Journal of Nano- and Electronic Physics
Vol. **6** No 1, 01031(5pp) (2014)

Журнал нано- та електронної фізики
Том **6** № 1, 01031(5cc) (2014)

Magnetoresistive Properties of Quasi Granular Film Alloys Fe_xPt_{1-x} at the Low Concentration of Pt Atoms

I.Yu. Protsenko[1,*], P.K. Mehta[2], L.V. Odnodvorets[1], C.J. Panchal[2], K.V. Tyschenko[1], Yu.M. Shabelnyk[1], N.I. Shumakova[1]

[1] *Sumy State University, 2, R.-Korsakov Str., 40007 Sumy, Ukraine*
[2] *University of Baroda, Kalabhavan, Post Box 51 , 390001 Vadodara, India*

(Received 04 March 2014; published online 06 April 2014)

Present results of studies of the phase composition, microstructure and magnetoresistive properties of three-layer film Fe / Pt / Fe (total concentration of platinum atoms $c_{Pt} \le 20$ at. %) and multilayers based on Fe and Pt ($20 < c_{Pt} \le 33$ at. %), where possible formation diluted s.s. of Pt atoms in α-Fe layers and phase Fe_3Pt based on Pt island, in non-annealed and annealed to 800 K states. Analysis of the results combined with literature data suggests that the phase composition of the magnetic grains did not significantly affect the efficiency of spin-dependent electron scattering.

Keywords: Three-layer films, Multilayers, Phase state, Magnetoresistance, GMR, Granular solid solution.

PACS numbers: 68.37.Lp, 75.47. – m, 81.40.Rs

1. INTRODUCTION

The great interest to the study the properties of film from Fe and Pt related to the fact that they have observed a number of phenomena that are of interest both from basic and practical points of view.

In particular, they stabilize disordered state (FCC lattice Fe_xPt_{1-x}) or at increased temperatures an ordered state (FCT phase $L1_0$). This phenomenon is observed both in the solid film samples [1-8], and in monoatomic multilayers in which FePt layer has a thickness $d \sim 1$-10 nm [9], ultrathin FePt island films with an effective thickness $d = 1$-10 nm [10], thin films of FePt ($d = 10$ nm) [11], granular films FePt, deposited in SiO_2 matrix granules with a diameter of 5.1 nm [12] and 6.7 nm [13] or Al_2O_3 matrix with a diameter of at least 7 nm [14]. In the last work observed that FePt grains with a diameter of less than 4 nm are ordering process was observed. In addition, the number of papers (see, for example, [1]) observed that nanoparticles (NP) FePt (as FeCo) with FCT lattice with large energy magnetocrystalline anisotropy, the coercive force, saturation magnetization and corrosion resistance and weakly interact. But the property functional NP for $L1_0$ phase should be considered their relatively high barrier transition in supermagnet state at the small sizes NP (less than 4 nm). This allows the use them for create media with high-density magnetic recording. Note that $L1_0$ is ordered phase is formed at annealing disordered solid solution (s.s.) based on the FCC-Fe (at low concentrations of Pt atoms) or based on the FCC-Pt (at low concentrations of Fe atoms).

In the phase diagram of the bulk binary alloy Fe-Pt (see, for example, [2]) indicated field stabilization phase Fe_3Pt; ordered phase FePt, which is stabilized in thin films at temperatures $T \ge 820$ K [1]; $FePt_3$; disordered FCC s.s. (γ-Fe, Pt) and at low concentrations of Pt atoms (up to 15 at. %) phases s.s. (α-Fe) and region of stabilization s.s. (γ-Fe, Pt) + s.s. (α-Fe).

Summarizing the literature data, we can conclude a significant impact process ordering and atoms concentration on the magnetic properties of the Fe-Pt alloys, which we will take into account when interpreting the results.

Since the structural and physical properties of the phases Fe_3Pt, FePt, $FePt_3$ and s.s. (γ-Fe, Pt) are studied to a large extent, the aim of our research can be summarized as follows: the study of magnetoresistive properties of three-layer film systems based on Fe and Pt atoms at a total concentration of Pt atoms 20 at. %. In non-annealed and annealed to 800 K states (see fragment of phase diagram on Fig. 1). In some cases we studied film samples as multilayers [Fe(3-5 nm) / Pt(3-5 nm) / Fe(3-5 nm)]$_8$ (total concentration of Pt atoms to 33 at. %), which may form the phase Fe_3Pt.

2. EXPERIMENTAL METHODIC

Forming film of Fe(30) / Pt(3-20) / Fe(30) / S and multilayers (S – thin films of carbon and microscopic and diffraction research or pyroceram plates to mea-sure electrical resistance) was performed in a vacuum $\sim 10^{-3}$-10^{-4} Pa at a condensation rate $\omega = 1$-1,6 nm/s by simultaneous deposition of Fe and Pt layers.

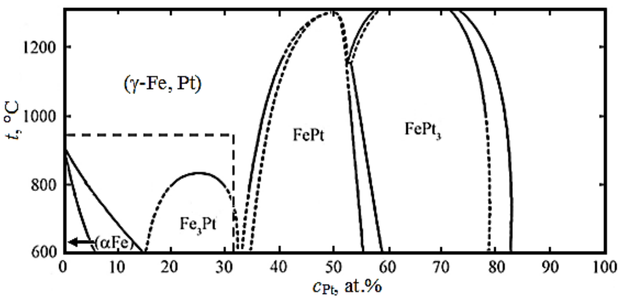

Fig. 1 – A fragment of the phase diagram system Fe-Pt [2]. The dotted line is region of stabilization diluted s.s. of Pt atoms in α-Fe and phase Fe_3Pt

As the thickness was controlled by quartz crystal, it provided high accuracy (± 1 nm) determination of the effective thickness of the individual layers. The total thickness of the samples was monitored after addition of condensation by interferometry.

Knowing the thickness of the layers, it is possible to calculate the concentration of the separate components:

* protsenko@aph.sumdu.edu.ua

$$c_i = \frac{D_i d_i \mu_i^{-1}}{D_{Fe} d_{Fe} \mu_{Fe}^{-1} + D_{Pt} d_{Pt} \mu_{Pt}^{-1}}, \qquad (1)$$

where $i = 1, 2$; D and μ – density and molar mass of Fe or Pt.

Additionally, the concentration of elements also controlled by energy dispersive analysis using scanning electron microscope SEM-103 («Selmi», Ukraine).

Investigation of phase composition and crystal structure of film samples based on Fe and Pt were carried out at the room temperature in the initial state and after annealing $T_{an} \leq 800$ K using electron microscope TEM-125K («Selmi», Ukraine).

Magnetoresistive properties of samples were studied at $T \cong 300$ K using four-point circuits in a constant magnetic field in three geometries measure: longitudinal, transverse and perpendicular (Fig. 2).

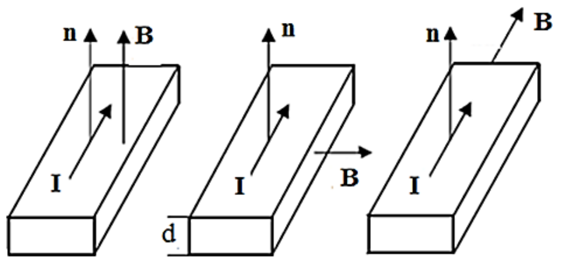

Fig. 2 – Geometry measurement of MR: a – perpendicular (⊥); b – transverse (┼); c - longitudinal (||) geometry

Magnetoresistance value was calculated based on the ratio:

$$MR = \frac{R(B) - R(0)}{R(0)}, \qquad (2)$$

where $R(B)$ and $R(0)$ – sample resistance on magnetic field and without it, accordingly.

The magnetic field was created electromagnets, the maximum value of the magnetic induction (B) was 450 mT and magnetoresistance measurements carried out automatically.

3. PHASE COMPOSITION

Electron diffraction research study found that in the process of condensation at the substrate temperature $T_n \cong 300$-350 K produced diluted BCC s.s. (α-Fe) with lattice parameters $a \cong 0{,}29$ nm. In this case the electron diffraction pattern from all the samples observed weak line (111) Pt (Fig. 3a), while for electron diffraction pattern from the sample annealed to 800 K, kept the system lines s.s. (α-Fe) and there are additional lines that match the phase Fe_3Pt (Fig. 3b), and the lines of the FCC-Pt is not observed. This means that some Pt atoms forms s.s. (α-Fe) based on Fe layer, and some – phase Fe_3Pt based on Pt islands. According to [15] the formation of this phase is due to the eutectoid reaction at the temperature $T_{an} \cong 800$ K. By increasing the total concentration of Pt atoms to 33 at. % (in our case – the transition to multilayers $[Fe(d) / Pt(d) / Fe(d)]_8$ / S) can form the phase composition of granules close up phase Fe_3Pt. Electron microscopic studies indicate that in this case, condensate Pt layer was island character at the $d_{Pt} < 10$ nm (average size of islands to 20 nm), which is three-layered systems Fe / Pt / Fe / S can be considered (modeled) as a granular alloy film. By increasing the effective thickness of the Pt film of 10 to 20 nm, it becomes almost structurally continuous with islands up to 60 nm. At the same time, according to data [16], the film during annealing of Fe(20) / Pt (20) (total concentration of atoms Pt – 50 at. %) to 800 K is formed granular alloy based on α-Fe and nanoparticles and that have a phase structure that meets Fe_xPt_{1-x} with the lattice parameters $a = 0{,}38$ nm, which agrees well with the value of the parameter Fe_3Pt.

The peculiarity of the phase formation in this case is that in a controlled inlet oxygen granules Fe_xPt_{1-x} shell covered with antiferromagnetic oxide γ-Fe_2O_3, allowing control of the magnetic properties of granular alloy. In our case, as the authors [16], the as deposition structure and mode of annealing samples were similar, but at the annealing in conditions of residual atmosphere (pressure 10^{-4} Pa) oxides formation was observed by us, which can be qualitatively show and relatively small size resistivity samples – $2 \cdot 10^{-7}$ Ohm·m.

4. MAGNETORESISTIVE PROPERTIES

On Fig. 4, 5 represent typical field dependence of the magnetoresistance for non-annealing and annealed to 800 K three-layer film systems. Note that the appearance of a sharp curve at the minimum and maximum on the demagnetization curve of magnetization associated with residual magnetization and coercive field of small value. Magnetoresistance hysteresis loop for the film systems which have been annealed at all three measurement geometries indicate the presence of GMR effect of relatively small amplitude (up 0,035 %). The observation of this effect this we connect with spin-dependent scattering of electrons on the grains of the alloy, formed from the islands Pt, a relatively small number of them and causing small amplitude effect. With the gradual increase of the effective layer thickness d_{Pt} amplitude increases almost no effect, while $d_{Pt} = 15$-20 nm, the effect of GMR transition into anisotropic magnetoresistance (AMR). This effect is well known, lot of times discussed in the literature and its essence consists in the fact that at a certain thickness of the nonferromagnetic layer disappears antiferromagnetic interaction (condition of realization GMR) between the magnetic moments of the lower and upper Fe layers. Note also that there is also some minimum effective thickness (about 1 nm) nonferromagnetic layer, which is implemented by another ferromagnetic interaction (condition for existence AMR).

In annealed to 800 K three-layer film systems Fe(30) / Pt(d) / Fe(30) / S effect GMR more distinctly and with large value of amplitude (Fig. 4 and Fig. 5). For multilayers in which the total concentration $c_{Pt} \cong 33$ at. %, depending on Fig. 6 and Fig. 7 illustrate the effect of GMR, the maximum value of which in the transverse geometry measurement reaches a value of 0,3 %. Anisotropy effects in annealed multilayers AMR = – 0,25 % ($[Fe(3) / Pt(3) / Fe(3)]_8$ / S) and – 1,20 ($[Fe(5) / Pt(5) / Fe(5)]_8$ / S).

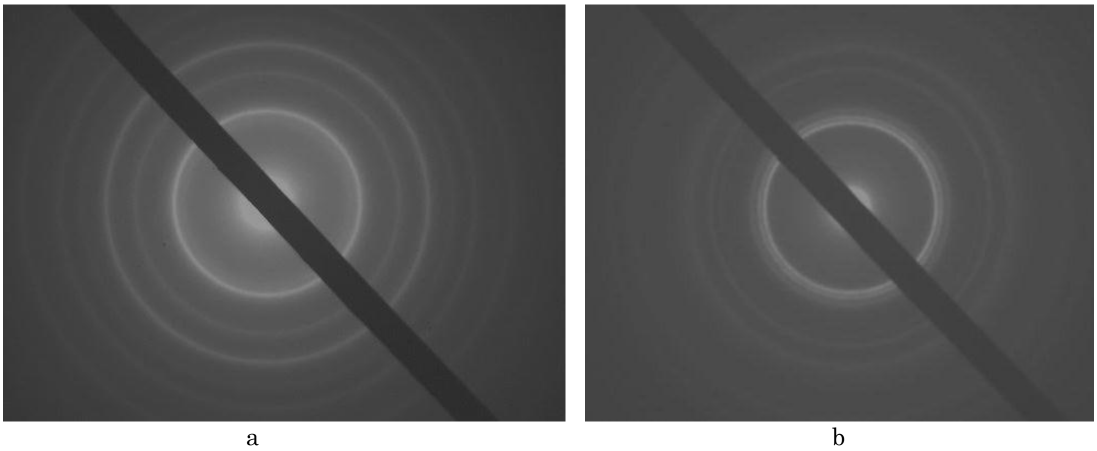

Fig. 3 – Electron diffraction pattern from film system Fe(30) / Pt(15) / Fe(30) / S: a – non-annealing state (phase s.s.(α-Fe)); b – after annealing to 800K (phase s.s. (α-Fe) + Fe_3Pt). Total concentration $c_{Pt} \cong 20$ at. %

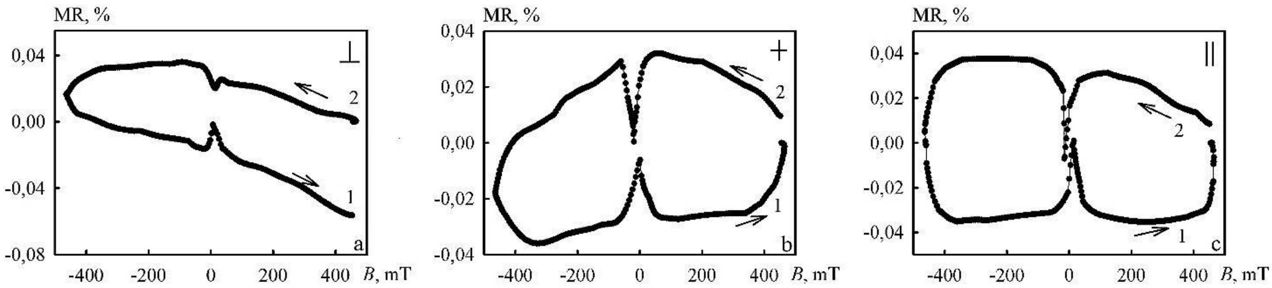

Fig. 4 – The dependence MR versus magnetic field induction for non-annealing film system Fe(30) / Pt(3) / Fe(30) / S: 1 – magnetization, 2 – demagnetization; ⊥, ┼, || – perpendicular (a), transverse (b) and longitudinal (c) geometry measurement of resistance. Temperature of measurement $T = 300$ K

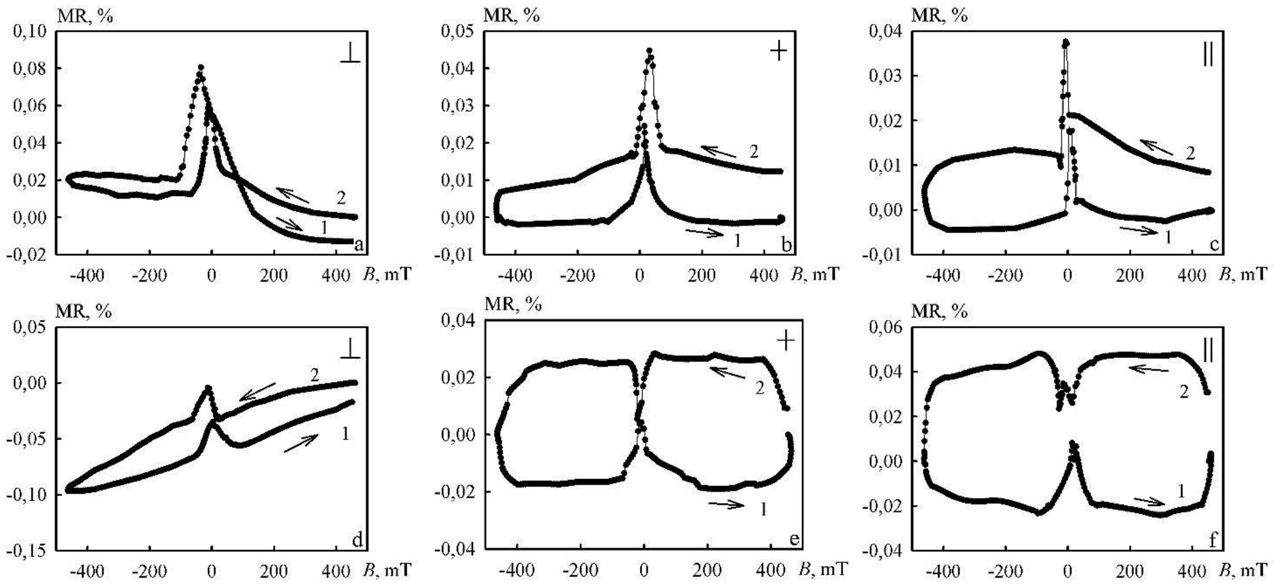

Fig. 5 – The dependence MR versus magnetic field induction for annealing from 800 K film system Fe(30) / Pt(3) / Fe(30) / S (a-c) and Fe(30) / Pt(15) / Fe(30) / S (d-f): 1 – magnetization, 2 – demagnetization; ⊥, ┼, || – perpendicular (a), transverse (b) i longitudinal (c) geometry measurement of resistance. Temperature of measurement $T = 300$ K

We were made to compare the results with the known literature data. So the authors [17] observed effect size of GMR to 0,2 % in the films Fe_xPt_{1-x} ($0,4 \le x \le 0,6$) of the $L1_0$ phase, which were obtained by ion sputtering in Ar atmosphere at substrate temperatures of 340 and 770 K, thicknesses in the range 100-300 nm in longitudinal and perpendicular geometry measurement. Note also that although the concentration composition three-layer films in our case, does not match the structure of $L1_0$, but magnetoresistive properties are similar to data of paper [17].

This gives reason to believe that the efficiency of spin-dependent electron scattering is independent of the phase composition of the magnetic granules.

In work [18] investigated the effect of GMR in electrolytically deposited films $FePt_3$ in perpendicular and longitudinal geometry. The nature of the magnetoresistive dependence is fully consistent shown in Fig. 5, but the value of GMR is 11 %. We believe a great value GMR is due to the method of calculation of MR [18] on the ratio $MR = [R(B) - R(B_S)]/R(B_S)$, where B_S – saturation field, whose value in experiments [18] is very small. Obviously, using the ratio (2) the value of MR would have less value.

Since our samples stabilized quasigranular state, it is advisable to compare our results with data for granular FePt films in the carbon matrix [19] or multilayers $[Fe_{53}Pt_{47}(3,6) / Ag(10)]_n$ / S [20].

Depending on the conditions for obtaining samples of the authors [19] observed value of GMR from 0,24 to 6,0 %, while in multilayers [20] depleted the concentration of phase $L1_0$ value MR ≅ 0,3 % even at the $T \cong 185$ K. Author [21] also presents the results according to which in multilayers $[Fe(0,2) / Pt(0,2)]_n$ / S phase $L1_0$ is stabilized and implemented relatively small size of GMR, because even at $T = 11$ K it value of not more than 0,8 %.

In several papers (see, for example, [17, 18]) is an attempt to explain the existence and cause of the relatively small size of GMR in granular thin film materials based on Fe and Pt. Likely reasons for this phenomenon may be that partially compensate for the spin-dependent scattering of electrons:

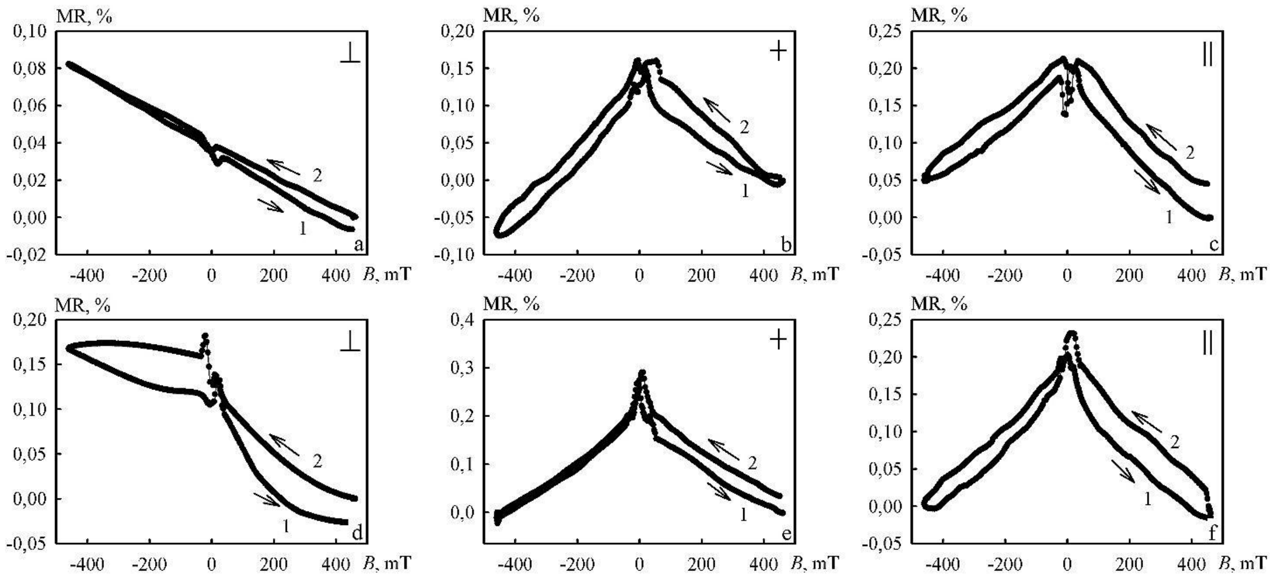

Fig. 6 – The dependence MR versus magnetic field induction for non-annealing (a-c) and annealing from 800 K (d-f) film system $[Fe(3) / Pt(3) / Fe(3)]_8$ / S. Temperature of measurement $T = 300$ K

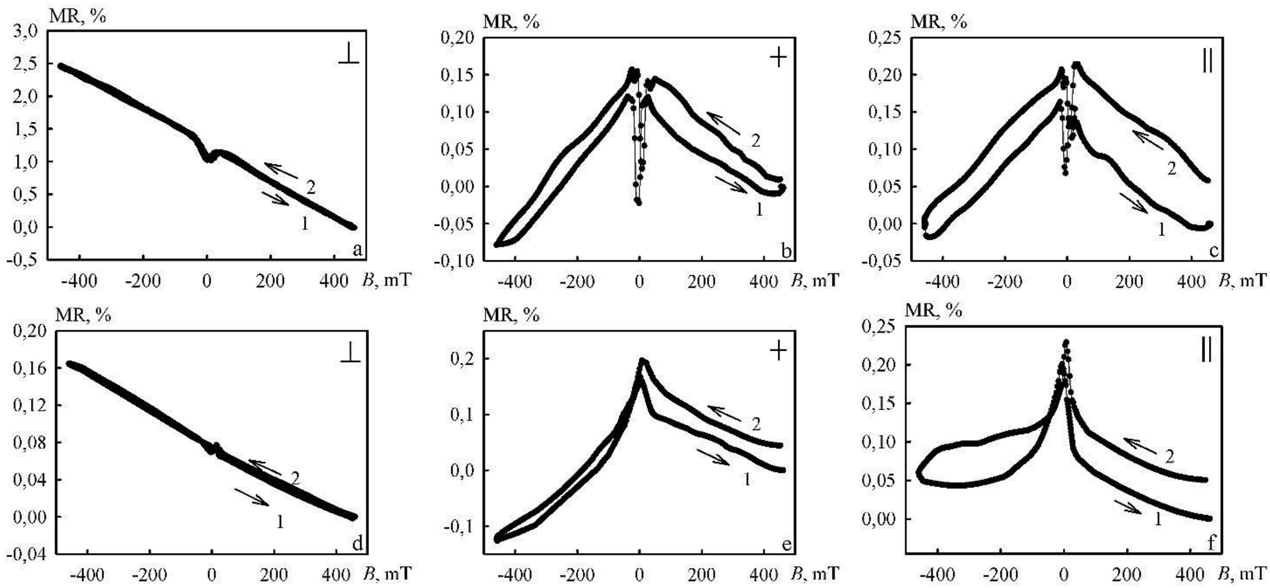

Fig. 7 – The dependence MR versus magnetic field induction for non-annealing (a-c) and annealing from 800 K (d-f) film system $[Fe(5) / Pt(5)Fe(5)]_8$ / S. Temperature of measurement $T = 300$ K

– realization of the anomalous Hall effect in the measurement of MR;
– electron scattering on domain walls in Fe layers;
– magnetic interactions between grains Fe_xPt_{1-x};
– uniaxial magnetocrystalline anisotropy in Fe layers, which causes strong spin-orbit coupling in atoms and Pt hybridization and polarization *d*-zone of Pt and Fe atoms, respectively.

In principle, these phenomena occur in all film systems of spin-dependent scattering of electrons (multilayers, spin-valves, granular alloys), but apparently that can cause a decrease of the GMR.

Work performed under the Ukraine-Indian joint project funded by the Ministry of Education and Science of Ukraine (2012-2014 years).

REFERENCE

1. A.S. Kamzin, E.V. Snetkova, Z. Yang, F. Wei,W. Hiang, *Tech. Phys. Lett.* **34**, 26 (2008).
2. Feng Wang, Sayaka Doi, Kaori Hosoiri, Tohru Watanabe, *Mater. Sci. Eng. A* **375-377**, 1289 (2004).
3. T. Katayama, T. Sugimoto, Y. Suzuki, M. Hashimoto, P. de Haan, J.C. Lodder, *J. Magn. Magn. Mater.* **104-107**, 1002 (1992).
4. M. Nakano, K. Matsuo, H. Fukunaga, J.M. Song, *J. Magn. Magn. Mater.* **272-276**, e1933 (2004).
5. Ichiro Fujii, Toshiyuki Shima, Koki Takanashi, *Mater. Transactions* **47** No1, 47 (2006).
6. J. Ikemoto, Y. Imai, S. Nakagawa, *J. Magn. Magn. Mater.* **320**, 3060 (2008).
7. W.C. Wang, J.H. Li, X. He, B.X. Liu, *J. Alloy. Compd.* **476**, L21 (2009).
8. Xuerang Hu, Peiwen Wu, Jun Yuan, *Thin Solid Films* **517**, 2602 (2009).
9. S. Imada, A. Yamasaki, S. Suga, *Appl. Phys. Lett.* **90**, 132507 (2007).
10. A. Perumal, Y.K. Takahashi, T.O. Seki, K. Hono, *Appl. Phys. Lett.* **92**, 132508 (2008).
11. C.C. Chiang, Chin-Huang Lai, Y.C. Wu, *Appl. Phys. Lett.* **88**, 152508 (2006).
12. Yun-Chung Wu, Liang-Wei Wang, Chin-Huang Lai, *Appl. Phys. Lett.* **91**, 072502 (2007).
13. Y. Tamada, S. Yamamoto, M. Takano, S. Nasu, T. Ono, *Appl. Phys. Lett.* **90**, 162509 (2007).
14. Y.K. Takahashi, T. Ohkubo, M. Ohnuma, K. Hono, *J. Appl. Phys.* **93**, 7166 (2003).
15. Н.П. Лякишев, О.А. Банных, Л.Л. Рохлин. *Диаграммы состояния двойных металлических систем* (Москва: Машиностроение: 1997).
16. I. Shpetnyi, A. Kovalenko, M. Klimenkov, I.Yu. Protsenko, S. Chernov, S.A. Nepijko, H.J. Elmers, G. Schonhense, *J. Magn. Magn. Mater.* (2014) (DOI: 10.1016/j.jmmm.2014.01.071).
17. S. Ishio, T. Yoshino, H. Saito, T. Suzuki, K. Ohuchi, *J. Magn. Magn. Mater.* **239**, 217 (2002).
18. V. Georgescu, C. Ilioaia, R. Musat, *J. Optoelectr. Adv. Mater.* **7** No 6, 3063 (2005).
19. Y.H. Lee, M.S. Guo, C.S. Wur, P.C. Lin, W.-H. Li, *J. Magn. Magn. Mater.* **286**, 113 (2007).
20. P. Tiberto, P. Allia, F. Celegato, M. Coisson, F. Vinai, F. Albertini, F. Casoli, S. Fabbrici, L. Nasi, F. Bolzoni, *J. Magn. Magn. Mater.* **310**, 2231 (2007).
21. P. Allia, F. Celegato, M. Coisson, P. Tiberto, F. Vinai, F. Albertini, F. Casoli, S. Fabbrici, *J. Magn. Magn. Mater.* **316**, e35 (2007).