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Strain Properties of Thin Film Systems Based on Ni and Ag

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Research results of influence of a uniform magnetic field by induction of 200 mT on the longitudinal gauge factor of nanocrystalline film systems of Ni/Ag/Ni with different thickness of non-magnetic layer of Ag within elastic deformation up to 1% are presented. The paper describes methods of forming three-layer structure based on thin films Ni and Ag and research of the structure and phase composition of the obtained samples. The correlation between the factor value of the longitudinal gauge and structural-phase state of film systems is set.

Keywords: Gauge factor, Phase composition, Three-layer film systems, Strain effect.

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1. INTRODUCTION

Physical properties of magnetic nanostructures of different types occupy one of the leading positions in advanced scientific researches [1-3]. The interest in them is due to both the fundamental issues of the nature of magnetism of nanoscale film systems and a wide range of their practical application [4, 5]. Studies in the area of magnetofield influence confirm that with moderate magnetic fields it is possible contactless effect on the dynamics of structural defects at different levels [6], and hence on the mechanical properties of materials and performance of devices [7, 8]. Thus, the study of the simultaneous effect of deformation and weak magnetic fields on the performance and mechanical properties of solids of different nature gives the possibility of building multi-functional controllers and sensors [9]. The study of influence of a weak magnetic field on the mechanical properties of various materials consistently were carried out in the works [6, 10]. In the case of non-magnetic crystals authors [6] could observe the motion of dislocations initiated by the magnetic field with induction 0,1 – 1,6 T without additional mechanical load. In the work [6] it is shown that magnetic fields reduce the height of the potential barriers to the motion of dislocations, and the driving force for the transportation of dislocations is a random distribution of fields of internal stresses. Exposure of aluminum samples in the magnetic field reduces the micro hardness and increases the strength of material [6]. The magnetic field is particularly affects the elastic properties of magnetically ordered materials [8, 11].

Thus, the aim of this study was to investigate the influence of a weak uniform magnetic field on a longitudinal gauge factor of three-layer systems based on nanocrystalline films of Ni and Ag within the elastic deformation up to 1%. Attention to the systems based on Ni and Ag films is connected with discovery of giant magnetoresistance phenomenon in the granular structure of ferromagnet-normal metal Ni-Ag [12]. Nanocrystalline materials are also characterized by high strength at low temperatures due to grain-boundary strengthening effect Hall-Patch and unique superplasticity at elevated temperatures [13].

2. EXPERIMENTAL

Thin films Ni, Ag, and three-layer systems of Ni(10)/Ag(d_{Ag})/Ni(30)/S (S – substrate, the value of thickness is in nm) were obtained by method of thermal evaporation in vacuum of 10^{-3} – 10^{-4} Pa. As substrates, during the tensoresistive studies served previously polished specially made Teflon substrates. This material was chosen because of its satisfactory heat resistance, elasticity and low chemical activity. Deposition of each layer of materials was carried out of two evaporators on the heated substrate (320 – 350 K) in a single technological cycle. Listed qualities of the substrate allowed to anneal film samples up to 520 K and to work within the elastic deformation from 0 to 1%. Films with substrates deformed in pace of 0.05%. To investigate the phenomenon of gauge of one- or three-layer films a specially designed device (deformation machine) was used that allowed to deform the film and simultaneously to measure its resistance to electricity directly in operating vacuum chamber installation VUP-5M. For the computation of the gauge factor 5-7 deformation cycles "load ↔ unload" were performed without field action and in perpendicular to the plane of the sample magnetic field by induction of 200 mT. For angular dependency ratio ΔR/R of ε_l gauge factor γ_l was calculated.

Thicknesses of individual layers were determined by method of quartz resonator and checked by interferometric method. The thickness of silver layer (d_{Ag}) varied in the range from 3 to 50 nm, and the thickness of the Ni layers remained fixed 10 and 30 nm for each film system.

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

3. RESULTS AND DISCUSSION

Taking into account the possible influence of the phase composition and the structure of components on the mechanical properties of three-layer samples, single-layer films Ni and Ag were investigated. Ag has fcc structure with the mean lattice parameter ā (fcc-Ag) = 0,408 ± 0,001 nm. The value agrees well with the

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tabulated data a_0 (fcc-Ag) = 0,409 nm [14]. The average crystallite size is L = 40 nm. Annealing of sample at the temperature of 750 K does not lead to changes in the phase composition, but causes the increase up to 65 nm. Single-layer film Ni also have fcc structure with the mean lattice parameter $\bar{a}$ (fcc-Ni) = 0,353 ± 0,001 nm, which corresponds to the tabulated value for bulk samples a_0 (fcc-Ni) = 0,352 nm [14]. When annealing in the temperature range of 600 – 750 K the average crystallite size increases from 35 nm to 50 nm. The average crystallite size of Ni and Ag films is also sensitive to the thickness of the sample.

It is known [15] that the degree of dispersion of crystallites affects the electrical and physical properties and parameters of films electromigration. Thus, forming film samples with a particular grain size allow to control electrical and physical properties and to consider them in the transition from one- to three-layer samples.

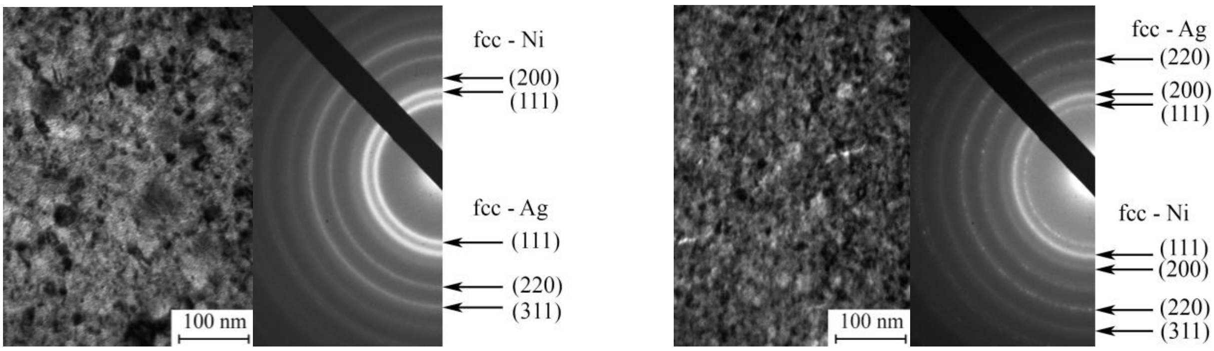
The diagram of Ag-Ni state is a simple monotectonic system. The maximum solubility of Ag in Ni is ~1% at. and decreases with temperature decrease [16]. So, electronographical data presented in figure 6 only prove the two-phase composition of film systems Ni(10)/Ag(d_{Ag})/Ni(30)/S (see Fig. 1). In the diffraction patterns rings of both metals can be observed (see Table 1). So, after condensation the personality of separate layers of Ni(10)/Ag(dAg)/Ni(30)/S system is maintained. Metals Ni and Ag in the three-layer structure have fcc lattice with the average parameters $\bar{a}$ (fcc-Ag) = 0,410 ± 0,001 nm and $\bar{a}$ (fcc-Ni) = 0,354 ± 0,001, which corresponds to the tabulated value for bulk samples [14].

Typical strain dependences of ΔR/R and R vs. ε_l for the three-layer film systems of Ni(10)/Ag(dAg)/Ni(30)/S in the absence of magnetic field and in the magnetic field of B = 200 mT are presented in Fig. 2 respectively. On the basis of indicated data the calculation of dependences of the gauge factor in the interval of deformation ε_l = 0 – 1% was carried out.

For thin films Ag are typical relatively small values of gauge factor γ_l = 2 – 2,3 and its linearity in the indicated interval of deformation. When putting single-layer films of silver in the external magnetic field induction of 200 mT gauge factor almost does not change (see Fig. 3a).

Strain dependences of Nickel films are characterized by a significant difference between the first cycle "load - unload" from the next ones that it is possibly associated with the occurrence of relaxation processes. Starting with the second cycle there is a stabilization of strain properties of thin film samples Ni. Gauge factor of monolayer films of Ni increases markedly with the introduction of the external magnetic field (see Fig. 3b).

Analysis of the results showed that the longitudinal gauge factor of film system (see Fig. 3c) with a relatively small thickness of the layer of silver (d_{Ag} < 10 nm) is of the order of 9 units. With increasing thickness of silver to d_{Ag} = 40 – 42 nm gauge factor is reduced up to 6 units and in the range of 40 – 50 nm it drops to 1,5. This can be explained by the fact that the total thickness of the film system increases and therefore the impact of interface scattering of electrons on the value of gauge factor reduces. In putting this film system to the external surface of the sample perpendicular to the magnetic field induction of 200 mT increases in gauge factor is observed regardless of the thickness of silver.



a b

Fig. 1 – Crystalline structure and diffraction patern of film systems Ni(10)/Ag(10)/Ni(30)/S (a) and Ni(10)/Ag(40)/Ni(30)/S (b) after condensation

Table 1 – The interpretation of diffraction pattern for film systems Ni(10)/Ag(10)/Ni(30)/S and Ni(10)/Ag(40)/Ni(30)/S

№	Ni(10)/Ag(10)/Ni(30)/S					№	Ni(10)/Ag(40)/Ni(30)/S				
	I, a.u.	d_{hkl}, nm	hkl	phase	a, nm		I, a.u.	d_{hkl}, nm	hkl	phase	a, nm
1	V H	0,236	111	fcc-Ag	0,409	**1**	m	0,237	111	fcc-Ag	0,410
2	V H	0,204	111	fcc-Ni	0,353	**2**	H	0,205	200	fcc-Ag	0,410
3	l	0,177	200	fcc-Ni	0,354	**3**	H	0,204	111	fcc-Ni	0,353
4	m	0,144	220	fcc-Ag	0,407	**4**	l	0,178	200	fcc-Ni	0,356
5	m	0,123	311	fcc-Ag	0,408	**5**	m	0,145	220	fcc-Ag	0,410
						6	m	0,125	220	fcc-Ni	0,354
						7	l	0,107	311	fcc-Ni	0,355
$\bar{a}$(fcc-Ag) = 0,408 nm; $\bar{a}$(fcc-Ni) = 0,354 nm a_0(fcc-Ag) = 0,409 nm; a_0(fcc-Ni) = 0,352 nm [14]						$\bar{a}$(fcc-Ag) = 0,410 nm; $\bar{a}$(fcc-Ni) = 0,354 nm a_0(fcc-Ag) = 0,409 nm; a_0(fcc-Ni) = 0,352 nm [14]					

H – high, m – medium, l – low.

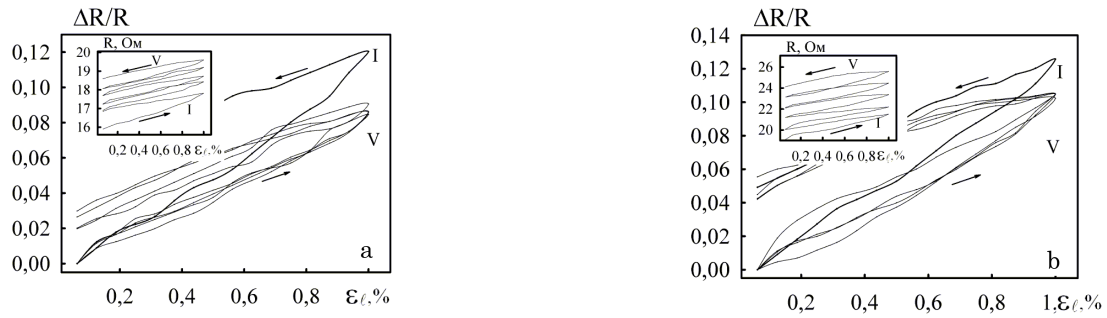


Fig. 2. – Dependences ΔR/R and R vs. ε_l for thin film system Ni(10)/Ag(10)/Ni(30)/S without field (a) and in perpendicular magnetic field induction of 200 mT (b)

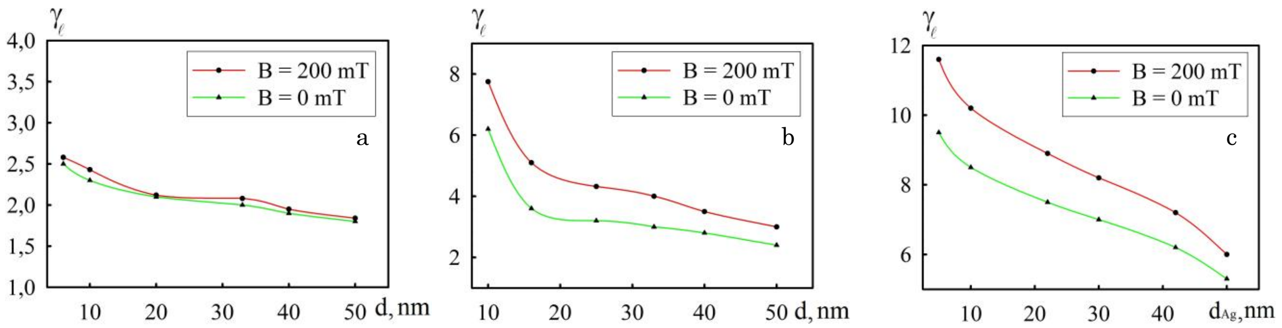


Fig. 3. – Dependences γ_l vs. d for thin film system Ni (a), Ag (b) and Ni(10)/Ag(d_{Ag})/Ni(30)/S: ▲ – without field, ● – in perpendicular magnetic field induction of 200 mT

Thus, at the thickness of 10 nm silver gauge factor increases by 22 – 24% and is 11 – 11,2 units. With increasing silver thickness up to 40 – 50 nm gauge factor increases only by 17 – 18% and is 7 – 7,1 units. Since in the system Ni(10)/Ag(d_{Ag})/Ni(30)/S the personality of separate layers is conserved, the contribution to the overall value of gauge factor make scattering processes at the interface layers, i. e. the presence of interface scattering increases the value of γ_l. This gives the possibility of building sensing element load cell based on multilayer film system [5, 17], the components of which are the films of Ag and Ni.

4. CONCLUSIONS

It is determined that three-layer film systems Ni(10)/Ag(d_{Ag})/Ni(30)/S (d_{Ag} = 10 – 50) have gauge factor greater than single-layer films Ni or Ag films of the same thickness do. With decrease in the average grain size of film system, gauge factor increases.

It is shown that in magnetic field induction of 200 mT gauge factor of film systems Ni(10)/Ag(d_{Ag})/Ni(30)/S increases. In the samples with thickness d_{Ag} = 10 nm the growth of gauge factor in magnetic field is 21 – 22%, while at dAg > 40 nm the growth decreases and is 13 – 16%.

REFERENCES

1. A.P. Boltaev, F.A. Pudonyn. I.A. Sherstnyov, *Solid State Phys*, **53** 5, 892 (2011).
2. B.A. Aronzon, V.V. Rylkov, S.N. Nikolaev, V.V. Tugushev, S. Caprara, V.V. Podolskii, V.P. Lesnikov, A. Lashkul, R. Laiho, R.R. Gareev, N.S. Perov, A.S. Semisalova, *Phys. Rev.*, **84**, 075209 (2011).
3. http://arxivs.org/archive/cond-mat/9906433v1.
4. Y. Nishibe, H. Yamadera, N. Ohta, K. Tsukada, Y. Nonomura, *Sensors and Actuators*, **82,** 155 (2000)
5. S. Dokupil, M.-T. Bootsmann; S. Stein, M. Löhndorf, E. Quandt, *J. Magn. Magn. Mater.*, **290**, 795 (2005).
6. Y.I. Golovin, *Solid State Phys*, **46** 5, 769 (2004).
7. O.V. Synashenko, Ye.P. Tkach, I.P. Buryk, L.V. Odnodvorets, S.I. Protsenko, N.I. Shumakova, VANT, **18** No6, 169 (2009).
8. N.I. Zakharenko, M.P. Semenko, *Phys Met Metallogr.*, **104**, 2, 150 (2007).
9. A. Ben Amor, T. Budde, H.H. Gatzen, *Sensor. Actuat. APhys.*, **129**, 41 (2006).
10. V.I. Al`shits, E.B. Darinskaia. E.A. Petrzhik, *Solid State Phys*, **35,** 2, 320 (1993).
11. O.V. Stolbov, Y.L. Raikher, M. Balasoiu, *Soft Matter*, **7**, 8484 (2011).
12. A. Gerber, A. Milner, B. Groisman, M. Karpovsky, A. Gladkikh, Phys. Rev., **55**, 6446 (1997).
13. G.A. Maligin, *Advances of Physical Sciences*, **181** No11, 1129 (2011).
14. S.S. Gorelik, L.N. Rastorguev, Y. Skakov, *X-ray and electron graphical analysis of metals* (Moscow: GNTI: 1963).
15. I. Protsenko, L. Odnodvoretz, A. Chornous, *Metallofiz Nov Tekh,* **20** No1, 36 (1998).
16. *Diagrams of Binary Metallic Systems*, V. 1 (Ed. N.P. Lyakishev) (Moscow: Engineering: 1996).
17. S.I. Protsenko, *J. Nano- Electron. Phys*. **2** No4, 7 (2009).