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Magnetooptical Properties of Film Systems Based on Ferromagnetic Materials

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The results of experimental studies of the magnetooptical Kerr effect of thin-film systems based on Ni and V, as well as film $Ni_{80}Fe_{20}$ and $Ni_{40}Fe_{10}Co_{50}$ alloys as sensitive elements of magnetic field sensors are presented. Dimensional and temperature dependencies of the Kerr effect are shown. A correlation between magnetooptical properties and changes in the structure of multilayer systems based on Ni and V is established. The negligible fluctuation of the magnetic parameters (B_C and B_S) of Ni-Fe samples depending on the thickness and annealing temperature was found. In contrast to this, Ni-Fe-Co films demonstrated a significant change of MOKE-loop shape at different annealing temperatures, that confirms the occurrence of phase transitions in the film samples.

Keywords: Magnetooptical properties, Kerr effect, Coercivity, MOKE, Thin film, Saturation field, Hysteresis loop, Alloy

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1. INTRODUCTION

Unique magnetic, transport and optical properties of nanodimensional film systems, such as ferromagnetic material / nonmagnetic metal have attracted much interest because of their application in nanoelectronics. Magnetization process in ferromagnetic materials is mostly governed by competition between three types of interactions: exchange interaction, magnetocrystalline anisotropy, and magnetic dipolar interaction [1]. Minimization of the total magnetic energy determines the stable magnetization configuration. During the magnetization reversal in thin films, magnetic domains of opposite direction start to nucleate and then propagate across the sample as a magnetic field B, is swept through B_C. One of methods to observe the detailed mechanisms of magnetization reversal is a spectrometry of the magnetooptic Kerr effect (MOKE) [1]. Although no direct information can be obtained regarding the absolute magnitude of the magnetization, the angle of Kerr rotation is directly proportional to the magnetization [2, 3] and make possible to finding such parameters like coercivety B_C, saturation field B_S and relative magnetization changes of the samples.

Film systems based on the soft ferromagnetic metals (Co, Ni, Fe) and their alloys (Ni-Fe, Ni-Fe-Co etc.) are known because their extensive using of magnetic, magnetostrictive and magnetoresistive properties for creating the sensitive elements of sensor technology, for example, in magnetic recording heads or highly sensitive measuring devices [4, 5].

The results of experimental studies of the magnetooptical properties dependence on the system composition and the annealing temperature for multylayer film systems based on Ni and V and the magnetooptical properties dependence on film thickness and annealing temperature for the film Ni-Fe and Ni-Fe-Co alloys are presented in this paper.

2. EXPERIMENT

Series of films were deposited in an oil vapor-free vacuum of ~ 10^{-4} Pa by thermoresistive and electron gun methods of deposition. Three-layered Ni(15 nm)/V(15 nm)/Ni(40 nm)/S or Ni(15 nm)/V(1.5 nm)/Ni(40 nm)/S structures and multilayer film systems with periodical structure [Ni(1.5 nm)/V(1.5 nm)]n (n = 1-4) were obtained by Ni and V layer-by-layer deposition on glass-ceramic substrates (S). Films deposition was carried out to substrate at T_s = 320 K and after were annealed at $T_a \leq$ 600 K. The bulk permalloy 79NM (c_{Ni} ~ 80 %) was used for receiving of Ni-Fe thin films. A series of Ni-Fe-Co films were deposited on the amorphous substrates by thermoresistive technique by co-evaporation using permalloy 79NM and Co independent sources at room temperature. The Fe-Ni-Co alloy was deposited on substrate before heated to 500 K. All samples were annealed within temperature range 500-1000 K for 20 minutes. Samples size is 10 × 10 mm^2. The films thickness was controlled by quartz resonator or interferometer. The chemical composition of the obtained Ni-Fe-Co alloy was calculated based on weight of the deposited components, and further controlled by energy-dispersive X-ray spectroscopy (EDX) with an error of ± 5 %. The component concentration in the Ni-Fe and Ni-Fe-Co alloys is in at.%: c_{Ni} = 80, c_{Fe} = 20 and c_{Ni} = 40, c_{Fe} = 10, c_{Co} = 50 respectively. Magnetooptical measurements were carried out in longitudinal geometry (magnetic field is applied in the film plane and parallel to the plane of light beam incidence). Kerr angle value (θ_k) measuring was estimated by zero-analyze technique using a twice modulation of fallen light yield polarization by azimuth on magnetooptic device (inductivity field value was ≤ 150 mT).

3. RESULTS AND DISCUSSION

MOKE hysteresis loop for multilayer film system

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[Ni (1.5 nm) / V (1.5 nm)]$_n$ and Ni (15 nm) /V (15 nm) / Ni (40 nm) are shown in Fig. 1. Further investigation of obtained dependencies shown that as-deposited multilayer systems (n = 1-2) in magnetic field ± 150 mT have a weak MOKE value (θ_k = 0.1 mrad) and its intensity almost was not depend on annealing. It may be caused by solid solutions formation during the films system condensation. At n = 4 the MOKE signal of as-deposited and annealed at 600 K patterns increased in several times (θ_k = 0.2-0.4 mrad) at simultaneously increasing of their coercivity to 5 mT. In case of three-layered Ni (15 nm) / V(15 nm) / Ni (40 nm) / S and Ni (15 nm) /V (1.5 nm) / Ni (40 nm) / S film systems the MOKE signals are considerably higher compare to [Ni(1.5 nm)/ V(1.5 nm)]n structures. It was estimated that as-deposited three-layered Ni (15 nm) / V (15 nm) / Ni (40 nm) / S film system has the maximum value of Kerr angle (θ_k = 15 mrad) in magnetic field ± 150 mT. Its demagnetization inductivity B_C and saturation inductivity B_S have values 10 mT and 25 mT respectively. Different parameters ratio of top and bottom ferromagnetic layers may significantly influence on the shape of hysteresis loops and their magnetic reversal nature [6]. An inhomogeneous magnetic reversal was observed for the annealed at 600 K Ni(15 nm)/V(15 nm)/Ni(40 nm)/S film system which can be caused by soft magnetic and hard magnetic independent reversal. An analysis of hysteresis curve (magnetic switching effect) shown that antiferromagnetic distribution in this system is not stable in our point of view [6].

Magnetooptical Kerr effect of the $Ni_{80}Fe_{20}$ film samples with different thickness and annealing temperature is shown on the Fig. 2. Well known that the bulk $Ni_{80}Fe_{20}$ alloy is magnetically soft with high permeability in low magnetic fields with saturation induction 0.65-0.75 T. The MOKE signal analysis of $Ni_{80}Fe_{20}$ alloy samples showed their strong sensitivity to the film thickness (Fig. 2a). Thus, by increasing the thickness of the sample from 17 to 23 nm, the coercivity of the film increases by 1.5 times. But the greatest value of the demagnetization induction B_C = 5 mT was found for 10 nm film thickness, that can be explained by the possible heterogeneity of the sample material. Hysteresis loops have almost rectangular shape with a sharp reversal when the sample orientation is parallel to the magnetic field. Rectangular hysteresis loop (Fig. 2) is typical for easy magnetization, indicating the presence of a plane of easy magnetization reversal which is parallel to the plane of the sample. The results are close to experimental studies of permalloy and Co in the works of Weber et al. [7-9].

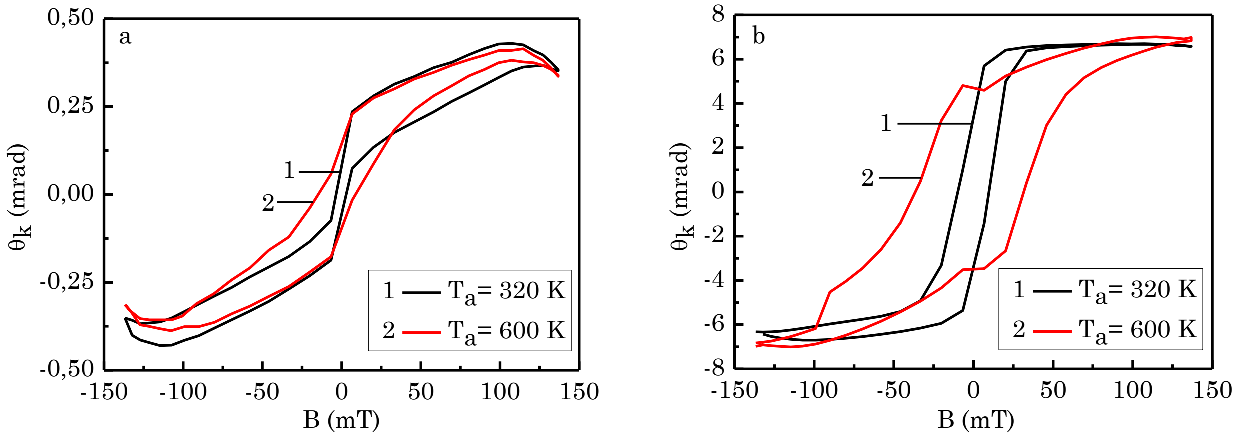

Fig. 1 – MOKE hysteresis loop for multilayer film system [Ni (1.5 nm) / V (1.5 nm)]$_n$ (a) and three-layer film system Ni (15 nm) / V (15 nm) / Ni (40 nm) (b) deposited on substrate heated to 320 K (loops "1") and annealed to 600 K (loops "2")

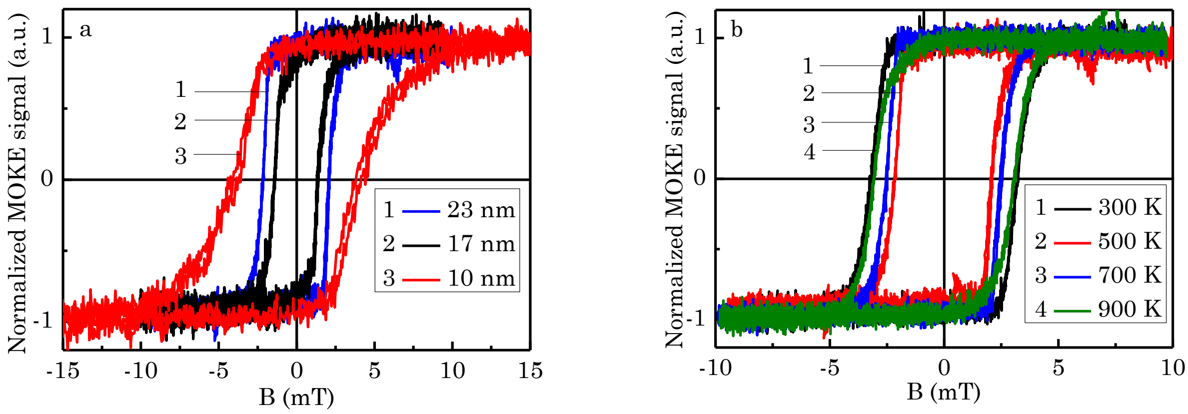

Fig. 2 – Normalized MOKE signal as a function of films thickness (a) and annealing temperature (b) for $Fe_{20}Ni_{80}$ film samples. The samples of 23 nm thickness were annealed

Annealing of permalloy thin film samples with thickness 23 nm in the temperature range 300-900 K weakly reflected on MOKE signals (Fig. 2 b), that indicate an immutability of the structural and phase composition of the samples. (More detail about determine the concentration, study of the crystal structure and phase composition of Ni-Fe and Ni-Fe-Co thin films see Ref. [10, 11]). The decreasing of B_C after annealing at 500 K is a consequence of the thermostabilization process, namely reducing the number of defects, which contribute to retardation the domain walls propagation at magnetization reversal [12]. A slight increase of saturation field and coercivity (a few mT) was observed with further heat treatment at 700-900 K that can be a consequence of the grain size increasing. Besides, the reason for fluctuations in the B_C values possibly is a presence of small magnetic anisotropy in the sample plane as a result of sample preparation technique [11].

Normalized MOKE signal for ternary film alloy $Ni_{40}Fe_{10}Co_{50}$ with 45 nm thickness is shown in Fig.3. MOKE loop of the as-deposited film (Fig. 3, loop 1) does not have a sharp magnetization reversal which suggests the presence of several phases with different magnetic parameters that the effect on the domain structure of the sample and its magnetization reversal processes. After annealing at 900 K (Fig. 3, loop 2) the MOKE loop changes shape on the rectangular. Coercivity and saturation field increased by 57 % and 36 %, respectively.

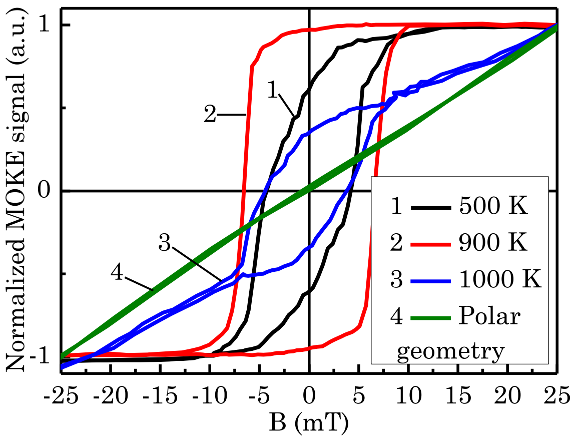

Fig. 3 – Normalized MOKE signal for ternary film alloy $Ni_{40}Fe_{10}Co_{50}$ (45 nm) deposited on heated to 500 K (1) substrate and annealed at 900 (2) and 1000 K (3). MOKE signal measured in polar geometry

A significant change of the magnetic parameters indicates a change in the phase state of the Ni-Fe-Co alloy, namely the formation of a solid solution [11]. Heat treatment of the sample at 1000 K (Fig. 3, loop 3) causes a decrease of B_C and the saturation field disappearance within the applied magnetic field, thereby approaching the magnetization loop to the form of hard magnetization reversal. As we reported previously [11] Ni-Fe-Co film loses its integrity and emptinesses appear in its volume after annealing temperature 1000 K, besides there is a considerable grains increasing that in total can be the reason of such magnetic behavior of the sample.

The MOKE measurement results in the polar geometry (the applied magnetic field is perpendicular to the sample plane and parallel to the plane of light beam incidence) are typical for hard plane of magnetization reversal (Fig. 3, loop 4).

4. CONCLUSIONS

In this article we discussed the results of experimental studies of magnetooptical properties of multilayer systems based on Ni / V with different numbers of layers, $Ni_{80}Fe_{20}$ and $Ni_{40}Fe_{10}Co_{50}$ alloys with different thickness at different annealing temperatures.

MOKE signals of annealed at 600 K film system Ni (15 nm) / V (15 nm) / Ni (40 nm) / S showed significant heterogeneity of magnetization reversal process of the samples, that can be explained by the independent magnetization reversal soft and hard layers.

The negligible fluctuation of the magnetic parameters (B_C and B_S) of $Ni_{80}Fe_{20}$ samples depending on the thickness and annealing temperature was found. In contrast to this, $Ni_{40}Fe_{10}Co_{50}$ films demonstrated a drastic change of MOKE loop shape at different annealing temperatures that confirm the occurrence of phase transitions in the film samples, namely the formation of a solid solution.

A wide range of coercivity and character of magnetization reversal process of samples may be available by combination a number of layers in the film systems $[Ni / V]_n$, the thickness change of the individual layers or by condensation conditions and heat treatment as in the case of ternary Ni-Fe-Co alloy that make its promising for practical use in the manufacture of magnetic sensor elements, read/write heads and magnetoresistive memory.

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