



STRUCTURAL PROPERTIES OF Fe/Pt MULTILAYERS

BEFORE AND AFTER ION BEAM IRRADIATION

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Introduction

FePt alloys are promising candidates for future high density recording media due to its high magnetic anisotropy up to 7×10^7 ergs/cm² which is attributed to the transformation of the disordered fcc (face centered cubic) FePt alloy to the ordered fct (face centered tetragonal) one [1]. Typical method of obtaining such alloy is post annealing of Fe/Pt multilayers at the temperature of about 700 °C. However, such high temperature can be troublesome in the manufacture of magnetic devices. The better method for intermixing of the Fe/Pt system is ion beam irradiation which does not require such high temperatures [2]. The intermixing of the Fe/Pt system may result in the formation of several different phases.

In this presentation we report the results of structural characterization of ten Fe/Pt multilayer samples: Al₂O₃(0001)/Pt (10 nm)/{Fe (1 nm)/Pt (1nm)}₁₅/Pt(10 nm) before and after Ne⁺ ion beam irradiation.

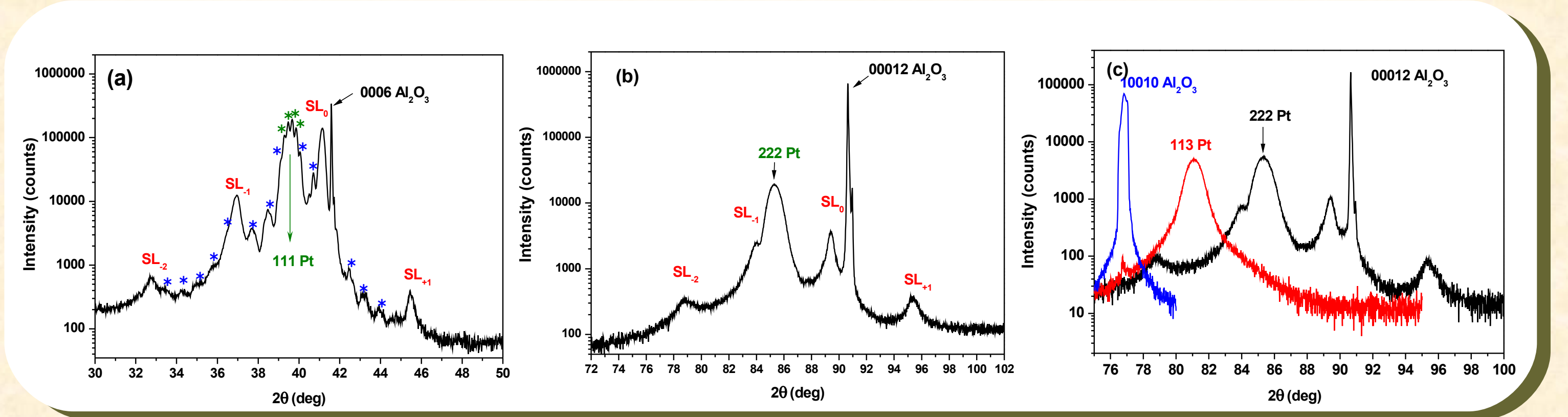


Fig. 1. X-ray symmetrical and asymmetrical diffraction patterns performed for the as grown Al₂O₃(0001)/Pt (10 nm)/{Fe (1 nm)/Pt (1nm)}₁₅/Pt(10 nm) sample:

(a) - in the vicinity of 111 Pt reflection, (b) - in the vicinity of 222 Pt reflection, (c) - symmetrical 222 Pt and 00012 Al₂O₃, and asymmetrical 113 Pt and 10010 Al₂O₃ reflections, respectively.

On the basis of above diffraction patterns can be concluded that Pt layers as well as the superlattice Fe/Pt grow in the [111] direction. The peaks marked by SL₋₁, SL₋₂ and SL₊₁ (red colour) are the satellite lines from superlattice - from their positions the thickness of the Fe/Pt bilayer (superlattice period C) has been calculated - the obtained value is C = 2.2 nm (nominal C = 2 nm).

In the vicinity of 111 Pt reflection (Fig.1 a) several small peaks (so called thickness fringes) are visible. These peaks originate from finite thickness of the layers and confirm very sharp interfaces inside the multilayer. The peaks marked with blue stars are from the Pt layers while the peaks marked with green stars - from the whole structure. From the positions of these peaks the suitable thickness have been calculated: for Pt layers $t = 11$ nm (nominal 10 nm) and for whole structure $T = 49.4$ nm (nominal 50 nm).

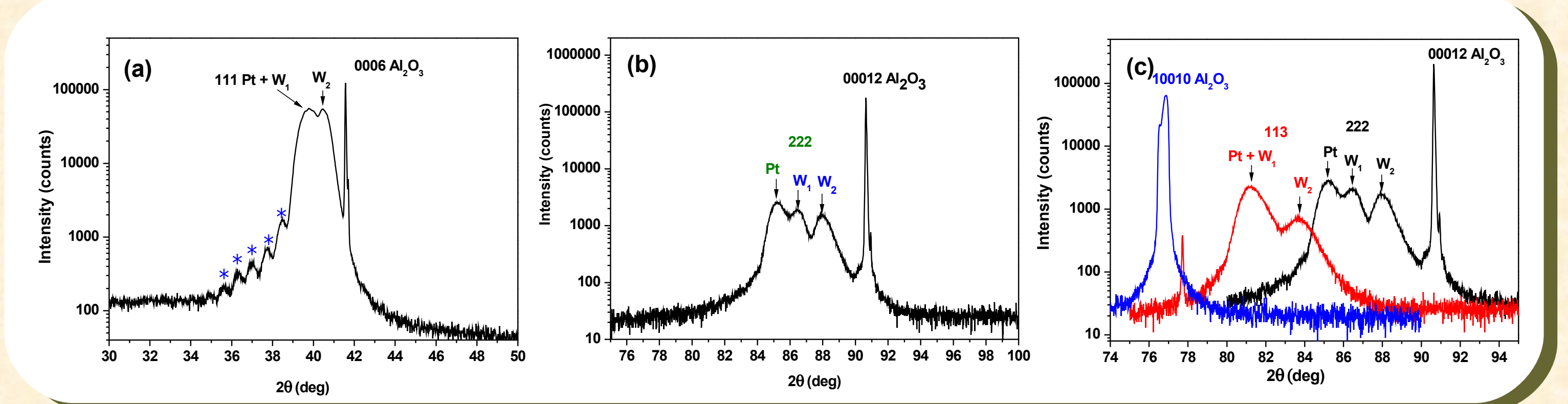


Fig. 2. X-ray symmetrical and asymmetrical diffraction patterns performed for the sample Al₂O₃(0001)/Pt (10 nm)/{Fe (1 nm)/Pt (1nm)}₁₅/Pt(10 nm) irradiated by N⁺ ions of the energy 25keV and 2×10^{15} ions/cm²

(a) - in the vicinity of 111 Pt reflection, (b) - in the vicinity of 222 Pt reflection, (c) - symmetrical 222 Pt, W₁, W₂ and 00012 Al₂O₃, and asymmetrical 113 Pt, W₁, W₂ and 10010 Al₂O₃ reflections, respectively.

Even the smallest of the applied doses of irradiation changed the crystal structures of the multilayer - two kinds of disordered Pt_{1-x}Fe_x alloys (W₁ and W₂) with different composition have been formed. The alloy W₂ is the result of intermixing of the almost all Fe/Pt superlattice with composition of about Pt_{0.5}Fe_{0.5} which practically does not change with increasing dose. The alloy W₁ is formed as the result of diffusion of some Fe atoms to the platinum cover layer - the Fe content in this alloy is low while for samples irradiated with higher doses increases slightly from $x = 0.05$ for doses $2 \times 10^{15} - 4 \times 10^{15}$ to $x = 0.12$ for the doses range $5 \times 10^{15} - 1 \times 10^{16}$ (see Table 1). Peak marked as Pt is related to the Pt buffer layer and it's position is the same as that for the as grown sample.

The quality of the thickness fringes from this layer (small peaks marked by blue stars in Fig. 2a) deteriorates with the increasing dose what evidences substantial damaging of the respective interfaces.

The composition of the alloys has been determined on the basis of relaxed lattice parameter calculated for the fcc unit cell using the literature dependence of the lattice parameters on the composition of fcc PtFe solid solution [4] (see Fig.3).

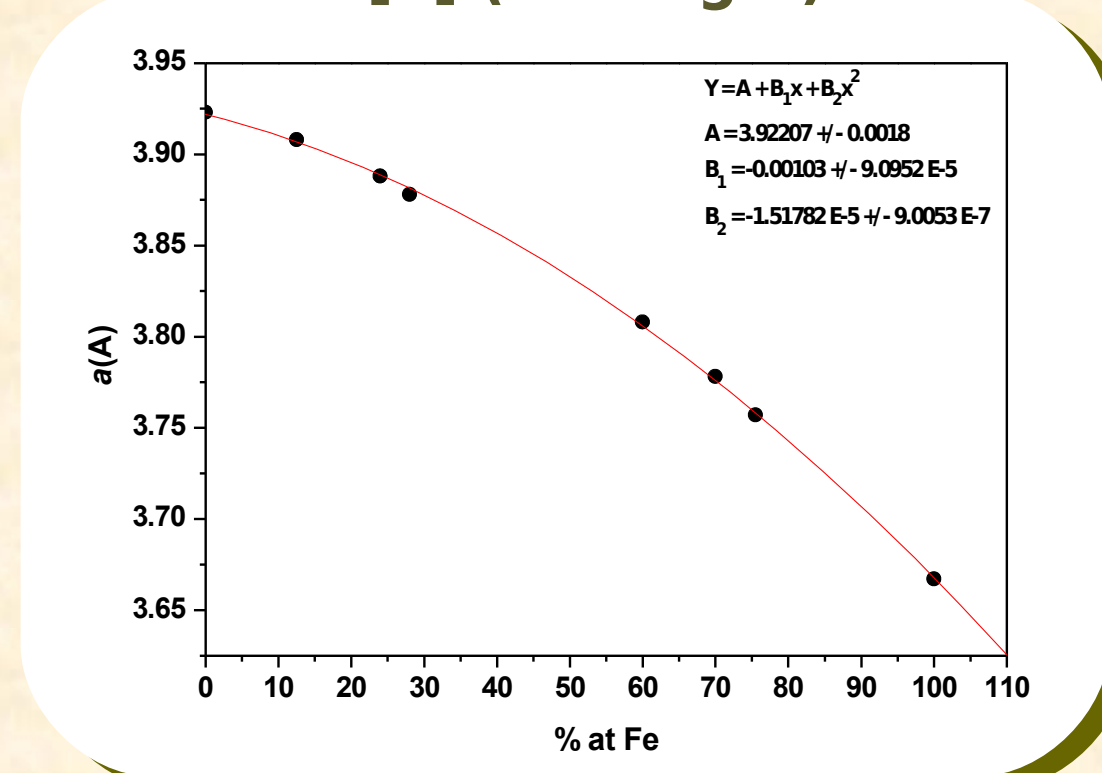


Fig. 3 The dependence of the lattice parameters on the composition of the fcc Pt_{1-x}Fe_x solid solution

Table 1. The final results of X-ray studies of Al₂O₃(0001)/Pt (10 nm)/{Fe (1 nm)/Pt (1nm)}₁₅/Pt(10 nm) irradiated by N⁺ ions of the energy 25keV with different doses

Energy of irradiation 25 keV, Dose:	Pt a _{rel} (Å)	W ₁ Pt _{1-x} Fe _x a _{rel} (Å)	Composition of W ₁ x	W ₂ Pt _{1-x} Fe _x a _{rel} (Å)	Composition of W ₂ x
2 × 10 ¹⁵	3.923(2)	3.917(3)	0.05(3)	3.824(3)	0.53(3)
3 × 10 ¹⁵	3.921(2)	3.913(3)	0.08(3)	3.828(3)	0.52(3)
4 × 10 ¹⁵	3.921(2)	3.917(3)	0.05(3)	3.826(3)	0.52(3)
5 × 10 ¹⁵	3.921(2)	3.908(3)	0.11(3)	3.824(3)	0.53(3)
6 × 10 ¹⁵	3.921(2)	3.908(3)	0.12(3)	3.817(3)	0.55(3)
7 × 10 ¹⁵	3.921(2)	3.904(3)	0.12(3)	3.823(3)	0.54(3)
8 × 10 ¹⁵	3.918(2)	3.909(3)	0.11(3)	3.823(3)	0.54(3)
9 × 10 ¹⁵	3.921(2)	3.906(3)	0.12(3)	3.823(3)	0.54(3)
1 × 10 ¹⁶	3.921(3)	3.908(3)	0.12(3)	3.835(3)	0.49(3)

Conclusions

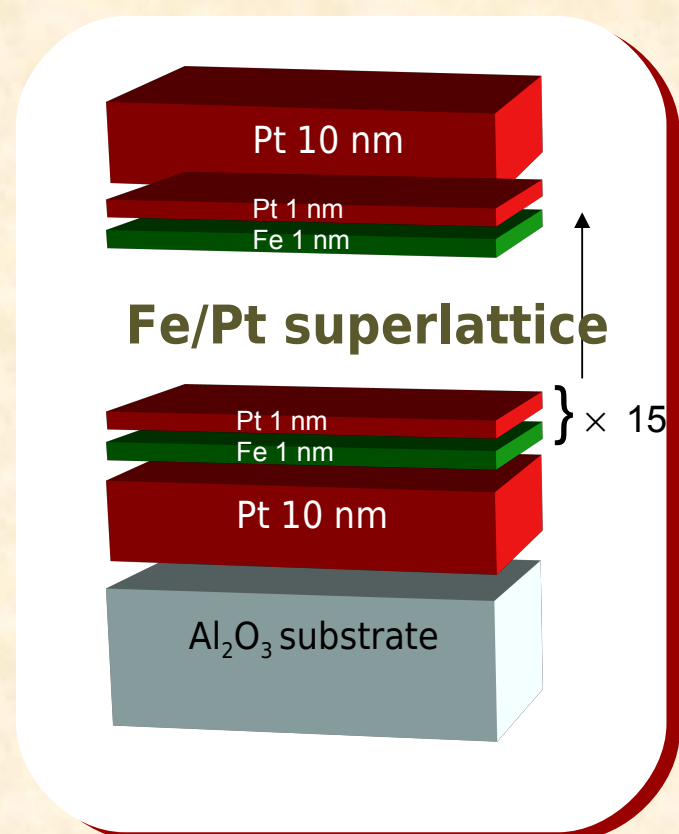
- The XRD studies have shown high quality of multilayers in particular a very sharp interfaces within multilayer as well as a very good compatibility of nominal and calculated thickness of the individual layers.
- It was shown that Ne⁺ irradiation causes intermixing of the Fe/Pt superlattice leading to formation of the disordered fcc PtFe alloys.
- Due to application of special procedures of measurements and interpretation the determination of the compositions of PtFe alloys formed in the samples irradiated by different doses of Ne⁺ ions has been done. The obtained results slightly depend on the irradiation dose.

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References

- V. R. Reddy, S. Kavita, S. Amirthapandian, A. Gupta, B.K. Panigrahi, *J. Phys. Condens. Matter*, 18, (2006) 6401
- D. Ravelosona, C. Chappert, V. Mathet, and H. Bernas, *J. Appl. Phys.* 87, (2000) 5771
- E. Dynowska, J.B. Pelka, D. Klinger, R. Minikayev, A. Bartnik, P. Dluzewski, M. Jakubowski, M. Klepka, A. Petruczuk, O.H. Seeck, R. Sobierajski, I. Sveklo, A.A. Wawro and A. Maziewski, Article in press, *Nucl. Instr. Meth. B*, (2015), <http://dx.doi.org/10.1016/nimb.2015.07.116>
- A. Kussman, G.G.v. Rittberg, *Z. Metallk.* 41, (1950), 470



Sample preparation

All samples of 5 × 3.3 mm size were grown simultaneously in molecular beam epitaxy system at room temperature in 10⁻¹⁰ Torr vacuum and next, nine pieces were irradiated with Ne⁺ ions of the energy 25 keV but each with different dose.

Experimental

The crystal structure of the samples has been examined by X-ray diffraction methods. The PANalytical Empyrean X-ray diffractometer with Cu Kα₁ radiation, equipped with the Johansson monochromator Ge(111) in the incident beam and a linear semiconductor strip detector has been used. The symmetrical and asymmetrical X-ray diffraction patterns were performed (see figures 1 and 2).

Methodology of the stress state and relaxed lattice parameters determination.

How it seen from the symmetrical patterns the multilayers grow in [111] direction - the (111) plane of Pt is parallel to the (0001) substrate plane. The epitaxial relationship between these planes causes the compressive strain of the thin Pt layers. To determine stress state and relaxed lattice parameter of the fcc unit cell the special procedure has been developed [3]:

1. The transformation of the fcc unit cell to the hexagonal one:

$$a_{hex} = a_{cub} \frac{\sqrt{2}}{2}, \quad c = a_{cub} \sqrt{3}$$

2. The symmetrical 222 and asymmetrical 113 indexes of fcc cell

should be transformed to the 0006 and 10-15 hexagonal indexes, respectively. The lattice parameters of the hexagonal cell are calculated as:

$$\frac{1}{d_{hkl}^2} = \frac{4}{3} \left(\frac{h^2 + hk + k^2}{a^2} \right) + \frac{l^2}{c^2}$$

3. Next: $V_{hex} = 0.866 a^2 c$, $V_{hex} = 0.75 V_{cub}$, and, assuming that after relaxation this volume is preserved:

$$a_{cub}^{relaxed} = \sqrt[3]{V_{cub}}$$