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The Dependence of the Magnetoresistance on the Orientation of Three-layer Film Systems Based on Co / n / Co (n = Gd, Dy, Bi) in an External Magnetic Field

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This work is devoted to general laws influence the orientation of the samples in an external magnetic field on the magnetic and magnetoresistive properties of three-layer film systems based on Co / n / Co (where n is intermediate layer of Gd, Dy and Bi). Found that the field dependence has anisotropic character, and most important magnetoresistance is observed in the perpendicular geometry measurement for all three-layer film systems. It is shown that the value of the coercive force and magnetoresistance decreases and the value of film sensitivity to the magnetic field increases in the transition from perpendicular to the transverse geometry.

Keywords: Magnetoresistive properties, Magnetoresistance, Coercive force, Three-layer film system, Sensitivity, Structural-phase state.

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1. INTRODUCTION

Magnetoresistive properties of film systems directly depend on their structure-phase state and the thickness of the ferromagnetic material and intermediate layers, geometry measurements, etc. Analysis of current research [1-3] in materials science, electronics and sensor technology shows the need to find new promising film materials that could be used to create a variety of sensors, such as magnetic field sensors, and install influence the orientation of the sample in an external magnetic field on the magnetoresistive properties. Actual task is to establish the impact and structure-phase state of the stability properties of three-layer film systems. Changing the material of the intermediate layer also affects both the magnetic and magnetoresistive properties of the sensor as a whole and its individual components [4].

Thus objective of this work was the establishment of the influence of the sample orientation relative to the applied external field and the intermediate material layers on the magnetoresistive properties of three-layer film systems based on Co / n / Co (n = Gd, Dy, Bi).

2. METHODOLOGY AND TECHNIQUE OF EXPERIMENT

Three-layer film Co / n / Co / S (where n = Gd, Dy, Bi, S – substrate) was obtained in the working volume high-vacuum appliance «VUP-5M» (residual gas pressure P ~ 10^{-4} Pa) by layer-metal vapor condensation electron-beam method. Substrate temperature was $T_s \cong 450$ K, and the average rate of condensation of metals accounted for Co – 0,1-0,3 nm / s for Gd, Dy, Bi – 0,03-0,15 nm / s. Control of the thickness of the samples was carried out using quartz crystal.

To investigate the magnetoresistive properties of the substrate as used ceramics plate measuring 10 × 10 mm. These studies were conducted on the external magnetic field with induction $B = \pm 450$ mT at room temperature. Resistance measurement was performed in 4-point scheme in three geometries by the method as described in [5]. The value of magnetoresistance (MR) was calculated using the formula:

$$MR = \frac{\Delta R}{R_0} = \frac{(R_B - R_0)}{R_0} \qquad (1)$$

where R_B i R_0 – film resistance at the set field and by saturation field respectively.

The study of structural and phase state and crystal structure was carried out using transmission electron microscope «PEM-125K» for his work in brightfield and microdiffraction modes. As the substrate used with carbon film and the supporting grid.

Decrypt electron (fig. 1) from the film systems showed that all systems in the freshly condensed state of Co layers have a two-phase structure of hcp-Co fnd fcc-Co, which is consistent with the known literature data (see eg. [6-7]). Layers of gadolinium are in amorphous state (as evidenced by 2-3 halo blur the electron). For Dy and Bi layers are fixed hcp + bcc-Dy_2O_3 and rhombohedral phase respectively.

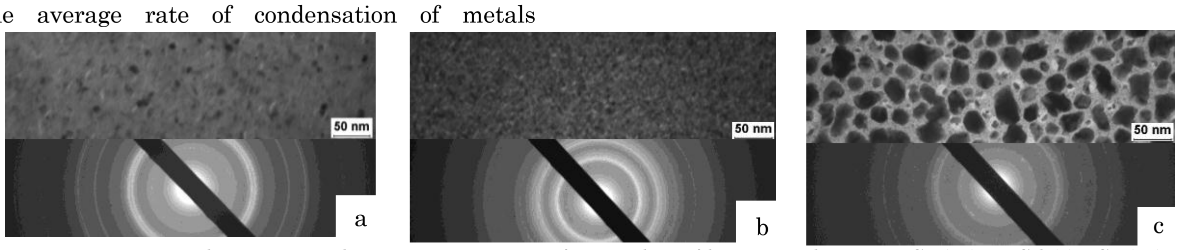

Fig. 1 – Microstructure and corresponding TEM-images from the film samples: a – Co (10) / a-Gd (1) / Co (10) / S, b – Co (5) / Dy (20) / Co (20) / S, c – Co (5) / Bi (15) / Co (10) / S of freshly fused state. In parentheses are thickness in nm.

3. RESULTS OF RESEARCH AND THEIR TREATMENT AND DISCUSSION

In Fig. 2 there is a typical family field dependence of the MR at three measurement geometries on the example of a monolayer film Co (20) / S. In the perpendicular and transverse geometry measurement value of MR increases with increasing magnitude of induction of an external magnetic field. When the value of $B = B_c$ (B_c – coercive force, which corresponds to the maxima of the field dependences) the value of MR begins to decrease and eventually saturates at $B \to \propto$. In the longitudinal geometry is bucking the trend that confirms the anisotropic character of magnetoresistive properties of monolayer Co films. As can be seen from the graph the greatest amount of MR observed in perpendicular geometry and measurement is 0,231 %. In the transition to the transverse geometry measurement is a sharp reduction MR to 0,098 % in the longitudinal geometry MR = – 0,0373 %.

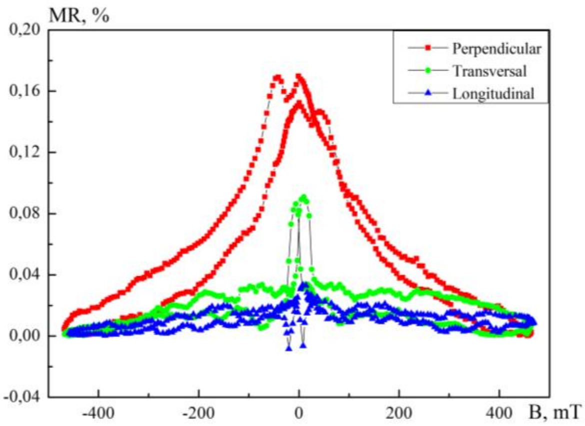

Fig. 2 – Dependence of magnetoresistance on the applied external magnetic field at three measuring geometries film of Co (20) / S. In parentheses are the thickness in nm.

Thus the monolayer film Co are characterized by anisotropy of magnetic properties that are characteristic of ferromagnetic materials. The main cause of anisotropy magnetoresistance in monolayer ferromagnetic materials is the interaction of conduction electrons with internal electron, and the spin moments determine the spontaneous magnetization [8].

The nature of the dependence of the MR of the applied external magnetic field in the transition from perpendicular to the transverse geometry and measurement in the longitudinal geometry for different film systems can be judged from the data are shown in fig. 3. Comparing the data in Fig. 2 and 3 show that as for the monolayer Co films and for three-layer systems Co / n / Co in making intermediate layers of Gd, Dy, Bi remains anisotropic character value of MR.

Compared with monolayer films of Co in the systems Co / Gd / Co and Co / Bi / Co with increase of coercivity value by an average of 80,3 % and 57,8 % respectively. While for the system Co / Dy / Co is a decrease of the B_c is 2,7 times. As for value of MR for systems Co / Gd / Co and Co / Dy / Co is growing at an average of 41,4 % and 56,5 % respectively, while for the system Co / Bi / Co decrease in 1,5 times. In the transition from perpendicular to the transverse geometry measuring systems Co / Gd / Co and Co / Bi / Co has seen a sharp decrease of MR, for Co / Dy / Co this transition is less pronounced. Attention is drawn to the fact that the film of Co (5) / Dy (20) / Co (20) / S in the longitudinal geometry measurement value of MR is less than 0,01 %. Analysis of reduced dependence on the angle of orientation of MR allows evaluating which of the geometries to be optimal for each system in terms of their potential use as magnetic sensors.

Using experimental data we calculated the maximum of MR, coercive power and sensitivity of film to the value of S_B induction of the applied external magnetic field. Graphically, the results presented in Fig. 4.

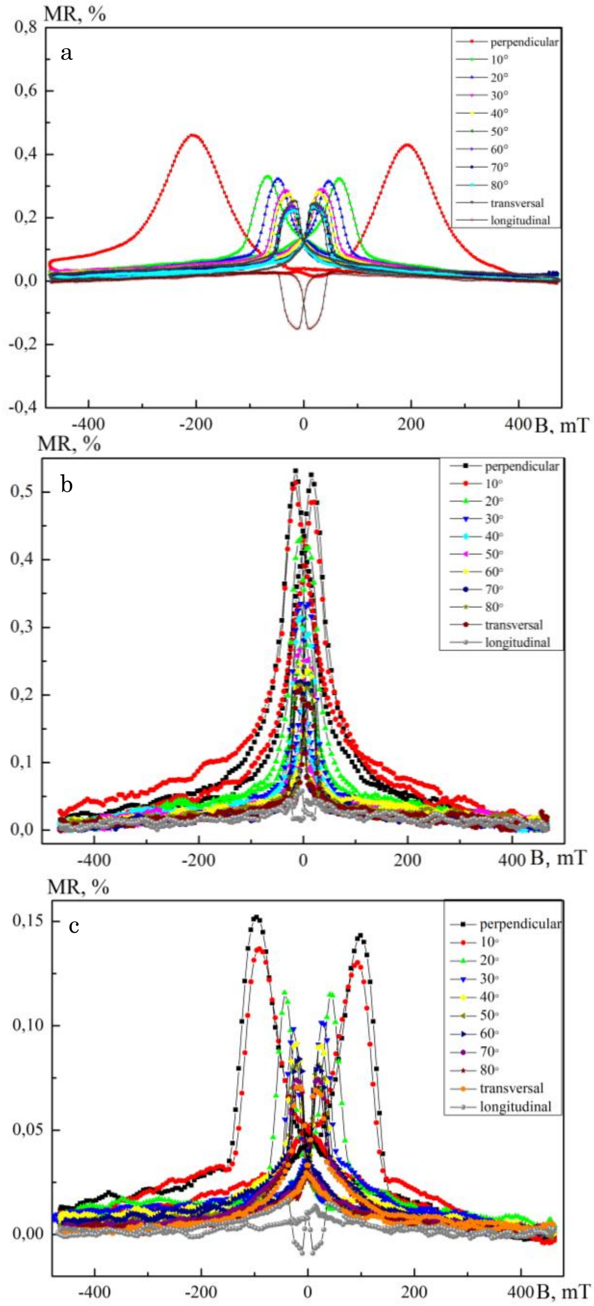

Fig. 3 – Dependence of magnetoresistance on the applied external magnetic field in the transition from perpendicular to the transverse geometry and in longitudinal geometry measurements from step 10° for film systems:
a – Co (10) / a-Gd (1) / Co (10) / S,
b – Co (20) / Dy (20) / Co (5) / S, c – Co (10) / Bi (15) / Co (5) / S.

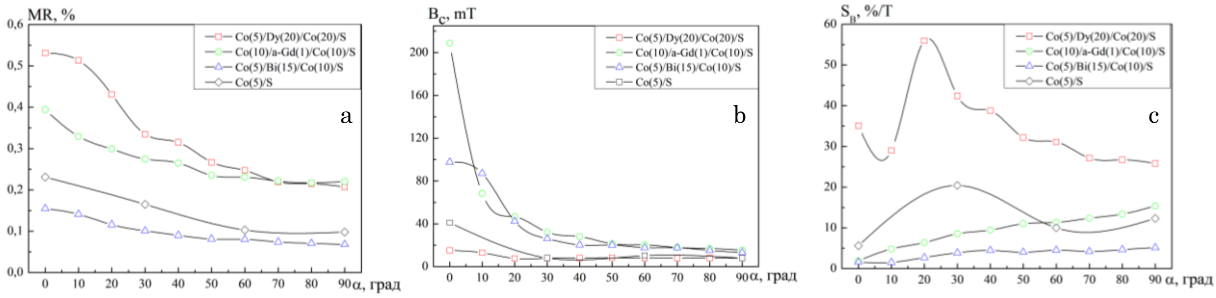

Fig. 4 – The dependence of magnetoresistance (a) and coercivity (b), the values of sensitivity (c) of applied external magnetic field in the transition from perpendicular to the transverse geometry measurement systems for film: Co (10) / a-Gd (1) / Co (10) / S, Co (5) / Dy (20) / Co (20) / S, Co (5) / Bi (15) / Co (10) / П, Co (20) / S

In the case of all three-layer systems in the transition from perpendicular to the transverse geometry of measuring the value of MR and B_c decreases with varying degree of monotony. For all three systems decreases the magnitude of MR about 2 times.

In [9] proposed a theoretical model of ro-zrahunku anisotropic magnetoresistance (AMR) for sensor or sensors. This model allows us to estimate the behavior of sensors in an external magnetic field. Value model [9] to calculate the AMR is:

$$AMR = \frac{3\Delta\rho}{\rho_{||} + \rho_{\perp}} \cdot 100\% \qquad (2)$$

where $\rho_{||}$, $\rho_{\perp}$ – values of resistivity in the transverse and perpendicular geometries respectively.

Table 1 – Experimental and calculated values AMR

System	Experiment, %	Calculating, %
Co (10) / a-Gd (1) / Co (10) / S	– 0,151	– 0,159
Co(10) / Gd(10) / Co(10) / S	– 0,0443	– 0,0441
Co(10) / Gd(5) / Co(10) / S	– 0,0897	– 0,0894
Co (20) / Dy (20) / Co (5) / S	– 0,0097	– 0,0099
Co(5) / Dy(13) / Co(20) / S	– 0,101	– 0,0909
Co(5) / Dy(15) / Co(20) / S	– 0,212	– 0,211
Co (10) / Bi (15) / Co (5) / S	– 0,01	– 0,0103
Co(10) / Bi(7) / Co(5) / S	– 0,0819	– 0,0818
Co(10) / Bi(5) / Co(5) / S	– 0,194	– 0,191
Co (20) / S	– 0,0373	– 0,0371

From Table 1 it is possible to judge the compliance of quantitative results which were calculated by the ratio of 1 and 2. Thus the use of mathematical models to predict the magnitude of MR in the longitudinal geometry measurement.

The criterion for application of film materials pursuant to the mikrosensor is the value for the sensitivity of film sensitivity to external magnetic fields, which can be calculated by the formula [10]:

$$S_B = \left| \frac{\left(\Delta R / R(B_s)_{\max}\right)}{B_c} \right|, \qquad (3)$$

where $\Delta R/R(Bc)_{\max}$ – maximum value of magnetoresistance.

From the data in Fig. 4c follows that of Co / Gd / Co and Co / Bi / Co values is an increase in sensitivity. For a system of Co / Dy / Co is a decrease of S_B due to the fact that the coercive force is almost constant, and the value of MR decreases with the change of the angle of orientation. In the longitudinal geometry measurements S_B values for all systems is somewhat less than the value in the transverse geometry and is for Co / Gd / Co 13,56 % / T, for the system Co / Bi / Co – 1,029 % / T, for the system Co / Dy / Co – 12,3 % / T. In terms of data samples in the film as sensors magnetic field is an important criterion for linear dependence of sensitivity. The present requirements are met by the system Co / Gd / Co and Co / Bi / Co. And in terms of high values of S_B to create sensor system can be used Co / Dy / Co, but in a narrow range of angles (40° -90°).

4. CONCLUSIONS

Thus, according to the study of the effect of orientation on the magnetoresistive properties the following conclusions can be drown.

1. The most important magnetoresistance is observed in the perpendicular geometry measurement for all film systems and is 0,40 % for (system Co / Gd / Co), 0,53 % (system Co / Dy / Co) and 0,16 % (system Co / Bi / Co). In the transition from perpendicular to the transverse orientation of the sample in an external magnetic field magnetoresistance value is rapidly decreasing in the interval from 0°-30° and then reduce the dependence of MR has a monotonic character. The value of coercivity in these systems is also reduced in the transition from perpendicular to the transverse geometry measurement.
2. For systems Co / Gd / Co and Co / Bi / Co sensitivity on the orientation of the external magnetic field is close to linear in nature, they can be used as sensors in a wide range of angles, while the system Co / Dy / Co is characterized by a relatively high value of S_B can be regarded as a material for sensors, but the range of angles from is 40°-90°.
3. It is shown that for the considered film systems can be performed AMR prediction value based on the model proposed in [9].

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