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Magnetoresistive and Magnetooptical Properties Nanosize Film Systems Based on Fe and Au

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The results of research magnetoresistive and magnetooptical properties of nanosize film systems based on Fe and Au are presented. It was shown that the value of magnetoresistance and magnetooptical properties depends on phase state of systems, concentration of Fe atoms and annealing temperature.

Keywords: Film system, Structure and phase state, Magnetoresistance, Magnetooptical properties, MOKE.

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1. INTRODUCTION

Magnetoresistive and magnetooptical properties of multilayers [1], granular film systems [2] or spin valves structures [3] is now attracting worldwide interest because of its high potential to applied as magnetic sensor. There has been a great interest to investigate film systems composed of Fe or Co based ferromagnets alternated with noble metals like Cu or Au [4, 5]. In this work we presented the magnetoresistance, magnetisation, structure and phase studies of polycrystalline film systems based on Fe and Au at different concentration of components.

2. EXPERIMENT

The experiments have been performed under high vacuum condition (the base pressure was 10^{-4} Pa) and samples have been prepared by method of thermal evaporation on substrates at temperature $T_s = 300$ K. The thickness of films was determined using the method of quartz resonator. Thermal annealing was carried out under high vacuum. The annealing duration was 30 min at annealing temperature $T_a = 700$, 800 and 900 K.

The resistance R of the samples in the magnetic field B was measured in standard in-plane geometry with current and magnetic field lying in longitudinal transverse and perpendicular geometries. The value of magnetoresistance (MR) as function of the field has been defined as $MR = (R(B) - R(B_s) / R(B_s)) \cdot 100$ %, where $R(B_s)$ is resistance at saturation field. Magnetooptical properties of the samples have been studied by the magneto-optical Kerr effect (MOKE) in longitudinal geometry. The phase state and structural characteristics were investigated by using diffraction and TEM measurements.

3. RESULT

3.1 Structural and Phase State

Detailed study of crystal structure and phase composition of Fe and Au thin films was done in earlier studies. It allowed us to pick deposition conditions so

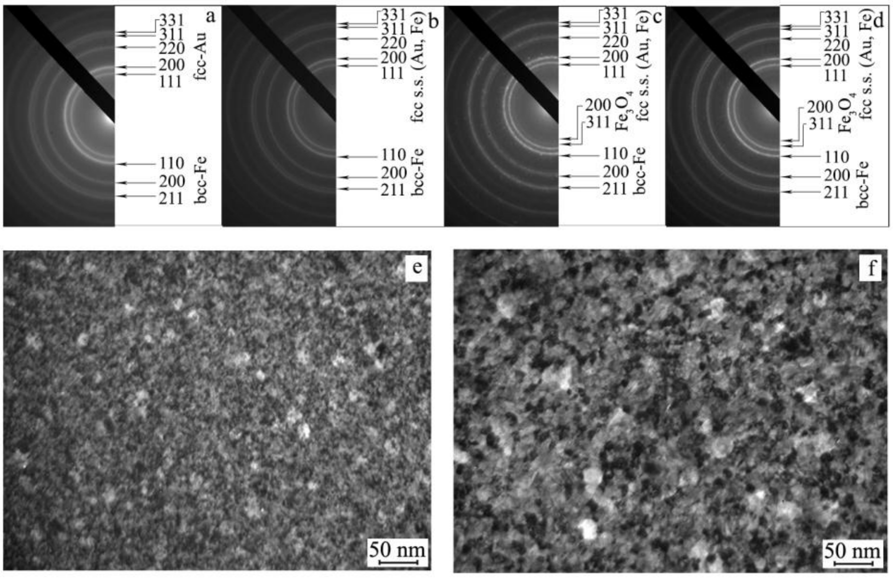

Fig. 1 – Diffraction pattern (a-d) and crystalline structure (e, f) of thin film system Fe(5)/Au(25)/Fe(5)/S after condensation (a, e) and annealing to 700 (b), 800 (c) and 900 K (d, f)

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that all components of systems have a crystalline structure.

Fig. 1 is showing the diffraction pattern (a-d) and microstructure (e, f) of thin film system Fe(5) / Au(25) / Fe(5) / S (S-substrate, the value of thickness is in nm) before and after annealing to 700, 800 and 900 K. The results of diffraction pattern interpretation presented at Table 1. The diffraction rings of as-deposited sample the corresponding to the face-centered-cubic (fcc) structure of Au and basic-centered-cubic (bcc) structure of Fe with lattice parameters 0.4074 and 0.2875 nm respectively. This values are close to that of bulk Au (a_0 = 0.4078 nm) and Fe (a_0(Fe) = 0.2870 нм). After annealing to 700 K, take place the formation of a solid solution (Au, Fe) and phase state of heat-treated sample correspond to s.s fcc-(Au, Fe) + bcc-Fe. The lattice parameter of annealed sample deviates from that of Au and Fe and take mean value $\bar{a}$ = 0.4065 nm. At increasing the concentration from 36 to 66 at.% Fe the lattice parameter decreases to $\bar{a}$ = 0.4054 nm.

Besides, after annealing to 800 and 900 K on diffraction patterns (Fig. 1c, d) fixed line d_{220} = 0.2961 nm, and d_{311} = 0,2524 nm which belonging to Fe_3O_4.

The analysis of sample crystalline structure after condensation and after annealing to 900 K indicates its nanoscale character.

3.2 Magnetoresistive Properties

The results of MR measurements for two systems Fe(5) / Au(25) / Fe(5) / S and Fe(10) / Au(15) / Fe(10) / S with total concentration 36 and 66 at.%. Fe presented at Fig. 2. The character of curves and MR value depends on geometry measurement of MR and annealing temperature.

Table 1 – The interpretation of diffraction pattern for film system Fe(5) / Au(25) / Fe(5) / S after condensation and annealing to 700, 800 and 900 K

№	After condensation				T_a = 700 K				T_a = 800 K				T_a = 900 K			
	d, nm	Phase	*hkl*	*a*, nm	*d*, nm	Phase	*hkl*	*a*, nm	*d*, nm	Phase	*hkl*	*a*, nm	*d*, nm	Phase	*hkl*	*a*, nm
1	–	–	–	–	–	–	–	–	0.2961	Fe_3O_4	220	0.8375	0.2961	Fe_3O_4	220	0.8375
2	–	–	–	–	–	–	–	–	0.2524	Fe_3O_4	311	0.8371	0.2525	Fe_3O_4	311	0.8274
3	0.2352	fcc-Au	111	0.4074	0.2350	fcc-Au, Fe	111	0.4070	0.2349	fcc-Au, Fe	111	0.4068	0.2349	fcc-Au, Fe	111	0.4068
4	0.2040	fcc-Au	200	0.4080	0.2038	fcc-Au, Fe	200	0.4076	0.2037	fcc-Au, Fe	200	0.4074	0.2037	fcc-Au, Fe	200	0.4074
		bcc-Fe	110	0.2885		bcc-Fe	110	0.2882		bcc-Fe	110	0.2880		bcc-Fe	110	0.2880
5	0.1442	fcc-Au	220	0.4078	0.1440	fcc-Au, Fe	220	0.4072	0.1438	fcc-Au, Fe	220	0.4067	0.1438	fcc-Au, Fe	220	0.4067
		bcc-Fe	200	0.2884		bcc-Fe	200	0.2880		bcc-Fe	200	0.2876		bcc-Fe	200	0.2876
6	0.1227	fcc-Au	311	0.4069	0.1225	fcc-Au, Fe	311	0.4062	0.1225	fcc-Au, Fe	311	0.4062	0.1224	fcc-Au, Fe	311	0.4060
7	0.1172	bcc-Fe	211	0.2870	0.1173	bcc-Fe	211	0.2873	0.1175	bcc-Fe	211	0.2878	0.1175	bcc-Fe	211	0.2878
8	0.0934	fcc-Au	331	0.4071	0.0932	fcc-Au, Fe	331	0.4063	0.0932	fcc-Au, Fe	331	0.4063	0.0931	fcc-Au, Fe	331	0.4060
	$\bar{a}$(Au) = 0,4074 nm; $\bar{a}$(Fe) = 0,2875 nm; a_0(Au) = 0,4078 nm; a_0(Fe) = 0,2870 nm				$\bar{a}$(fcc-AuFe) = 0.4068 nm; $\bar{a}$(Fe) = 0.2878 nm;				$\bar{a}$(fcc-AuFe) = 0.4066 nm; $\bar{a}$(Fe) = 0.2878 nm;				$\bar{a}$(fcc-AuFe) = 0.4065 nm; $\bar{a}$(Fe) = 0.2879 nm;			

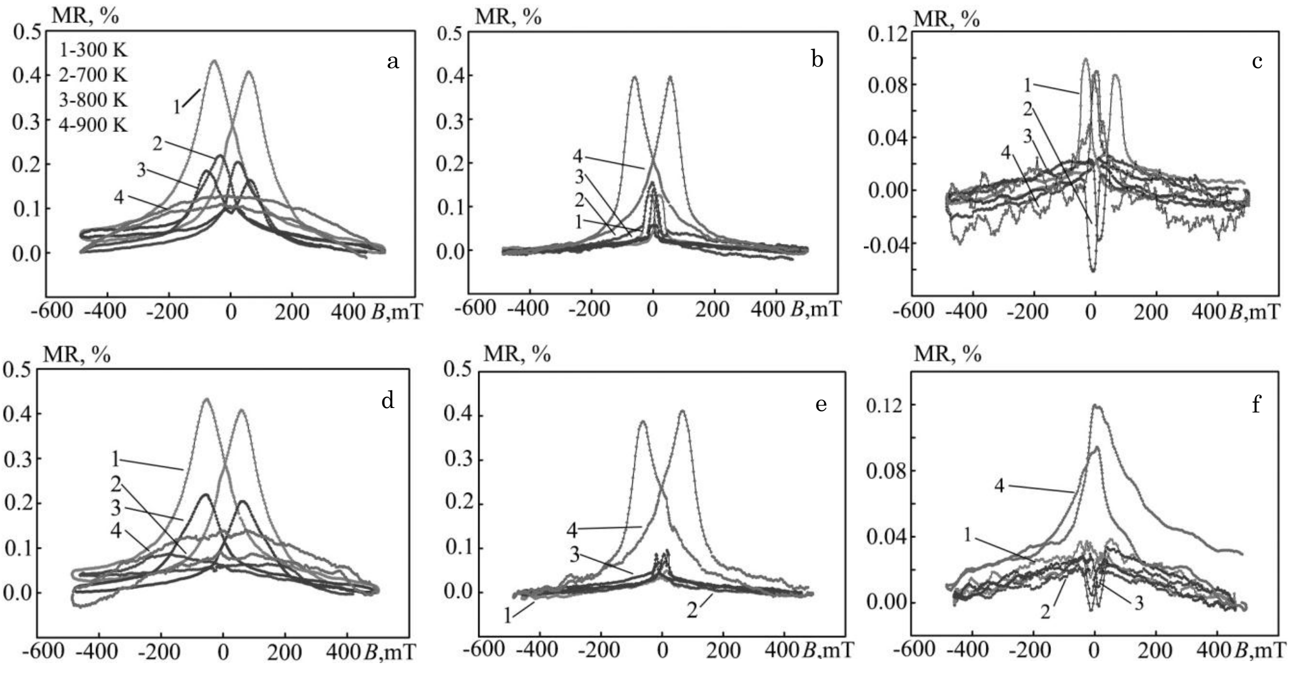

Fig. 2 – Magnetoresistance dependence vs. applied field for film systems Fe(5) / Au(25) / Fe(5) / S (a-c) and Fe(10) / Au(15) / Fe(10) / S after condensation and heat treated to 700, 800, 900 K. Magnetic field lying in longitudinal (a, d), transverse (b, e) and perpendicular geometries (c, f)

So in longitudinal (Fig.2 a, d) and transverse (b, e) geometries observed hysteretic behavior of magnetoresistance. The magnitude of MR (*B*) after heat treated decreases at $T_a = 700$ K then increase $T_a = 800$ K and after that decreases again (900 K) in longitudinal geometries for both samples. These changes of MR value can attributed with changes phase state of samples. The formation of s.s. (Au, Fe) leads to increases MR at 800 K and the increases of mean grain size of Fe at 900 K leads to decreases of efficiency of spin-depended electron scattering and as a results to decreases MR.

The MR curves also characterized by anisotropic magnetoresistance (AMR) that appearing at perpendicular geometry. Comparative analysis of dependence AMR on the total concentration of atom Fe indicates that with a decrease of concentration from 66 to 36 at. % Fe the magnitude of AMR is increase. The process of heat treated leads to formation of solid solution and as a result to disappearing AMR (for system with total atom concentration of magnetic component 36 at. % Fe at 700 K and with 66 at. % Fe at 800 K).

3.3 Magnetooptical Properties

We investigated magnetooptical properties of bilayer model film systems Au / Fe / S with different upper non-magnetic and magnetic layer thickness and in accordance with different total atomic concentration of component in the film system. Fig. 3a, b represents a MOKE of Au(5) / Fe(*x*) / S with the thickness of the magnetic layer $x = 5 \div 30$ nm. With increasing thickness *x* overall MOKE loops area increases. It has a characteristic rectangular shape with the exception of thickness 5 nm when the Fe film has no continuity. Rectangular shape of MOKE loops typical for ferromagnetic state of a continuous film with domain structure. After annealing up to 700 K (Fig. 3b) an increase in coercivity, which is associated with the processes of recrystallization during annealing with corresponding increase in the average grain size, which changes the domain structure of all layer. Fig. 3c, d shows the dependence MOKE for two-layer systems Au(20) / Fe(*x*) / S with thick layer of Au at different annealing temperatures. The difference in shape between the curves with $x = 5$ nm on Fig.3 a, b, c and d clearly demonstrates the effect of s.s. formation processes on the magnetic properties of the whole film system. Form of MOKE in the case of Au(20) / Fe(5) / S after annealing becomes more pronounced rectangular shape as in the case of Au(5) / Fe(5) / S, by contrast there has been blur shape that associate with of s.s. (Au, Fe) formation processes. Since the system Au-Fe has limited solubility [6] thermodiffusion of Fe atoms occurs more intensively when the thickness of Au is 20 nm and total atomic concentration of magnetic component in this system is less than in systems with more thin layers of Au.

In the case of a spin-valve-type three-layer systems where two magnetic layers separated by non-magnetic on base Fe and Au also observed the s.s. formation characteristics after annealing depending on the total atomic concentration in the samples. Thus Fig. 4 shows the MOKE for Fe(10) / Au(5) / Fe(*x*) / S, where *x* takes values 15 and 30 nm. Note that in the case of thicker bottom Fe layer MOKE have rectangular loop shape which is primarily due to the fact that the magnetic properties of the system in this case depends on lower hard layer Fe. In film systems with more thin bottom magnetic layers after annealing up to $T_a = 700$ K noticeable shape change associated with s.s. formation process. But these changes are not significant because the thickness of the intermediate layers is thin and the magnetic layers remain relatively continuous. Summing up the results of study magnetooptical properties of film system based on Au and Fe can be represented as concentration dependences of such important

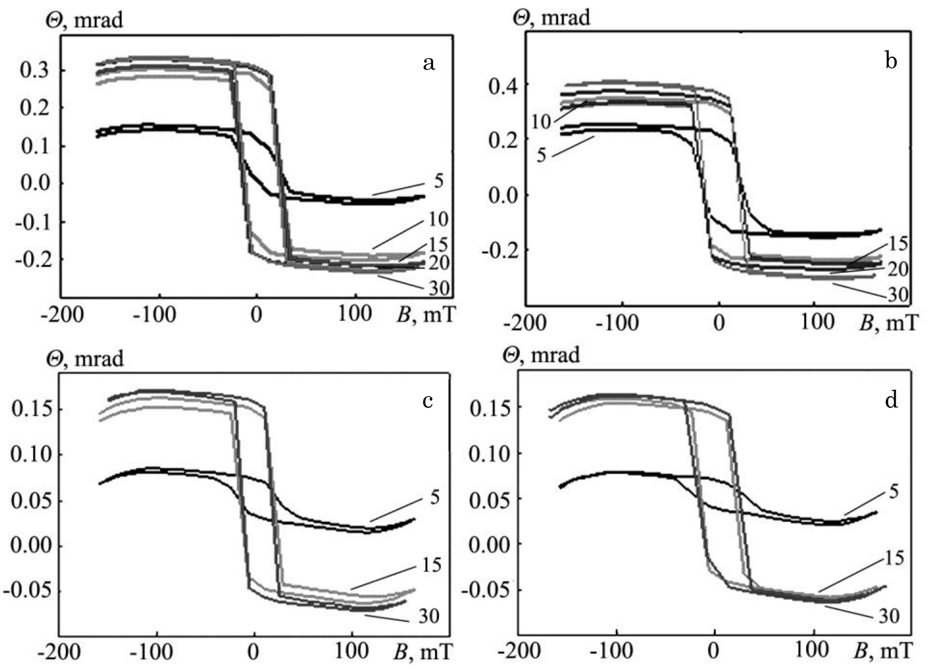

Fig. 3 – MOKE in film systems Au(5) / Fe(*x*) / S (a, b) and Au(20) / Fe(*x*) / S, *x* = 5, 10, 15, 20, 30 nm for 300 K(a, c) and 700K (b, c)

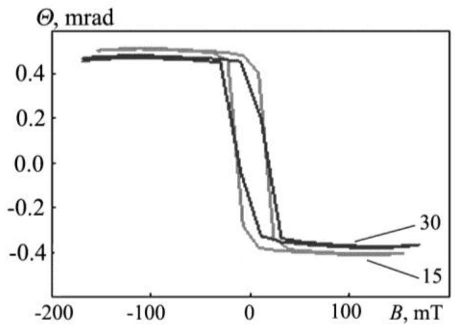

Fig. 4 – MOKE in film system Fe(10) / Au(5) / Fe(x) / S, where x = 15 and 30 nm

parameters as coercivity B_c, saturation field B_s and Kerr angle Θ_r. For all this parameters were typical concentrations 60 at. % Fe. Where observed clearly defined minimum on dependence of Kerr angle and visible maxima of the saturation field and coercivity values. After annealing was found that the values of the Kerr angles are slightly higher and saturation field values are decreases when the coercivity is almost unchanged. So it can be argued that the results of magnetooptical properties study confirm the conclusion above s.s. (Au, Fe) formation during annealing film systems based on Au and Fe. Moreover, the intensity of its formation is highly dependent with total atomic concentration of components in the system

4. CONCLUSION

The formation of solid solutions (Au, Fe) during heat treated, as a result of diffusion processes, in film systems based on Fe and Au accompanied by the formation of areas of inhomogeneous magnetic states that leads to changes of MR curves character, magnitude of magnetoresistance and to blurring curve shape of MOKE.

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