and, consequently, the characteristic switching frequencies between different states exceed the analogous values for typical ferromagnetic materials by several orders of magnitude [3]. This means the possibility of creating of high-speed devices operating not in gigahertz, but in terahertz range. Finally, the antiferromagnetic order in magnetic semiconductors is observed much more often and under much milder conditions than ferromagnetic ordering [4], which allows combining in one device the advantages of both electronics (operational speed, easy controllability) and spintronics (high sensitivity, low power consumption). However, the antiferromagnetic spintronics still is in its infancy [5,6]. The combined dynamics of the AFM/FM structures, in which the features of the AFM layer behavior, the exchange bias, and the effects of spin polarization would be considered, have not been studied in practice. The results of such studies would allow not only to interpret the already known data, but also to effectively manage the properties of spin gates.

The purpose of this paper is to study the peculiarities of magnetoresistance of a spin valve with an antiferromagnetic fixing layer, taking into account the effect of exchange bias. The effect of exchange bias besides the Néel temperature for AFM material is also characterized by the blocking temperature TB and the value of the shift of the loop (the value of the displacement field, HE).

II. MODEL

A magnetoresistance model is considered that takes into account the exchange bias in a spin valve containing a fixing antiferromagnetic layer. The total energy of the spin valve system is described by the equation [7]

$$E_{TOT}(H) = -\mu_0 M_1\, t_1\, H \cos\vartheta_1 - \mu_0 M_2\, t_2\, H \cos\vartheta_2 \\ -E_{EB}\cos\vartheta_2 - J\cos(\vartheta_1 - \vartheta_2), \quad (1)$$

where ET0T is the total energy of the spin valve system; θ1, θ2 are the angles between the direction of magnetization of the FM layers and the positive direction of application of the external magnetic field.
The first two terms represent the Zeeman energy of the magnetic layers, with the magnetizations M_1, M_2 and thicknesses t_1,t_2 in the magnetic field H. The third term corresponds to the unidirectional exchange anisotropy energy, EEB, which occurs by means of the exchange bias of the FM layer due to the exchange interaction of the FM and AFM layers. The fourth term determines the exchange interaction between the FM layers separated by a nonmagnetic spacer (J is the exchange coupling constant). The directions of the magnetization vectors of the FM layers M_1 and M_2, depending on the applied external field, can be determined by minimizing the total energy of the system at angles θ_1 and θ_2:

$$\left(\frac{\partial E_{TOT}}{\partial \vartheta_1}\right)_{\vartheta_2,H} = 0, \qquad \left(\frac{\partial E_{TOT}}{\partial \vartheta_2}\right)_{\vartheta_1,H} = 0 \quad (2)$$

To simplify the designations, the following dimensionless values are introduced:

$$j = \frac{J}{E_{EB}}\ , \qquad h = \frac{\mu_0 M_2\, t_2\, H}{E_{EB}} = \frac{H}{H_{EB}}\ , \\ x = \frac{M_1\, t_1}{M_2\, t_2} = \frac{t_1}{t_2} \qquad (M_1 = M_2) \quad (3)$$

Several sets of angles θ1(h) and θ2(h) satisfy the equation (2). The solution for the minimum total energy, θ1min, и θ2min one may obtain by substitution of all possible solutions in equation (1). The magnetoresistance is determined by expression

$$r(h) = 1 + \frac{1}{2}\{1 - \cos\,[\,(\vartheta_{1,min}(h) - \ (\vartheta_{2,min}(h)]\}\,, \quad (4)$$

where

$$\cos[\,(\vartheta_{1,min}(h) - \ (\vartheta_{2,min}(h)] = \frac{(h+1)^2(-j^2 + h^2x^2) - h^2x^2j^2}{2hxj^2(h+1)}. \quad (5)$$

The dimensionless function r (h) is related to the resistance R (H) by the expression

$$r(h) - 1 + \left(\frac{R[H(h)] - \ R_{min}}{R_{ap} - \ R_{min}}\right). \quad (6)$$

Here R_{ap} denotes the resistance in the case of an antiparallel arrangement of the magnetizations of the FM layers, R_{min} is the minimum resistance corresponding to the case of parallel magnetization of the FM layers.

III. RESULTES AND DISCUSSIONS

The results of calculating of the magnetoresistance by expression (6) for different values of the parameters j and x are presented in Fig. 1 and 2, respectively.
The calculations have shown that the magnetoresistance value depends as well on the properties of AFM: the value of the displacement field HE and the exchange coupling constant J. For a certain combination of parameters, it is possible to increase the magnetoresistance of the structure by several fold due to the contribution of the exchange bias effect. The increase of the magnetoresistance is determined by decrease of j ratio (see expressions (3)), i.e. due to a decrease in the exchange constant and growth of exchange bias. The change in the external magnetic field in this case gives a nonmonotonic dependence r(h), which is characterized by the presence of a maximum. Upon changes of x ratio characterizing the ratio of the

magnetizations of FM layers and their thickness, this maximum shifts to a region of higher values of h (in absolute value).

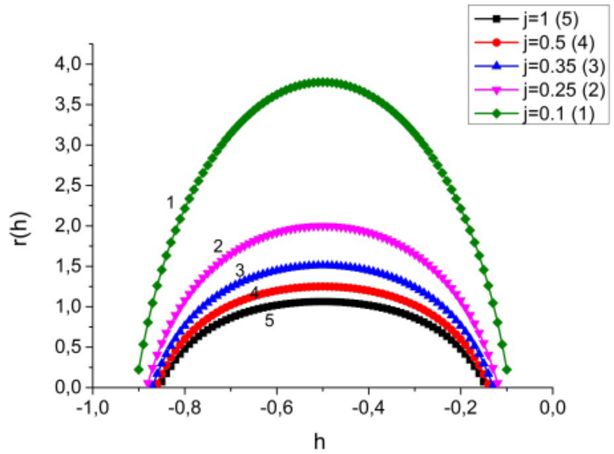

Figure 1 – Relative magnetoresistance of the AFM/FM/NI/FM structure as a function of the h parameter for different values of the j exchange constant.

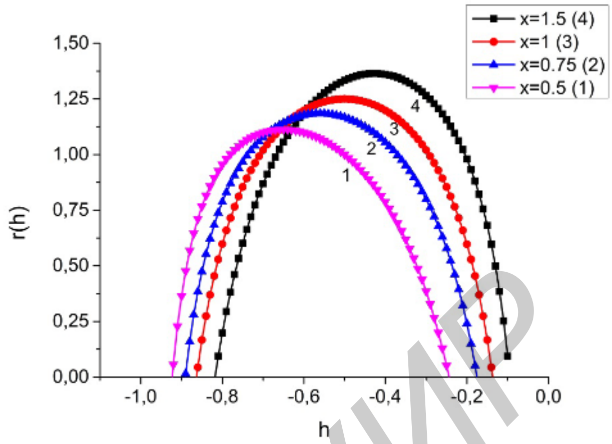

Figure 2. Relative magnetoresistance of the of the AFM/FM/NI/FM structure as a function of the h parameter at different values of x parameter.

IV.CONCLUSIONS

The simulation of the magnetoresistance of a spin valve containing an antiferromagnetic fixing layer is performed. It is shown that the effect of exchange bias that occurs at the contact of the ferromagnetic and antiferromagnetic layers with certain combinations of parameters of the spin-valve can lead to an increase in the magnetoresistance in several times (from 1.5 up to 4) due to the presence of the field of exchange bias.

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ANALYSIS AND DIGITAL PROCESSING OF SEM IMAGES OF ANODIC ALUMINA FILMS WITH NANOPOROUS STRUCTURE

N. Lushpa, T. Dinh
Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus

INTRODUCTION

The study of the morphology and structure of nanoporous materials is one of the important tasks of modern materials science. The creation and development of new nanostructured materials containing arrays of nanoscale pores are impossible without determining the pore sizes and density of their distribution. When you analyze images of an object with a nanoporous microstructure, it is first of all necessary to solve the following problems: performing segmentation, filtering the microstructure deficiencies, and isolating the objects from the background, determining the limits of objects, and pattern recognition. Correctness of the image segmentation is an important prerequisite for the success of the subsequent analysis.

Various application programs for image analysis are currently developed and available. Among the variety of software based on their functionality the most successful are Photom, Optimas, Image Expert Pro, ImageJ, Avizo and Smart-eye. In our work the ImageJ program was chosen for research. There are all necessary algorithms for image processing: high-frequency and low-frequency filtering, selection of image