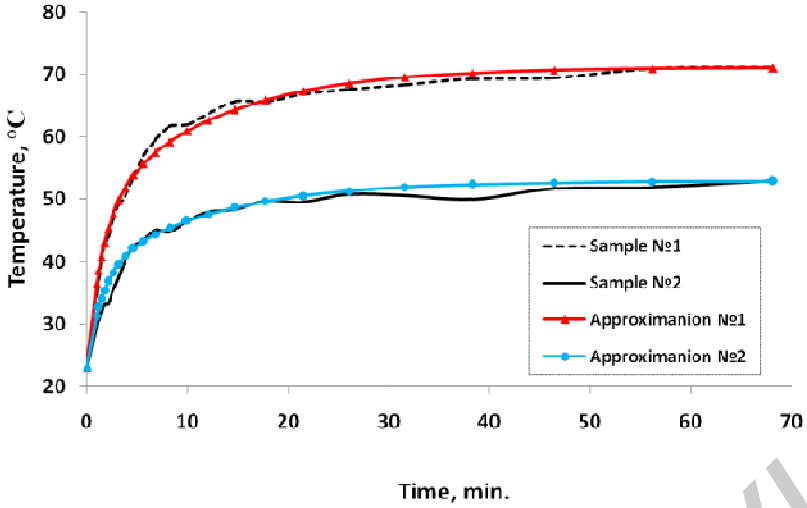

Figure 3 – Results of approximating the experimental data

Figure 3 shows that function (1) can be used to approximate temperature dependences, that was obtained experimentally. For the samples under study, the value of the time constant was the same, which indicates, that the addition of nickel increased the absorbing capacity of the surface, but practically did not affect the thermophysical characteristic of the oxide layer.

III. CONCLUSIONS

Based on the result of the work, it can be concluded, that the absorbing capacity of anodized aluminum depends on the structure of the oxide layer, and can be increased by the formation of nickel columns in the oxide channels. However, the law of temperature variation of the surface of aluminum samples in general will be the same.

Prediction of the temperature of structured surfaces can be carried out on the basis of the method of the electrothermal analogue, which allows replacing the actual sample with an electrical substitution circuit for simplifying thermal calculations.

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MAGNETORESISTANCE OF MULTILAYERED NANOSTRUCTURES

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I. INTRODUCTION

The technological achievements in recent years have made possible creation of ultrathin layers with an almost perfect structure and design of fundamentally new magnetic materials on their basis: magnetic multilayer nanostructures (MMNS) and superlattices. The discovery of the effect of giant magnetoresistance (GMR) in such systems gave a powerful impetus to the work on creation of superdense memory on magnetic media. However, the progress achieved so far in the field of creation of magnetic nanostructures makes possible as well other applications that traditionally perform semiconductor electronics.

In the field of fundamental research the GMR effect observed in a large number of MMNCs, consisting of alternating ferromagnetic and conducting non-magnetic layers, still attracts significant interest. The GMR effect is observed in many MMNCs, where ferromagnetic layers are separated by nonmagnetic metal layers with a 1-2 nm width. The resistance increases in the antiferromagnetic configuration and

decreases when exposed to a magnetic field that induces the ferromagnetic configuration of the layers. It is now widely recognized that coherent spin-dependent scattering is the main mechanism of this effect. It is important that the electron free path length without spin-flip in a multilayered structure is much greater than the thickness of each layer.

There are several approaches to the theoretical description of GMR. The main essential details can be taken into account in a simple phenomenological model. However, it is worthwhile to use the Kubo formalism [1, 2], since it allows to take into account both the geometry of the structure and its conductivity and quantum effects. To describe the scattering effect, the coherent potential approximation (CPA) is used. It makes possible to calculate the exact expression of the Green's function for a macroscopically inhomogeneous system, to which spin-valve multilayered structures belong too.

In this paper the results of a simulation of GMR in a three-layer spin valve by taking quantum effects into account are presented.

II. MODEL

Spin-dependent scattering is taken into account in the ferromagnetic layers and at the interfaces of phase boundaries. The scattering potential could be written in the form [1]:

$$V^{\mu}(r,\sigma) = \sum_i V_i^{\mu}(\sigma)\,\delta(r - R_i) \tag{1}$$

where R_i denotes the impurity position, $V_i^{\mu} = V^{\mu} \pm j^{\mu}$,the + or – sign refers to the up and down spin directions of the electrons relative to the direction of the local magnetization in different μ layers. Within the coherent potential approximation, the scattering potential is replaced in each layer by the $\sum^{\mu}$ effective potential, which is determined by the following equation for the averaged t-matrix [2]:

$$<t> = < \frac{V_i^{\mu} - \sum^{\mu}}{1-(V_i^{\mu} - \sum^{\mu})G(z,Z)} >= 0 \tag{2}$$

Here $G(Z,Z) = \left(\frac{1}{n}\right)\sum_R G_R(Z,Z)$; $G_R(Z,Z)$ is an effective Green function for multilayer structures in the R, Z representation; n is the number of nodes in the plane of (*x*, *y*) layers; $R = (R_x, R_y)$ is a electron momentum component in the plane of the layers (*x*, *y*). This component is a continuous variable, while *Z* component of electron momentum k_z (≡*k*) is quantized due to the boundary conditions. *Z*-dependent conductivity is written in the form [3]

$$\sigma(Z) = \frac{\hbar e^2}{\pi N \alpha_0^4}\int\int_0^D dZdZ'\{\sum_R v_R^2 G_R(Z,Z',E+i0)G_R(Z',Z,E-i0)\}_{E=E_F} \tag{3}$$

where α_0 is the lattice constant, $D = a + b + c$ is the total thickness of the nanostructure. For a multilayer structure, *G (Z, Z')* is a solution of the differential equation

$$\left(E - \frac{\hbar^2 R^2}{2m} - \frac{\hbar^2 \partial^2}{2m\partial Z^2} + \sum^{\mu}\right) G(Z,Z') = \alpha_0 \delta(Z - Z') \tag{4}$$

where $\sum^{\mu} = \sum^1$ for O <Z <a, $\sum^{\mu} = \sum^2$ for *a* <*Z* <*a* + *b*, $\sum^{\mu} = \sum^3$ for *a* + *b* <*Z* <*D; G (Z, Z')* = 0 at the outer boundaries. The condition for continuity for *G (Z, Z ')* and *(∂G / ∂Z) (Z, Z ')* on interior boundaries lead to simple equations. In addition, for ε → 0, *G (Z '+ ε, Z')* = *G (Z'-ε, Z)* and $(\partial G / \partial Z)|_{Z \to Z'+\varepsilon} - (\partial G / \partial Z)|_{Z \to Z'-\varepsilon} = \alpha_0\, 2m/\hbar^2$.

To obtain an analytical expression for conductivity, we use the limit $|\sum|/E_F << 1$ (the scattering potential is much less than the Fermi energy, which is a reasonable assumption for real systems).

III. RESULS AND DISCUTIONS

The change of the conductivity and magnetoresistance of a NiFe/Cu/NiFe nanostructure as a function of the layer thickness is shown in Figures 1 and 2.

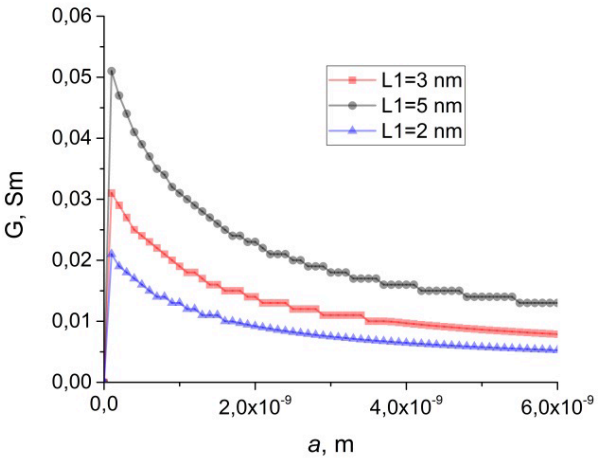

Figure 1 – Conductivity of the NiFe/Cu/NiFe nanostructure as a function of the layers thickness and the mean free paths (L1)

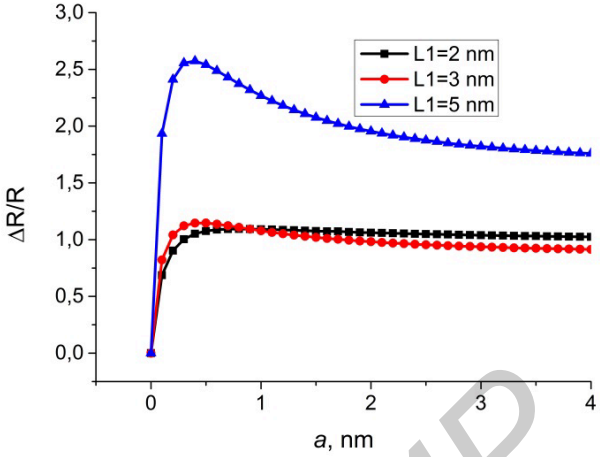

Figure 2 – Magnetoresistance of the NiFe/Cu/NiFe nanostructure as a function of the layers thickness

The obtained results showed that, depending on the thicknesses of the layers and the spin-dependent parameters of the materials, the values of resistance and, correspondingly, the magnetoresistance, can vary nonlinearly, reaching its maxima. This fact is important for the design of spintronic elements of information data processing, for which it is essential to achieve the high values of the magnetoresistance of nanostructures. The reason for the appearance of nonlinearities in the obtained dependences is the competition between the contributions of scattering at the interfaces and in the volume of the ferromagnetic layers.

These nanostructures are actual for using in magnetoresistive memory, and are also promising for application in the just emerging new field – spin calorimetry.

IV. CONCLUSIONS

In this paper we presented the results of simulation of the magnetoresistance of a three-layer ferromagnet / non-magnetic metal / ferromagnet nanostructure, taking into account the quantum scattering effects at the boundaries and in the volume of layers with a characteristic thickness of 2-15 nm. The presence of a nonmonotonic change in the GMR as a function of the thickness of the layers is established, characterized by the presence of maxima, which can be used for design of spintronic elements based on such nanostructures.

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USING THE SIMULATION MODEL AS TOOL FOR PLANNING THE OPERATION IN THE DIAMOND MINE

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The present research was aimed at developing a simulation model of the production process of diamond mining in an open-pit mine which allows you to evaluate different management decisions aimed at the reorganization of production, evaluate the cost-effectiveness of proposed alternatives [4]. The use of technologies of simulation analysis of mine have long been widespread in international practice, and in the Russian literature, the topic is just beginning to attract the interest of the scientific community [1, 2, 3].