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Magneto - Optical Properties of Two - Layer Film Systems Based on Fe and Pt

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The paper shows the experimental results of the study of magneto - optical properties and phase composition of thin films and multilayers based on Fe and Pt. Samples were obtained in a high-vacuum chamber (10^{-8} Pa) by layer-by-layer deposition from pots at room temperature.

It has been shown that FCC solid solution of FePt is formed already in the process of deposition on the substrate (sital plates). Depending on the concentration of the atoms of the components in the unannealed samples, three phases can be formed: (i) s.s.Fe(Pt); (ii) Fe_3Pt; (iii) FePt.

The first sign of the beginning of ordering in the FCC phase of FePt should be considered the appearance of superreflections in the form of lines (001) and (002) during heat treatment. Depending on the total thickness of the multilayer or individual layers, the annealing temperature at which extrareflexes appear can vary in the range of 300 - 570 K. All the samples obtained have a low coercivity (0.25 - 0.4 mT). Magneto-optical studies have shown that an increase in the content of the non-magnetic component decreases the main magnetic characteristics. However, In $[Fe(3)/Pt(3)]_n/S$ multilayers with the number of repeatable elements from 2 to 8 an increase in the main magnetic parameters is observed compared with bilayer films at the same effective thickness.

Keywords: thin films; spintronics; magneto-optical properties; Fe; Pt.

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Introduction

Due to the appearance and development of new high-tech methods of thin films production, it has become possible to create layered film structures with high localization of components. This led to the discovery of a number of new effects, in particular the giant magnetoresistance (GMR), which is observed in magnetically inhomogeneous film materials [1, 2]. Interesting hysteresis effects arising from the interaction of contacting magnetic layers or layers separated by nonmagnetic layers have also been found in multilayer film systems [3]. Based on them, new materials with a given set of kinetic and magnetic properties are created, in particular, magnetic field sensors and various sensors are developed [4-6]. Thin-film systems are also used to store and record information in storage devices, allowing to obtain high density and rate of information recording.

New technologies make it possible to obtain a special morphology of both the layers themselves and the interlayer boundaries. This, in turn, leads to special cooperative magnetic properties of multilayer structures. Hence the need for a detailed analysis of the magnetic properties of multilayer films.

In [7], the magnetic properties of multilayer structures $[Fe/Pt]_n$ obtained by magnetron sputtering were investigated. From Mesbauer studies and the obtained hysteresis magnetic loops, it was found that $[Fe/Pt]_n$ films at n = 16 have a magnetic anisotropy that is predominantly perpendicular to the plane of the films. Based on X-ray photoelectron spectroscopy (XPS) data, it was found that in the films there is an intermediate layer between the substrate and the multilayer structure. The performed micromagnetic modeling allows us to conclude that the induction of magnetic anisotropy perpendicular to the plane of the films $[Fe/Pt]_n$ (at n = 16) occurs due to the formation of an anisotropic intermediate layer.

Based on the above, the purpose of this work was an experimental study of the magnetic characteristics of two-layer Fe/Pt films with different layer thicknesses.

I. Methods and experimental techniques

Multilayer film systems based on Fe and Pt were obtained in ultra-high vacuum in a vacuum chamber Caburn MDC Europe. The vacuum in the system was created using forvacuum (10^{-2} Pa), turbomolecular (10^{-5}-10^{-6} Pa) and heteroionic (up to 10^{-8} Pa) pumps from Pfeiffer Vacuum. Fe and Pt-based samples were obtained by layer-by-layer deposition from pots. Deposition of the samples was carried out at room temperature Ts = 300 K. This greatly preserved the individuality of the layers, and the formation of disordered solid solutions most likely occurred near the interfaces.

Sital plates were used as substrates for the MOKE study. Before putting the substrates into the vacuum chamber, they were pre-cleaned in an ultrasonic chamber in isopropanol or acetone. To ensure the uniformity of the sample thicknesses (excluding the occurrence of a gradient of thicknesses and concentrations), the distance between the substrates and the evaporator was maintained at least 6 - 7 cm. For this purpose, special quartz plates with an operating frequency of 10 MHz were used, on which the investigated film was directly deposited. Measurement accuracy is 10 %.

The installation for studying the magneto-optical properties consists of a light generator (laser) VolkraftLabornetzgerat TNG 30, a polarizer, an optical condenser lens, which forms a beam of plane-polarized light with a wavelength λ = 670 nm and is directed to a sample in a magnetic field of 150 mT. After reflection from the sample, the light from flat-polarized was transformed into elliptically polarized, and the plane of polarization was rotated. Then the signal went to another converging lens and Faraday modulator, which was a solenoid with a glass core, where the change in the angle of rotation of the plane of polarization was compensated by the current applied to the Faraday modulator. The signal was then fed to a transducer, photodetector, amplifier and output to a computer, where a hysteresis loop was built in an automated mode, from which the Kerr rotation angle, saturation induction, remanent magnetization, and coercive force were determined. The maximum (critical) current that can be passed through the coils of the electromagnet - 10A, the optimal current value was 5A, which corresponded to an induction of 150mT. The control of current supply to the coils was carried out by the controller GAF 971107.

II. Results and discussion

In systems based on Fe and Pt, structural ordering processes are important. Depending on the concentration of components, production conditions, annealing temperature, the formation of a large number of both ordered and disordered phases is possible. Structurally ordered phases in this case will be Laves phases. Laves phases are formed by atoms of two grades A and B, and an atom of grade A always has a larger atomic radius (R) than an atom of grade B, and there is an ideal ratio of the component radii R_A: R_B = 1.225. Laves phases include compounds crystallizing into several related structural types, of which the three are the most numerous: (i) hexagonal type $MgZn_2$; (ii) cubic type $MgCu_2$; (iii) hexagonal type $MgNi_2$.

Electrographic studies have shown that in such systems already in the process of condensation at a substrate temperature Ts≅ 300 - 350 K, a FCC s.s. is formed (Fig. 1).

For all obtained samples, the concentration of the components was calculated according to (1), the calculation data are presented in Table 1.

$$c_i = \frac{d_i \rho_i \mu_i}{d_1 \rho_1 \mu_1^{-1} + d_2 \rho_2 \mu_2^{-1}} \cdot 100\%, \quad (1)$$

Depending on the concentration of the atoms of the components in the unannealed samples, three phases can be formed: (i) s.s.Fe(Pt); (ii) Fe_3Pt; (iii) FePt (Fig. 2).

The lattice constant for these systems is very close and lies in the range of 0.384 - 0.386 nm. The difference can be noticed by analyzing the line intensity indicator. By the intensity of certain lines, we can talk about the formation of a particular phase. Also, the line intensity is important in determining the ordered $L1_0$ phase [9].

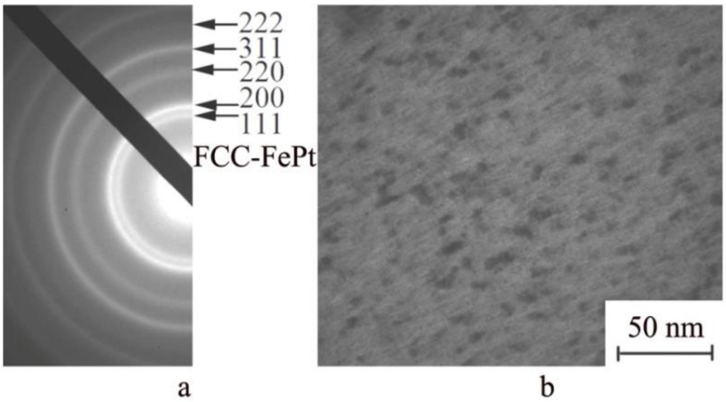

Fig. 1. Diffraction from the Fe (22) / Pt (15) sample without annealing.

Table 1

Calculated values of concentrations for the studied samples (d.p. – disordered phase).

Sample	c_{Fe}, at.%	c_{Pt}, at.%	Phase composition
Fig2. :			
Fe(22)/Pt(3)	91	9	s.s. α – Fe(Pt)
Fe(22)/Pt(9)	75	25	Fe_3Pt ($L1_1$) d.p.
Fe(22)/Pt(15)	65	35	FePt($L1_0$) d.p.
Fig. 3:			
Fe(12)/Pt(9)	44	56	FePt($L1_0$) d.p.
Fe(22)/Pt(9)	75	25	Fe_3Pt ($L1_1$) d.p.
Fe(32)/Pt(9)	82	18	Fe_3Pt ($L1_1$) d.p.
Fig.4:			
Fe(3)/Pt(3)	56	44	FePt($L1_0$) d.p.

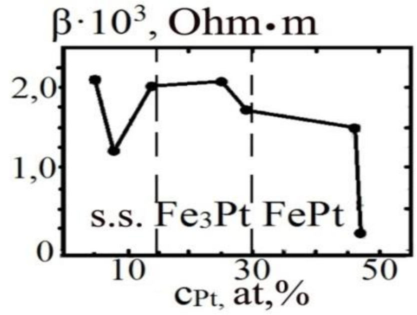

Fig. 2. Dependence of the formed phase on the concentration of components in the system.

The first sign of the beginning of ordering in the FCC phase of FePt should be considered the appearance of superreflections in the form of lines (001) and (002) during heat treatment. Depending on the total thickness of the multilayer or individual layers, the annealing temperature at which extrareflexes appear can vary in the range of 300 – 570 K. Here the following peculiarity occurs: an increase in the intensity of lines (001), (002), (112), and others occurs very slowly and only at T_a> 630 K the ratio $I_{002} / I_{001} \cong$ 0.5 is observed, which corresponds to the theoretical value. The complete system of extralines and baselines (001), (110), (111), (200), (002), (112), (202), (310), (222) is formed in the interval T_a = 620 - 820 K. The intensity of the ordering process can be deduced from the rate of increase of the intensity of the line (111) as the line with the highest intensity [8]. This phenomenon is observed both in continuous film samples [9-15] and in monoatomic multilayers, in which the FePt layer has a thickness d ~ 1 nm [16]; ultrathin islet FePt films with an effective thickness d = 1 - 10 nm [17]; FePt thin films (d = 10 nm) [18]; granular FePt films deposited in the SiO_2 matrix [19, 20] or in the Al_2O_3 matrix [21].

The magneto-optical Kerr effect is widely used to study the magnetic properties of film systems. The shape of the MOKE hysteresis loop can be used to describe the structural-phase state of the sample, and MOKE microscopy allows to characterize the domain structure. The expediency of studying magneto-optical properties in materials with possible spin-dependent electron scattering is related to obtaining information on the rate of magnetization, magnetic anisotropy, domain structure mobility, features of spin-polarization of the magnetic component in film structures, etc. Such systems can be used for creation of sensitive elements of sensors of a magnetic field, magneto-optical devices of record-reading of information, etc.

Firstly, single-layer films of iron were investigated. It is shown (Fig. 3) that with increasing thickness, a linear increase in all the magnetic characteristics under study is observed. In the case of single-layer Fe films, the coercivity increases with a thickness in the range from 0.25 to 0.45 mT, which is still an extremely small value. We think that such values of coercive force are due, to the small size of crystallites (5 - 10 nm). The demagnetizing factors, in this case, do not differ significantly for different directions. Therefore, the magnetostatic energy will be less than the energy of crystallographic anisotropy. It means that the energy of crystallographic anisotropy determines the magnitude of the coercive force. The increase in coercivity with increasing thickness of Fe films is associated with growing of the size of the crystallites. H_S linearly increases from 3.255 to 3.287 abr. units.

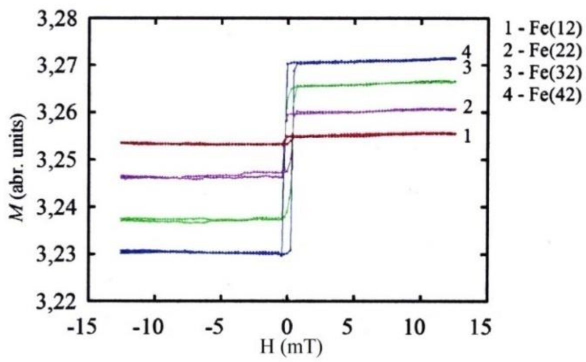

Fig.3. Magnetic dependences for single-layer Fe films with different thicknesses (in parentheses thickness in nm).

After studying single-layer films, the magnetic characteristics of two-layer Fe/Ft films were investigated,

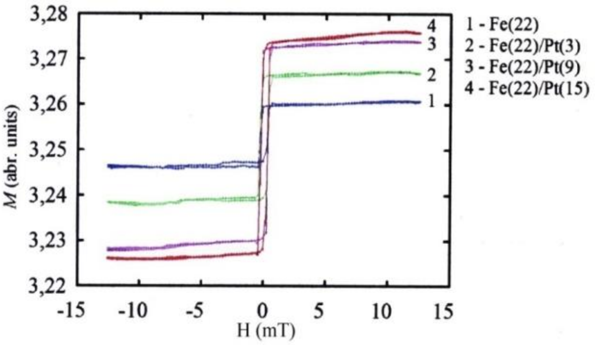

Fig. 4. Magnetic dependences for two-layer films Fe (const)/Pt (x) with different thicknesses.

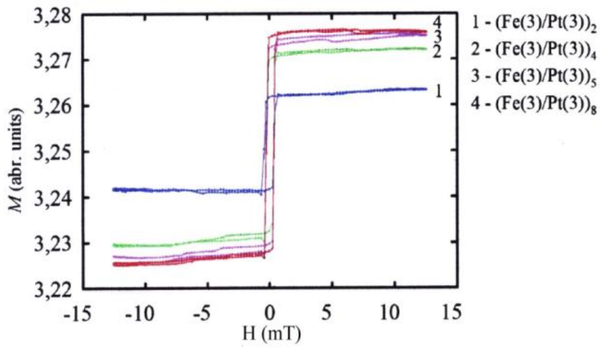

Fig. 5. Magnetic dependences for two-layer films Fe (x)/Pt (const) with different thicknesses.

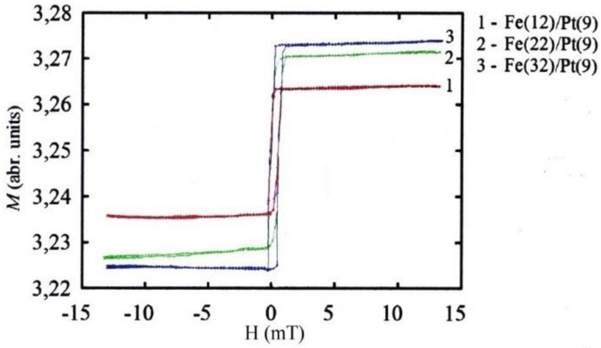

Fig. 6. Magnetic dependencies for multilayer $[Fe(3)/Pt(3)]_{2-8}$.

since such a combination is interesting from the point of view of use in systems with spin-dependent scattering. Alternately, the thicknesses Fe or Pt acted as a constant. If we change the thickness of the Pt layer (Fig. 4) in the range of 3 - 15 nm, then the coercive force changes from 0.34 to 0.26 mT and saturation magnetization from 3.261 to 3.276 abr. units. As expected, an increase in the concentration of the nonmagnetic component leads to a decrease of the magnetic characteristics (in comparison with single-layer films), which is also due to the formation of solid solutions already at the stage of sample deposition.

In another case, when we change the thickness of the iron (Fig. 5) and Pt remains constant (9nm), coercivity increases with an increase in the thickness of the iron layer from 0.28 to 0.3 mT. In double - layer films with a similar Fe thickness, in comparison with single-layer films, a significant decrease in the coercive force of the samples is observed, which we also associate with the formation of solid solutions. H_S linearly increases from 3.267 to 3.275 abr. units.

An interesting result is for the Fe (3)/Pt (3) multilayers with the number of repeatable elements from 2 to 8 (Fig. 6). For these multilayers, an increase in the main magnetic parameters is observed compared with bilayer films at the same effective thickness. Figure 7 shows a generalized graph comparing the observed magnetic characteristics, where the total thickness of the sample is plotted along the X axis, for a more visual comparison.

Conclusions

Increasing the concentration of the non-magnetic component leads to a decrease in the measured magnetic characteristics such as: coercive force, saturation magnetization and remanent magnetization. In addition, even with the same thickness of the magnetic component, the magnetic characteristics are less than in single-layer films, which is due to the formation of solid solutions already in the process of condensation of the film.

In $[Fe(3)/Pt(3)]_n/S$ multilayers with the number of repeatable elements from 2 to 8 an increase in the main magnetic parameters is observed compared with bilayer films at the same effective thickness.

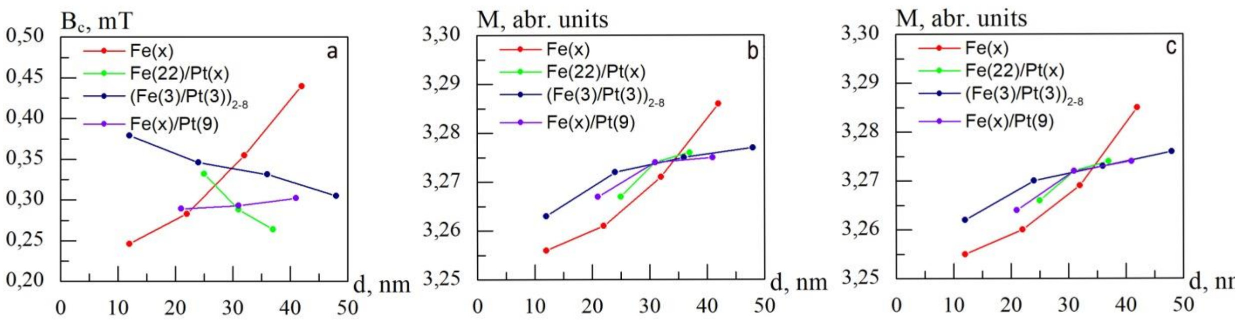

Fig. 7. Comparison of magnetic characteristics depending on the total thickness of the system: a - coercive force; b- saturation magnetization; c - remanent magnetization.

The shape and nature of the hysteresis loop, as well as low coercivity show the possibility of using such materials in devices such as magnetic relays, where, unlike sensors, sharp response is more important rather than measurement accuracy.

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[1] M.N. Baibich, J.M. Broto, A. Fert et al., Physical Review Letters 61(21), 2472 (1988) (https://doi.org/10.1103/PhysRevLett.61.2472).
[2] G. Binasch, P. Grunberg, F. Saurenbach et al., Physical Review B. 39, 4828 (1989) (https://doi.org/10.1103/PhysRevB.39.4828).
[3] P. Grunberg, R. Schreiber, Y. Pang et al., Physical Review Letters 57(19), 2442 (1986) (https://doi.org/10.1103/PhysRevLett.57.2442).
[4] T. Shinjo, Nanomagnetism and spintronics (Second edition) (Elsevier Science and Technology, Japan, 2013).
[5] B.Q. Wu and A. Kumar, Appl. Phys. Rev. 1, 011104 (2014) (https://doi.org/10.1063/1.4863412).
[6] K. Barmak, A. Darbal, K.J. Ganesh et al., J. Vac. Sci. Technol. A 32, 061503 (2014) (https://doi.org/10.1116/1.4894453).
[7] A.S. Kamzin, W. Fulin, V.R. Ganeev, A.A. Valiullin, L.D. Zaripova, Fizika tverdogo tela 55(9), 1743 (2013) (in Russian).
[8] A. Anjana, Y.K. Takahashi, Matsui Yoshio, K. Hono, J. Magn. Magn. Mater. 320, 250 (2008) (https://doi.org/10.1016/j.jmmm.2007.05.027).
[9] A.S. Kamzin, E.V. Smetkov, E. Young, F. Wei, V. Khiang,Pysma V Zhurnal Tekhnycheskoi Fyzyky 34(1), 57 (2008) (in Russian).
[10] F. Wang, S. Doi, K. Hosoiri, T. Watanabe, Mater. Sci. Eng. A. 375 1289, (2004) (https://doi.org/10.1016/j.msea.2003.10.211).
[11] T. Katayama, T. Sugimoto, Y. Suzuki, M. Hashimoto, P. de Haan, J.C. Lodder, J. Magn. Magn. Mater. 104 - 107, 1002 (1992) (https://doi.org/10.1016/0304-8853(92)90461-V).
[12] M. Nakano, K. Matsuo, H. Fukunaga, J.M. Song, J. Magn. Magn. Mater. V. 272 – 276, e1933 (2004) (https://doi.org/10.1016/j.jmmm.2003.12.907).
[13] I. Fujii, T. Shima, K. Takanashi, Mater. Transactions. 47(1), 47 (2006) (https://doi.org/10.2320/matertrans.47.47).
[14] J. Ikemoto, Y. Imai, S. Nakagawa, J. Magn. Magn. Mater. 320, 3060 (2008) (https://doi.org/10.1016/j.jmmm.2008.08.018).
[15] W.C. Wang, J.H. Li, X. He, B.X. Liu, J. Alloy. Compd., 476(1-2), L21 (2009). (https://doi.org/10.1016/j.jallcom.2008.09.154).
[16] S.Imada, A.Yamasaki, S.Suga // Appl. Phys. Lett., 90, 132507 – 1 (2007) (https://doi.org/10.1063/1.2717516).
[17] A. Perumal, Y.K. Takahashi, T.O. Seki, K. Hono, Appl. Phys. Lett. 92, 132508 (2008) (https://doi.org/10.1063/1.2830708).
[18] C.C. Chiang, Chin-Huang Lai, Y.C. Wu, Appl. Phys. Lett. 88, 152508 (2006) (https://doi.org/10.1063/1.2191422).
[19] Y.C. Wu, L.W. Wang, C.-H. Lai, Appl. Phys. Lett. 91, 072502 (2007) (https://doi.org/10.1063/1.2770652).
[20] Y. Tamada, S. Yamamoto, M. Takano, S. Nasu, T. Ono, Appl. Phys. Lett. 90, 162509 (2007) (https://doi.org/10.1063/1.2728760).
[21] Y.K. Takahashi, T. Ohkubo, M. Ohnuma, K. Hono, Journal of Applied Physics 93, 7166 (2003) (https://doi.org/10.1063/1.1555895).

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Магніто - оптичні властивості двошарових систем на основі Fe та Pt

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У статті наведені результати експериментальних досліджень магнітооптичних властивостей та фазового складу тонких плівок та мультишарів на основі Fe та Pt. Зразки отримували у високовакуумній камері (10^{-8} Па) шляхом пошарового осадження з тиглів при кімнатній температурі.

Показано, що ГЦК твердий розчин FePt утворюється вже в процесі осадження на підкладку (пластини ситалу). Залежно від концентрації атомів компонент у невідпалених зразках можна сформувати три фази: (i) т.р. Fe (Pt); (ii) Fe3Pt; (iii) FePt.

Першою ознакою початку впорядкування у ГЦК фазі FePt слід вважати появу надрефлексів у вигляді ліній (001) та (002) під час термообробки. Залежно від загальної товщини мультишару або окремих шарів, температура відпалу, при якій з'являються екстрарефлекси, може коливатися в межах 300 - 570 К. Усі отримані зразки мають низьку коерцитивність (0,25 - 0,4 мТл). Магнітооптичні дослідження показали, що збільшення вмісту немагнітного компонента зменшує основні магнітні характеристики. Однак у мультишарів [Fe(3)/Pt(3)]n/S із кількістю повторюваних елементів від 2 до 8 спостерігається збільшення основних магнітних параметрів порівняно з двошаровими плівками при однаковій ефективній товщині.

Ключові слова: тонкі плівки; спінтроніка; магніто - оптичні властивості; Fe; Pt.