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Magnetoresistance and the Domain Structure of Film Nanostructural Alloys

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Abstract—**The results of investigation of the domain structure and anisotropic magnetoresistance of permalloy ($Fe_{0,5}Ni_{0,5}$) nanocrystalline thin films are presented, the interrelation of their domain structure and magnetoresistance is established.**

Keywords—thin pheromagnet nano-structure film; permalloy; domain structure; anisotropic magnetoresistance

I. INTRODUCTION

During the last decades, systematic studies of thin films of 3d metals, their alloys and nanostructures on their basis, in which the features of their electrophysical, magnetoresistive and structural properties were found [1-10]. The results of research contribute to the use of such films for the manufacture of various types of devices of modern micro and nanoelectronics. The study of ferromagnetic film alloys became of particular relevance after the discovery of the phenomenon of a giant magnetic resistivity in multilayer systems, magnetic layers of which are ferromagnets [11, 12]. Against this background, today, film nanostructured Fe and Ni alloys (permalloy) remain objects of intensive experimental research, since this opens up wide opportunities for the creation of new materials with predetermined properties for the needs of micro and nanoelectronics.

The purpose of this work is to study the connexion between the magnetic structure and the magnetoresistance of film nanostructured alloys $Fe_{0,5}Ni_{0,5}$.

II. EXPERIMENTAL DETAILS

The film with thickness of the layers 10-100 nm were prepared in the vacuum chamber with a base pressure of 10^{-4} Pa. Condensation was carried out by metals electron-beam evaporation. The bulk alloys of corresponding composition used as initial materials for obtaining $Fe_{0,5}Ni_{0,5}$. The condensation was carried out at room temperature with rate ω = 0,5-1 nm/s corresponding on evaporator operating conditions. A glass plates with previously deposited pads were used as substrate for magnetoresistive properties investigations. Geometrical sizes of thin films for measurement their resistance were specified by windows in the nichrome foil mechanical masks.

The results of X-ray spectrometry analysis have been shown that chemical composition of prepared thin films coincides with chemical composition of initial bulk alloys. The measurement error does not exceed 2%.

According to the results of electron microscopic analysis, the obtained $Fe_{0,5}Ni_{0,5}$ film alloys have a fine crystalline structure about several nanometers (depending on the temperature of annealing) crystallites.

In order to study of the connexion of magnitude and behavior of the magnetoresistance of film ferromagnets of their domain structure, an experimental magneto-optical device for the visual (using the magneto-optical Kerr effect) observation of the domain structure of the films and its change with the simultaneous measurement of the film magnetoresistance in CIP-geometry was created.

The principal scheme of the magneto-optical device is shown in Fig. 1 (optical part of the device for monitoring the domain structure of ferromagnetic films) and in Fig. 2 (electrical part of the device for measuring the magnetoresistance of ferromagnetic films).

A beam of light (Fig. 1) from the source (1) falls on the ferromagnetic film under study (film sample) (4) at an angle close to 45°. The value of the light flux is regulated by the diaphragm (2). After the diaphragm, the light beam passes through the polarizer (3). By rotating the polarizer around its axis, you can change the plane of the polarization of the incident light. Reflected from the surface of the film (4) the light becomes elliptically polarized and passes through the analyzer (5), which is constructively mounted in the frame of the objective MBS-10 microscope (6). The resulting light pattern can be observed visually through the microscope eyepiece and photographed using a digital video camera (photo camera) (7).

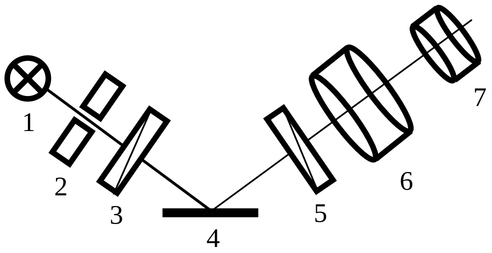

Fig. 1. Schematic representation of the optical part of the magneto-optical device: 1 – light source; 2 – diaphragm; 3 – polarizer; 4 – a film sample; 5 – analyzer; 6 – microscope; 7 – video camera

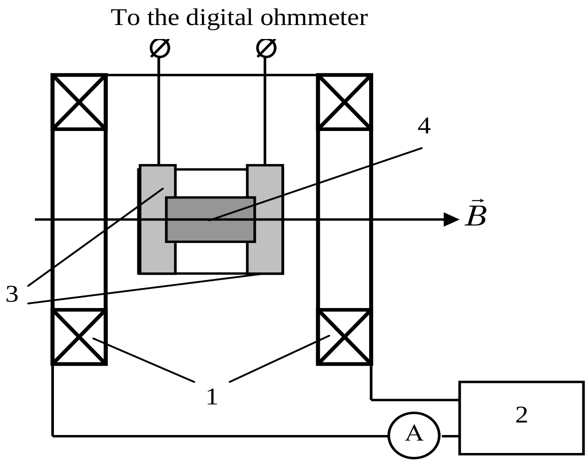

Fig. 2. Schematic representation of the electrical part of the installation for measuring of magnetoresistance of ferromagnetic films: 1 - Helmholtz rings; 2 - Helmholtz rings power supply; 3 - contact pads; 4 - a film sample

The film sample (4) (Fig. 2) is located in a magnetic system formed by two Helmholtz rings (1) that create a homogeneous magnetic field in the plane of the sample. The sample is located so that its axis of easy magnetization lies in the plane of falling light. The magnetic system, along with the sample, is fixed to Fedorov's table, which makes it possible to orient them in a space for adjustment. The magnitude of the induction of the magnetic field generated by the Helmholtz rings varies from 0 to 15 mT, depending on the value of the electric current of the power supply (2) of the rings.

The electrical resistance (magnetoresistance) of the film sample is measured using a digital ohmmeter.

III. RESULTS AND DISCUSSION

To establish the connection of the ferromagnetic films' magnetoresistance with a change in their magnetic structure, a study of the domain structure of films $Fe_{0,5}Ni_{0,5}$ on glass substrates and its change in the process of magnetization of a film sample with simultaneous measurement of its magnetoresistance was carried out. Due to differences in the angles of rotation of the plane of polarization of light by adjacent domains (depending on the orientation of their magnetic fields), after passing the reflected light through the analyzer in the field of view of the microscope, there is a light contrast between the regions with different magnetization, that is, the visually observed domain structure of the film. Unfortunately, this light contrast is not very significant, since the light reflected from the surface of the metal film is polarized elliptically, not flat-polarized.

In fig. 3 shows the domain structure of the film and its connection with the loop of the magnetoresistive hysteresis at the longitudinal geometry of the measurement for a $Fe_{50}Ni_{50}$ film of thickness d = 50 nm.

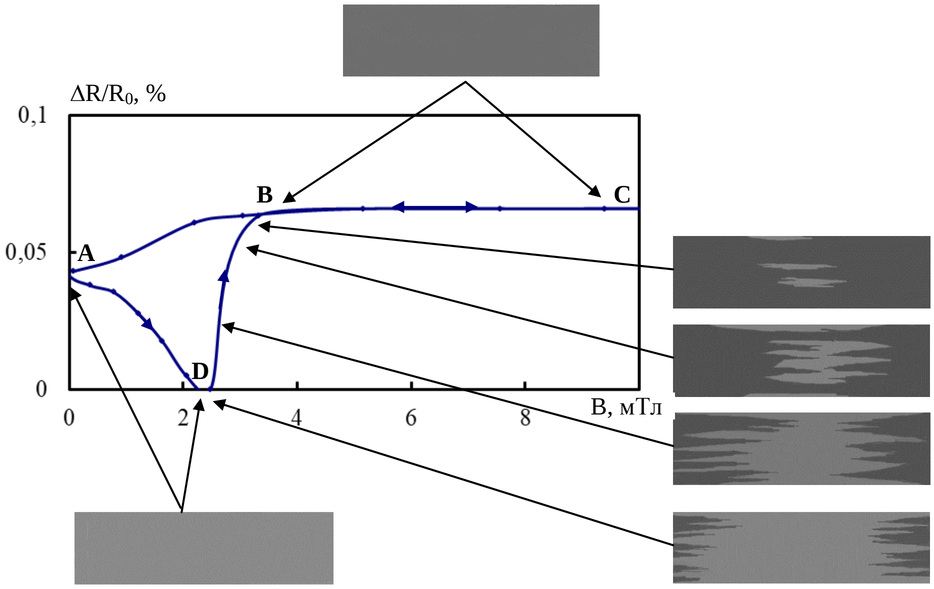

Fig. 3. Magnetoresistive loop and domain structure of film $Fe_{0,5}Ni_{0,5}$ thickness of 50 nm

First, the film is magnetized to saturation (it becomes one-domain) in a magnetic field directed along the axis of easy magnetization (point C). With further reduction of the magnetic field to zero (point A) the film remains single-domain. Also, the film's magnetoresistance does not change substantially (section BA). Then we change to the opposite direction of the magnetic field induction vector of the Helmholtz rings (we change the opposite direction of the electric current through the rings). At the first moment of the induction of the field of opposite direction, the film remains one-domed, but its electrical resistance is significantly reduced (section AD). Then, when the induction of the external magnetic field reaches 2,5 mT, the magnetization vectors turn around at the edges of the film and the domains of the wedge-shaped form (embryos of the reciprocal magnetization) are formed. In this case, the longitudinal magnetoresistance reaches its minimum (point D).

We note that the minimum for field dependencies of anisotropic magnetoresistance, as a rule, corresponds to the demagnetized state of the sample. A slight discrepancy in our case may be due to the peculiarity of the method of observing the domain structure. It is known that the magneto-optical Kerr effect is sensitive to the magnetization of the near-surface film layer. According to the existing experimental data, the thickness of such a layer for metallic ferromagnets does not exceed 15 nm. Consequently, the surface-level values of the coercive force may differ from its corresponding bulk values. That is, the near-surface layer of the film (which forms the image of the domain structure) and the inner volume of the film (which mainly causes the magnetoresistance of the film) may have a slightly different domain structure.

With further increase in the magnetic field induction, an increase in the size of the newly formed domains is observed mainly due to the displacement of their boundaries. The electroical resistance of the film sample also begins to increase. Further, even a small increase in the induction of a magnetic field leads to a sharp increase in the number of favorably oriented domains due to neighbors and the whole film is magnetized in this direction (again becoming one-domed). The field dependence of the magnetoresistance is also obtained by saturation. It should be noted that the process of film re-magnetization proceeds in the form of several jump-like landslides of domain boundaries in the narrow interval of the magnetic field induction change.

IV. CONCLUSION

It was established that for film alloys $Fe_{0,5}Ni_{0,5}$ the extremums on field dependences of the magnetoresistance correspond to the moment of the beginning of processes of film re-magnetization due to the movement of the domain walls. The incomplete coincidence of extrema on the field dependence of the magnetoresistance and the state of the magnetization of the sample is due to the peculiarities of the magneto-optical method of observing the domain structure.

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