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SIMULATION OF THE OPTICAL WAVES INTERACTION WITH NANOSTRUCTURE THIN ALUMINUM-NICKEL FILMS

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I. INTRODUCTION

Nanomaterials are widely used in different branches of science and technology – optics, power engineering, photoelectrochemistry, electronics, medicine and others. Thin films of nanometer sizes are used in luminescent materials, in solar batteries, in colorants with special properties, in mini sensors for adsorption of gases, in gas sensors, in explosives, etc. [1].

Thin films can be obtained by physical and chemical methods. The most popular of these are vacuum deposition, ion-beam sputtering, sol-gel method, thermal evaporation, chemical vapor deposition, spray pyrolysis of aerosols. The last noted method is one of the simple and economical. It is important that when thin films are obtained by pyrolysis, light alloying of any element in the corresponding fractions is ensured. This method is convenient to use when it is necessary to produce a homogeneous surface of thin films of highly required thickness and fully dense material [2].

The method of aerosol pyrolysis spray can be used for metal oxides, semiconductor oxides, superconducting thin films, binary and triple chalcogenides. The deposition velocity, the substrate temperature, the air pressure, the distance between the nozzles and the template are the main parameters that can be varied in this method. The ideal condition for the preparation of a film is the case when the droplets are completely removed from the solvent. In [3] the mathematical model of evaporation of micro- and nanosized drops is given, which allows to determine whether the particles will be filled or hollow.

Thin films, which represent a two-component structure of the absorber-reflector type, are at present the most common. Aluminum is a good absorber (absorption coefficient is more than 0.7, and the reflection coefficient is less than 0.3) in the ultraviolet range of wavelengths. The coefficient of reflection of nickel in this range is higher [4]. Therefore, the investigation of the optical properties of the aluminum-nickel nanomaterial is a priority.

II. EXPERIMENTAL METHOD

Different numerical methods allow analyzing the interaction of electromagnetic waves with nanoparticles. Classification of methods of wave modeling, as a rule, is carried out depending on their method of solution. The most known are the following methods: 1) finite differences in the time interval (FDTD), 2) finite elements (FE), 3) final integration (FIT), 4) moments (MoM), 5) integral equations.

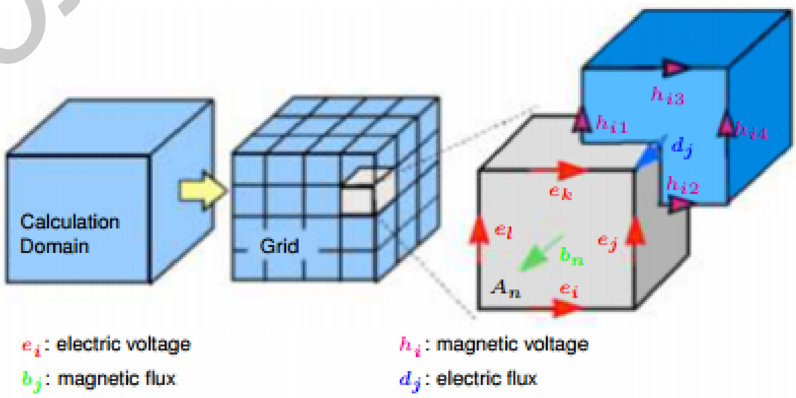


Figure 1 – Graphical interpretation of the finite iteration method (FIT)

Software for solving such problems in the optical range is developed by the following companies: Rsoft's FullWaVE, Optiwave's OptiFDTD, EM Explorer Studio, EM Photonics FastFDTD, COMSOL

Multiphysics. In [5] the analytical review of software products of the specified manufacturers is presented. From the point of view of the simplicity and convenience of modeling we chose CST Studio Suit, which is developed on the basis of the finite integration method (FIT) by Computer Simulation Technology (CST).

Briefly explain the main provisions of the program CST Studio Suit, used for modeling [6]. The numerical solution of Maxwell's equations is realized in integral form, and not in differential form. As shown in Figure 1 to determine the final area of calculations, the computational domain (interval) is divided into a set of grid cells.

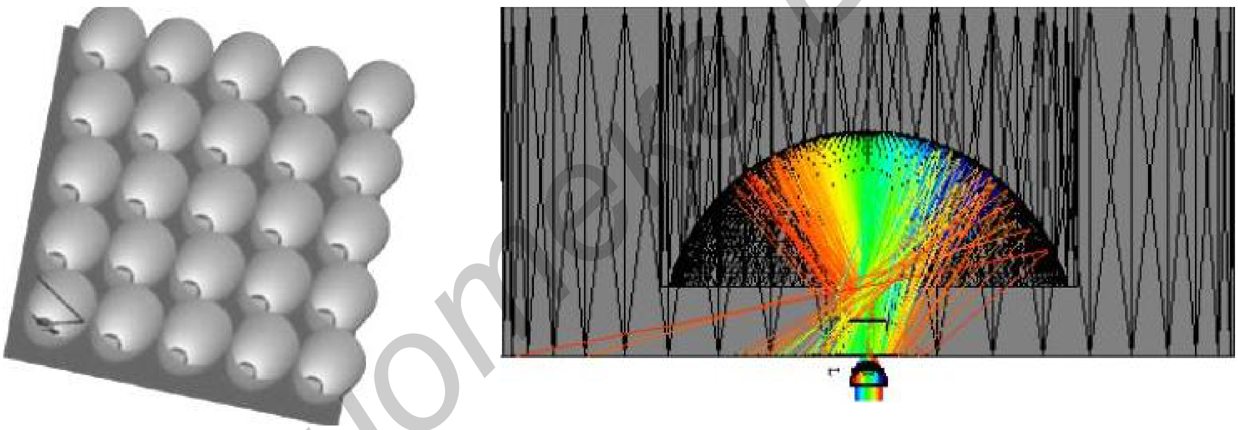
Therefore, in this method, the spatial discretization of Maxwell's equations is established on two orthogonal grid systems (see Figure 1 two rightmost extreme elements). For each element of the grid, Maxwell's equation is formulated:

$$\int \vec{E}\cdot\overrightarrow{dS} = -\frac{\partial}{\partial t}\iint \vec{B}\cdot\overrightarrow{dA} \qquad (1)$$

For further calculations, Faraday's law is applied in this method and equality (1) is rewritten as follows:

$$e_i + e_j - e_k - e_l = -\frac{\partial}{\partial t} b_n \qquad (2)$$

It is important that in CST Studio Suit you can specify different properties of multilayer materials: the properties of conductors, metals with losses, dispersion materials, coatings with surface impedance and others. In Figure 2 shows: a) the model of the coating under investigation; b) a fragment of the image of the simulation of the process of interaction of the EMW with the material under study.



a) the appearance of the coating; b) a fragment of the model element under study

Figure 2. The image of the modeled object in CST Studio Suit

Therefore, the program CST Studio Suit, in which Maxwell's equations are based on the method of finite iterations and the numerical result is made in integral form, is the most optimal for modeling in the optical wavelength range.

III. RESULTS AND DISCUSSION

The task that was solved in the modeling process was to establish the relationship between the optical properties and the substrate temperature and the ratio of the film components, i.e. aluminum (Al) and nickel (Ni).

Due to the fact that the optical properties of the coatings under investigation depend on the temperature, in the first stage of the simulation it was decided to conduct a study of a coating of nickel (60%) and aluminum (40%) at different temperatures (300 ... 550 ° C). As a result, the absorption coefficient values (see Table 1) were calculated for the temperature range indicated above in increments.

As can be seen from Table. 1, the absorption coefficient has a maximum value at temperature T = 500°C, and the minimum – T = 500°C. Consequently, the optical properties of a given nickel-aluminum coating strongly depend on temperature.

Table 1. The main characteristics of the coating, consisting of nickel (60%) and aluminum (40%), used for simulation in CST Studio Suit

№	Temperature, °C	Absorption coefficient
1	300	0,86
2	350	0,77
3	400	0,87
4	450	0,79
5	500	0,69
6	550	0,72

Then, in the second stage of modeling, the dependence of the reflection coefficient of this coating (Ni – 60% and Al – 40%) was studied in the CST Studio Suit program at various temperatures from the wavelength in the wavelength range from ultraviolet to near infrared (200 ... 1000 nm). In Figure 3 shows the graphs of the dependences obtained.

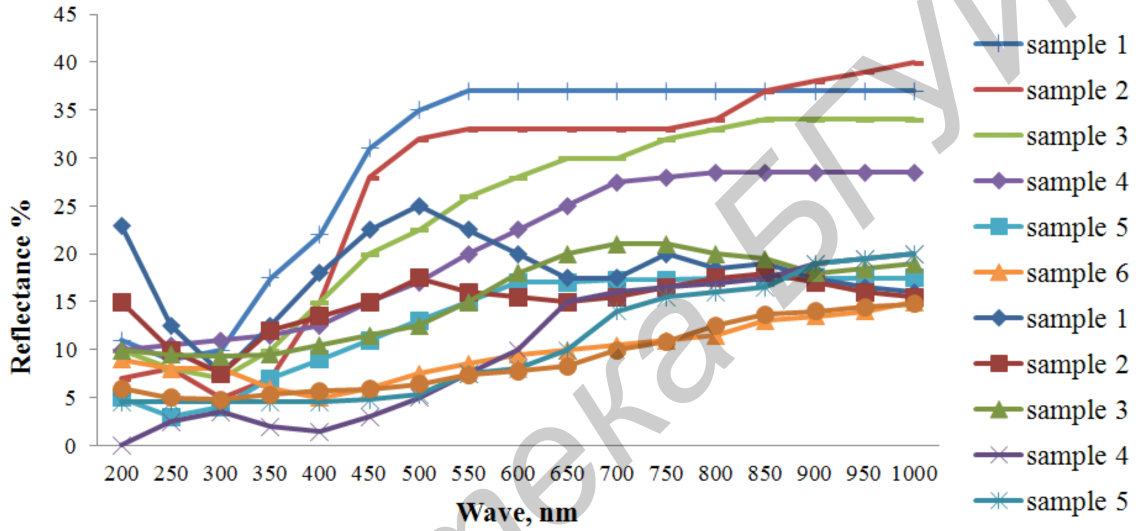


Figure 3 – Dependence graphs of the reflection coefficient of a coating consisting of nickel (60%) and aluminum (40%), on the wavelength in the optical wavelength range: sample 1 – with T = 500°C; sample 2 – with T = 550°C; sample 3 – with T = 350°C; sample 4 – with T = 450°C; sample 5 – with T = 300°C; sample 6 – with T = 400°C

In accordance with the results of the simulation presented in Figure 3, the value of the reflection coefficient for the UV region does not exceed 25%, and at and 400 ° C the value of this parameter is less than 5%, which indicates the possibility of using this coating with such a nickel content (60%) of aluminum (40%) at the indicated temperature mode. In the visible and near-IR regions, the value of the reflection coefficient varies little (almost constant): at this value it is 40%, and at –10%.

At the next stage of the simulation, studies were carried out to establish the regularities of the influence of different contents of nickel and aluminum in the composition of coating samples on optical properties.

The results obtained at this stage during modeling in the CST Studio Suit program showed that the content of the nickel mass fraction is optimal for low reflection coefficient in the ultraviolet region. The most uniform dependence of the reflection coefficient in the entire wavelength range is characterized by sample No. 6 (Ni – 90% and Al – 10%). The worst result is for sample 1 (Ni is 10% and Al is 90%). In the ultraviolet region at a wavelength equal to 300 nm, the value of the coefficient is minimum – 7%, and at the length of 490 nm – the maximum (25%).

III. CONCLUSIONS

Simulation of the interaction of electromagnetic waves with a screening thin-film aluminum coating with the addition of nickel nanoparticles in the program CST Studio Suit allowed to conduct research and establish: 1) optimal content of nickel nanoparticles in the coating – 60%; 2) the nonlinear character of the dependence of the reflection coefficient on the wavelength in the optical range at different temperatures;

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

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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).