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Strain Properties of Nanodimentional Film Systems Based on Fe and Pt

K.V. Tyschenko*, I.M. Pazukha, N.I. Shumakova

Sumy State University, 2, Rymsky Korsakov Str., 40007 Sumy, Ukraine

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The results of research structural, phase state and strain properties of nanodimentional film systems based on Fe and Pt at deformation intervals $\Delta\varepsilon_1$ = (0 - 1)%, $\Delta\varepsilon_2$ = (0 - 2)% and $\Delta\varepsilon_3$ = (0 - 3)% are presented. After condensation in films occurred initiation disordered solid solution fcc-FePt with the mean value of lattice parameter $\bar{a}$ = 0,385 nm. The analysis of experimental deformation dependence at different Fe thickness, which changes in the range from 4 to 57 nm, while the thickness of Pt = 18 nm = const, were presented. It was shown that the value of mean strain coefficient depends on total film thickness and Fe concentration.

Keywords: Film System, Structure and Phase State, Strain and Plastic Deformation.

PACS numbers: 60.68.Bs, 72.10.Fk, 73.63.Bd

1. INTRODUCTION

Thin film systems based on Fe and Pt have attracted significant attention as possible high-density recording media [1], high coercive force, and good corrosion resistance as well as wear resistance. These characteristics have stimulated numerous studies, both in bulk and in thin film form [2, 3], but in the same time, their strain properties has not investigated. That's way the purpose of this work was investigation of strain properties of nanosize film systems based on Fe and Pt.

2. EXPERIMENT

Nanodimentinal film systems were prepared at vacuum chamber of VUP-5M (the base pressure was 10^{-4} Pa) by method of thermal evaporation with a speed 0,5 – 1 nm/s on polistirol substrates at temperature T_s = 300 K. The concentration of components determined according to equation

$$c_{Fe} = \frac{D_{Fe} d_{Fe} \mu_{Fe}^{-1}}{D_{Fe} d_{Fe} \mu_{Fe}^{-1} + D_{Pd} d_{Pd} \mu_{Pd}^{-1}}$$

where D – density of components; μ – molar mass of elements; d_{Fe}, d_{Pt} – films effective thickness.

The control of chemical state of samples carrying out by method of energodispersion analysis (scanning electron microscope SEM – 103) with accuracy of concentration interpretation ± 5%. The thickness of the films was measured by method of optical interference (device MII – 4).

The investigation of strain properties for film systems Fe(x)/Pt(18)/S (S – substrate, the value of thickness is in nm) were carried out at three deformation interval $\Delta\varepsilon_l$: (0 – 1); (0 – 2) and (0 – 3) %.

The mean strain coefficient (γ_l) was calculated as angular coefficient of dependence $\Delta R/R_i$ vs. ε_l, where R – electrical resistance of the film, R_i – initial value, $\varepsilon_l = \Delta l / l_i$ – longitudinal deformation (l_i – initial of samples length). The instantaneous strain coefficient (γ_{li}) was calculated by equation

$$\gamma_{li} = \frac{1}{R_i} \frac{dR_i}{d\varepsilon_{li}},$$

where де $d\varepsilon_{li}$ – infinitesimal interval of deformation (i – the interval number), R_i and dR_i – resistance, which correspond to beginning of interval $d\varepsilon_{li}$, and its change at increase of deformation by value $d\varepsilon_{li}$. The measurements of resistance and deformation of system film/S (S – substrate) and calculation γ і γ_{li} were realized using computerized system for data acquisition and experiment control, which described at work [4, 5].

The phase state and crystalline structure were investigated by electron diffraction and electron microscopy methods (high resolution transmission electron microscope TEM – 125K).

3. RESULT

3.1 Structural and phase state

Consider the results of investigation of crystalline structure and phase state at thin film systems based on Fe and Pt.

Typical diffraction and TEM-image for film system Fe(46)/Pt(18)/S after condensation are presented at Fig. 1. The results of diffraction data analysis are presented in Table 1.

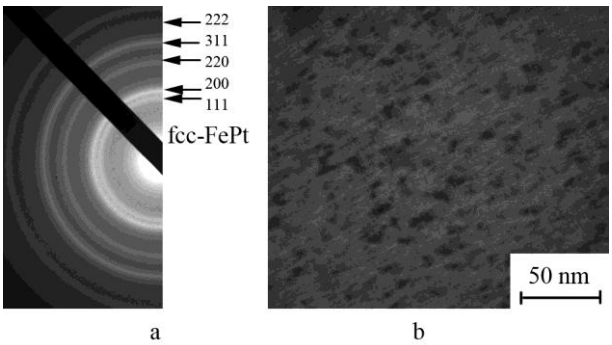

Fig. 1 – Diffraction pattern (a) and crystalline structure (b) of thin film system Fe(46)/Pt(18)/S after condensation

* tyshenko@aph.sumdu.edu.ua

Table 1 – The interpretation of diffraction pattern for film system Fe(46)/Pt(18)/S after condensation

№	I, a.u.	d, nm	Phase	hkl	a, nm
1	V.H.	0,222	fcc-FePt	111	0,385
2	H	0,193	fcc-FePt	200	0,386
3	m	0,136	fcc-FePt	220	0,385
4	m	0,116	fcc-FePt	311	0,385
5	l	0,111	fcc-FePt	222	0,384
ā(fcc-PtFe) = 0,385 nm; a_0(Pt) = 0,392 nm; a_0(Fe)=0,286 нм [8]					

V.H. – very high, H. – high, m. – medium, l. – low.

As can see from Tabl. 1, after condensation in films occurred initiation disordered solid solution fcc-FePt with the mean value of lattice parameter ā (fcc-FePt) = 0,385 nm. Necessary to note that single valued tabulated data of lattice parameter for fcc-FePt phase is missed. It's being caused by concentration dependence of lattice parameter, and according to degree of order the value of ā changed from 0,382 to 0,387 nm.

Fig. 2 illustrated the energodispersion (EDS) spectrum for film system Fe(46)Pt(18)/S, which evidenced of chemical purity of sample. It should be noted that the difference between the experimental values of film components and calculated values is less then 5%.

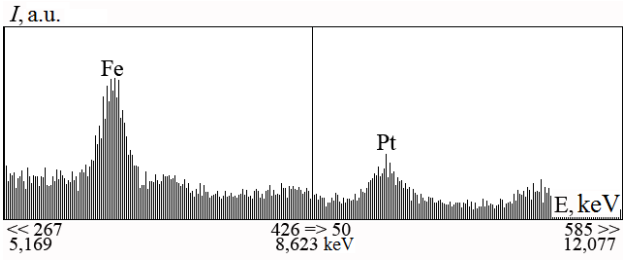

Fig.2 – EDS spectrum for film system Fe(46)Pt(18)/S (c_{Fe} = 76 %)

3.2 Strain properties

At investigation of strain properties of film systems Fe(x)/Pt(18)/S the deformation dependences were received. On the base of this dependences the value of γ_l, γ_{li} at three deformation intervals $\Delta\varepsilon_l$ = (0 – 1); (0 – 2) and (0 – 3) % were calculated.

Typical dependences $\Delta R/R$, R and γ_{li} vs. ε_l are presented at Fig. 3. First deformation cycle at deformation interval $\Delta\varepsilon_{l1}$ = (0 – 1)% for all samples is characterized by difference from another. It's can be explained by different recrystallization processes. Starting from second deformation cycles strain properties are stabilized. Dependence γ_{li} vs. ε_l is presented for last cycle.

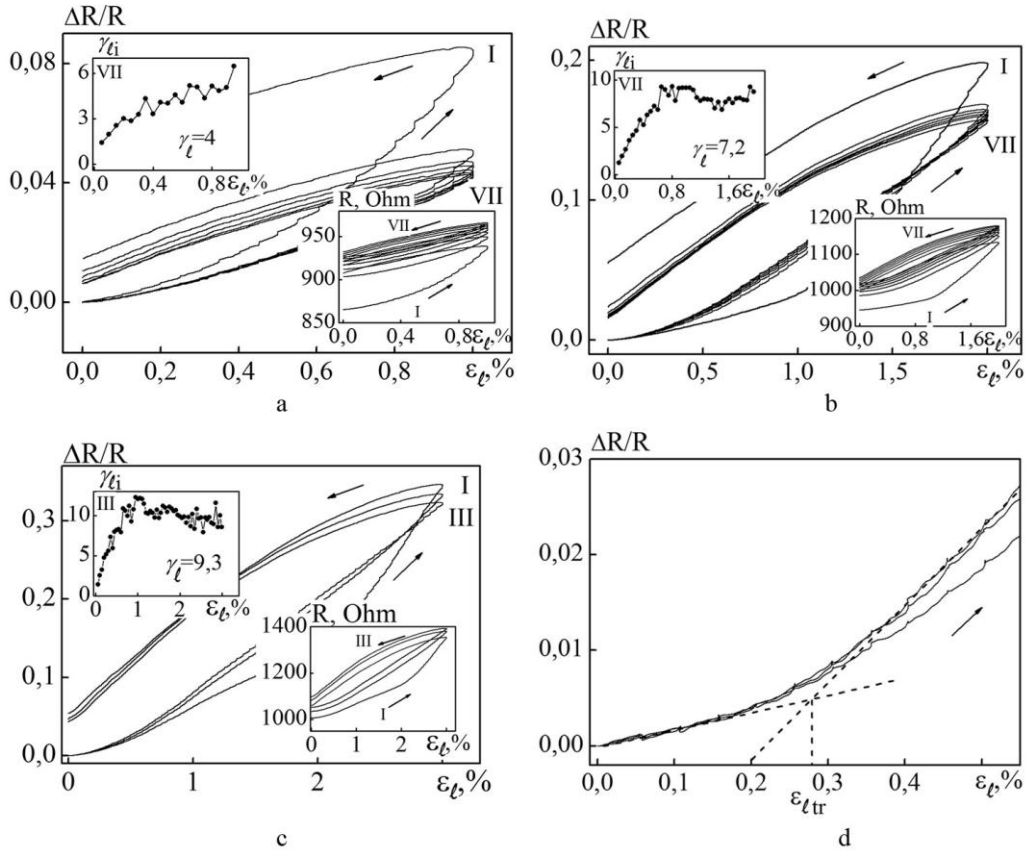

Fig. 3 – Dependences $\Delta R/R$, R and γ_{li} vs. ε_l (a-d) for thin film system Fe(22)/Pt(18)/S at three deformation intervals $\Delta\varepsilon_l$, %: (0 – 1) (a), (0 – 2) (b) and (0 – 3) (c); the method of interpretation of ε_{ltr} value (d). I, III, VII – number of deformation cycles "load – unload"

The nonlinear character at dependences γ_{li} vs. ε_l appeared at deformation ranges $\Delta\varepsilon_{l2}$, and $\Delta\varepsilon_{l3}$ for all samples. According to the work [6] the appearance of a maximum is caused by the nonlinear variation of the resistivity that occurs under corresponding deformation. The value of this maximum differed from value of transition from elastic to plastic deformation (ε_{ltr}). The method of interpretation ε_{ltr} is presented at Fig. 3,d.

The dependences ε_{ltr} vs. Fe thickness for film systems Fe(x)/Pt(18)/S at three deformation intervals $\Delta\varepsilon_l$ are shown at Fig. 4. The calculation results of value of transition from elastic to plastic deformation are presented at Tabl. 2. The analysis of data presented at Fig. 4 and Tabl. 2 suggested that hat samples characterized by narrow interval of elastic deformation. The value of transition from elastic to plastic deformation ε_{ltr} at interval $\Delta\varepsilon_{l1}$ is decreases from 0,22 to 0,11 at increases of Fe concentration from 22 to 80 at.%. A similar result was obtained for Fe thin films. According to work [7], Pt thin films characterized by a wide interval of elastic deformation (more than 1%). So for nanodimentional film systems based on Fe and Pt the conclusion can be done that the range of elastic deformation depends on total thickness of film system.

Fig. 5 presents summarized results of the study tensoresistive properties of film systems Fe(x)/Pt(18)/S. The graph shows that at narrow deformation interval $\Delta\varepsilon_{l4}$ = 0-0,1 % at d_{Fe} = 4-34 nm size dependence has typical character for metal thin films [8]. At increases of Fe thickness the slight increase of strain coefficient is observed. This can be explained by the effect of plasticity, which takes place at about 0,1% at d_{Fe} = 46-57 nm. It is clear that not only the effect of plasticity influences on the value of γ_l. Such effect as reducing the concentration of Pt atoms that are dissolved in the bcc lattice of Fe at increase of Fe top layer thickness influences too.

At high deformations (the intervals $\Delta\varepsilon_{l1}$, $\Delta\varepsilon_{l2}$, $\Delta\varepsilon_{l3}$) in the range of Fe thickness from 4 to 22 nm observed close to the linear size dependence γ_l versus d. The increases of Fe thickness leads to a change in the angle dependence, since the d_{Fe} = 34 nm. This change evidences of plastic deformation, which changes conditions of electron scattering at external surfaces, grain boundaries, interfaces etc. and, as a result, the total value of strain coefficient.

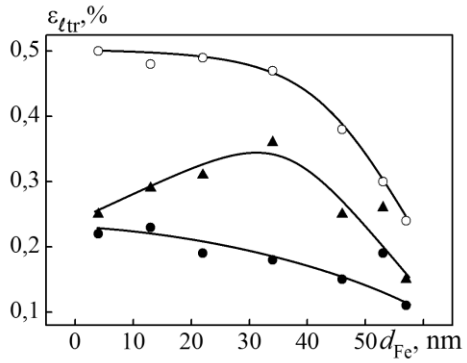

Fig. 4 – Dependence ε_{ltr} vs. Fe thickness for film systems Fe(x)/Pt(18)/S. The deformation intervals, %: ● – $\Delta\varepsilon_{l1}$, ▲ – $\Delta\varepsilon_{l2}$ and ○ – $\Delta\varepsilon_{l3}$

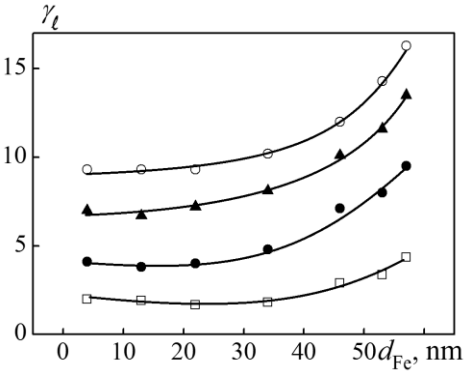

Fig. 5 – Dependence γ_l vs. Fe thickness for film systems Fe(x)/Pt(18)/S. The deformation intervals, %: ● – $\Delta\varepsilon_{l1}$, ▲ – $\Delta\varepsilon_{l2}$, ○ – $\Delta\varepsilon_{l3}$ and □ – $\Delta\varepsilon_{l4}$

Table 2 – The values of transition from elastic to plastic deformation ε_{ltr} and strain coefficients γ_l for film systems Fe(x)/Pt(18)/S at three deformation intervals $\Delta\varepsilon_l$, %: (0 – 1), (0 – 2) and (0 – 3)

№	film system	c_{Fe}, at.%	ε_{ltr1}, %	ε_{ltr2}, %	ε_{ltr3}, %	γ_{l1}	γ_{l2}	γ_{l3}
1	Fe(4)/Pt(18)/S	22	0,22	0,25	0,50	4,1	7,0	9,2
2	Fe(13)/Pt(18)/S	48	0,23	0,29	0,48	3,8	6,7	9,3
3	Fe(22)/Pt(18)/S	61	0,19	0,31	0,49	4,0	7,2	9,3
4	Fe(34)/Pt(18)/S	71	0,18	0,36	0,47	4,8	8,1	10,2
5	Fe(46)/Pt(18)/S	77	0,15	0,25	0,38	7,1	10,1	12,0
6	Fe(53)/Pt(18)/S	79	0,19	0,26	0,30	8,0	11,6	14,3
7	Fe(57)/Pt(18)/S	80	0,11	0,15	0,24	9,2	13,5	16,3

4. CONCLUSION

The experimental studies of structural, phase state and strain properties of nanodimentional film systems based on Fe and Pt with different concentration of component were carried out.

The analysis of phase state showed that these films at all thicknesses and concentrations has occurred initiation disordered solid solution fcc-FePt, which lattice parameter changes has concentration dependence. The experimental data of investigation strain properties characterized by nonlinear effects at dependences γ_{li} versus ε_l. The local peak takes place at deformation dependences. Its position varies depending on the concentration of the component in the systems and the Fe thickness and caused by the nonlinear variation of

the resistivity that occurs under corresponding deformation or is the result of structural changes in the film system. Besides, dependences $\Delta R/R$, R vs. ε for film systems Fe(x)/Pt(18)/S at three deformation intervals $\Delta\varepsilon$ characterized by narrow range of strain deformation, the limits of the transition elastic / plastic deformation dependence on concentrations of systems components.

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