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The structure and magnetic properties of sputtered FePtM (M = Ta, Cr) thin films

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Abstract

FePt thin films with various Ta and Cr concentrations ranging from 3.6 to 11.6 at.% were prepared by rf magnetron sputtering and characterized for structure and magnetic properties. The films were post-annealed in vacuum at 600 °C for 1 h, followed by quenching in argon to room temperature. The additive elements are found to be beneficial for refining the grain structures of FePt alloy films. All the concentrations of Cr used in the present study (5.3–9.6 at.%) and a high Ta content (11.3 at.%) are observed to effectively inhibit the formation of ordered phase during annealing. The addition of Ta and Cr decreases the coercivity in FePt thin films and increases the saturation magnetization except for a doping of 9.6 at.% Cr. The high energy product of 32.1 MG Oe is obtained for 7.1 at.% Cr-doped film as a consequence of the grain refinement and retention of disordered phase. The optimum doping concentrations were 7.9 and 7.1 at.%, respectively, for Ta- and Cr-doped FePt alloy thin films. The addition of non-magnetic atoms in FePt thin films thus enhances the magnetic properties and leads to noise reduction for the potential high density recording media application.

High coercivities, small grain sizes and intergranular decoupling are some of the key requirements for high performance thin film longitudinal recording media [1]. FePt alloys with a tetragonal CuAuI-type structure have a strong uniaxial anisotropy [2] and a large magneto-optical Kerr rotation in the short wavelength region around 300 nm [3]. Our previous studies showed that high coercivity with high energy product, $(BH)_{max}$, for equiatomic FePt thin films can be obtained using the argon quenching technique during the post-deposition vacuum

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annealing process [4, 5]. In addition to post-deposition heat treatments, alloying with non-magnetic metals is found to play a vital role in the enhancement of magnetic isolation due to the segregation of non-magnetic solute atoms in grain boundaries [6]. Earlier investigations have revealed that the media noise could be considerably reduced by dispersing the ferromagnetic FePt grains in an SiN matrix [7]. Doping of B [8] and Ag [9] was found to promote the ordering process, whereas Nb enhanced the formation of disordered phase [10]. There are only a few reports available on the doping of W, Ti [11] and Cr [12] with FePt films, and the results exhibited a reduction in grain growth in these films. The addition of Ta and Cr in the FePt films affords a possibility of changing the grain nucleation behaviour of the alloy films and consequently the structure and magnetic properties of the films. In the present work, FePt alloy films with Ta and Cr additive elements are synthesized by an rf magnetron sputtering technique. The equiatomic compositions ($x = 50$) of $Fe_{100-x}Pt_x$ alloy films are found to exhibit high magneto crystalline anisotropy, and interesting structural and magnetic properties leading to device applications [4, 13]. Hence, in the present work, the additive elements (Ta and Cr) are doped with equiatomic composition of FePt alloy films. The effects of doping concentration on the crystal structure and magnetic properties of FePt alloy thin films were investigated.

FePt and FePtM (M = Ta, Cr) thin films were prepared by the rf magnetron sputtering technique onto pre-cleaned silicon wafer substrates at room temperature. The sputtering target consisted of a high purity ferrous disc (99.99%) overlaid with platinum segments (99.99%) and small pieces of doping element. The vacuum chamber was initially evacuated to 2×10^{-7} Torr and then high purity argon gas was introduced in the sputtering chamber. The pressure and rf power during sputtering were maintained at 10^{-3} Torr and 150 W, respectively. The film thickness was measured by an α-step surface profilometer and was found to be in the range between 550 and 700 nm. The films were *ex situ* annealed at 600 °C for 1 h in a vacuum of 5×10^{-7} Torr, followed by quenching in argon to room temperature. The crystal structure of the film was examined by an x-ray diffraction (XRD) technique using Cu Kα radiation. The grain sizes of various FePt alloy films were estimated using Scherrer's method [14]. The film compositions in atomic percent measured using an electron probe microanalyser were $Fe_{49.2}Pt_{50.8}$ for pure FePt, $(FePt)_{96.4}Ta_{3.6}$, $(FePt)_{92.1}Ta_{7.9}$, $(FePt)_{88.4}Ta_{11.6}$ for Ta-doped films and $(FePt)_{94.7}Cr_{5.3}$, $(FePt)_{92.9}Cr_{7.1}$, $(FePt)_{90.4}Cr_{9.6}$ for Cr-doped films. The error in the standardless analyses was around $\pm 2\%$. The magnetic properties of the alloy films were measured using a vibrating sample magnetometer.

Figure 1 shows the x-ray diffraction spectra of $(FePt)_{100-x}Ta_x$ and $(FePt)_{100-x}Cr_x$ alloy films after annealing. It is observed that as-deposited pure and doped FePt thin films are nano-crystalline with broad Bragg peaks, and they revealed a disordered fcc γ-FePt phase [4, 5]. However, when the films are annealed in vacuum at 600 °C and argon quenched, pure FePt (figure 1(a)) revealed an ordered fct γ_2-FePt phase with the appearance of (001) and (110) superlattice peaks. Also, the splitting of (200) peak into two peaks corresponding to the $(200)_{fct}$ and $(002)_{fct}$ phases suggests the transformation of the cubic phase to a tetragonal $L1_0$ phase. It is found that 3.6 at.% Ta and 7.9 at.% Ta-added films (figures 1(b), (c)) also revealed the transformation from the disordered fcc γ-FePt to ordered fct γ_2-FePt phase. However, further addition of 11.6 at.% Ta inhibits the transformation from a disordered cubic to ordered tetragonal structure under the same annealing condition (figure 1(d)). Chen *et al* [15] have reported that the maximum tantalum content in the magnetron sputtered $(Fe_{72}Pt_{28})_{100-x}Ta_x$ film was about $x = 1.84$ at.% for the suppression of ordered phase. In the case of Cr additive element, it is observed that all the Cr-doped FePt films are predominately polycrystalline disordered fcc γ-FePt cubic phase. Superlattice peaks and transformation from disordered cubic to ordered γ_2-FePt tetragonal phase were not observed in the annealed temperature

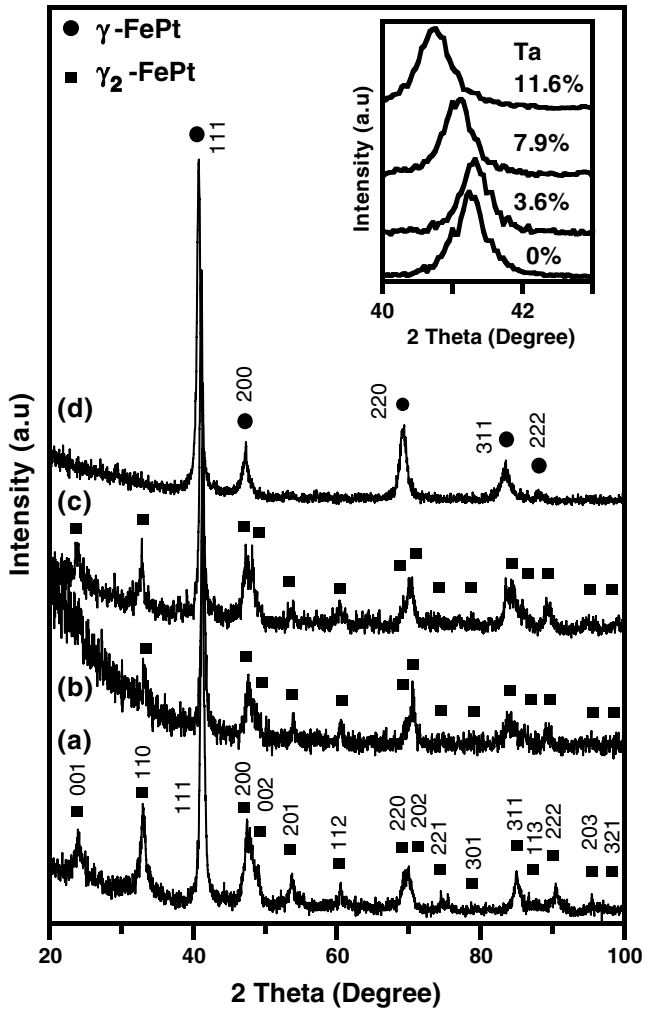

Figure 1. X-ray diffraction patterns of $(FePt)_{100-x}Ta_x$ (x = (a) 0, (b) 3.6, (c) 7.9 and (d) 11.6) alloy thin films annealed at 600 °C in vacuum for 1 h (x in at.%). The inset shows details of (111) Bragg peaks taken from these patterns for various Ta doping.

range. Kuo *et al* [12] reported that addition of 12 at.% Cr resulted in the increase of the $\gamma \rightarrow \gamma_2$ transformation temperature to 650 °C. It is worth mentioning here that their film samples were quenched in ice water after annealing at 650 °C for 15 min. Even though the quenching methods are different, it is interesting to note that their findings are consistent with our results.

The insets in figures 1 and 2 show details of (111) Bragg peaks for the Ta- and Cr-doped FePt alloy thin films. The shifts of Bragg peak indicate the distortions created in the lattice of the films due to the addition of a third element. Ta addition causes the lattice expansion, whereas the addition of Cr results in the contraction of lattice. The broadening of the (111) Bragg peak with different Cr and Ta concentrations is also noticed, revealing the grain refinement effect. The grain sizes of $(FePt)_{100-x}Ta_x$ and $(FePt)_{100-x}Cr_x$ thin films with Ta and Cr addition measured using Scherrer's formula with the (111) Bragg peaks were obtained and they are

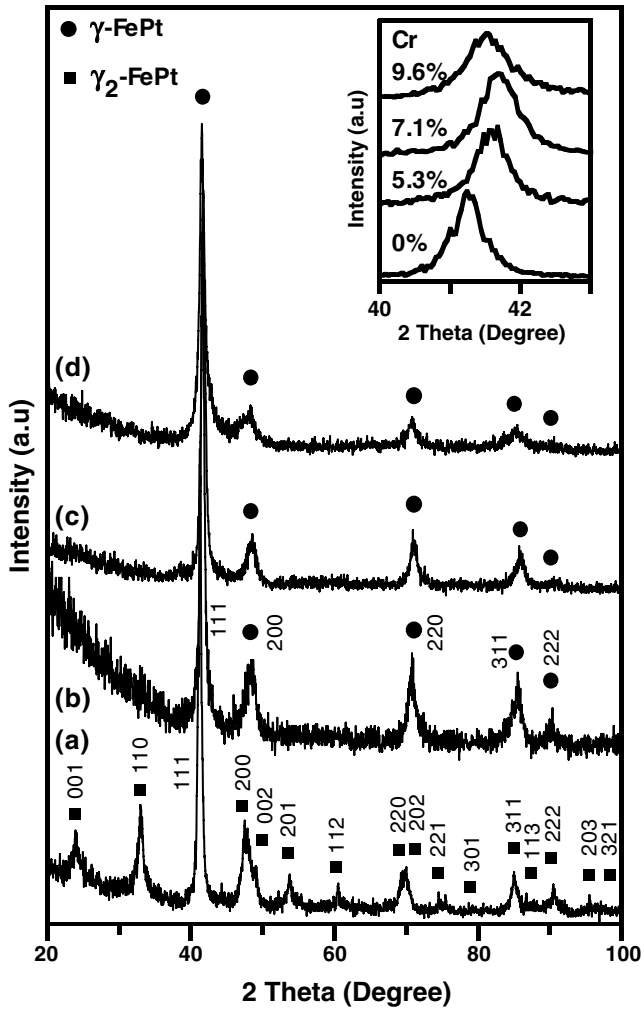

Figure 2. X-ray diffraction patterns of $(FePt)_{100-x}Cr_x$ (x = (a) 0, (b) 5.3, (c) 7.1 and (d) 9.6) alloy thin films annealed at 600 °C in vacuum for 1 h (x in at.%). The inset shows details of (111) Bragg peaks taken from these patterns for various Cr doping.

listed in table 1. Scherrer's formula is commonly used to estimate grain sizes [6, 10, 16]. It is observed that the addition of Ta reduces the grain sizes of the films from ∼18 nm for pure FePt to ∼11 nm for 11.6 at.% Ta-added film. A similar grain-refinement effect is observed for the addition of Cr with the grain size reduced to ∼13 nm. Our results are in conformity with earlier reports on Cr-doped FePt [12] and Ta-doped CoCrPt [6] thin films. For the purpose of high-density recording, the recording media should contain a fine grain distribution with smaller grains. Our studies indicate that the addition of a few per cent of Ta and Cr in FePt films may yield beneficial effects in high-density recording.

The influence of the third additive element on the magnetic properties of FePt alloy thin films was studied. Figure 3 shows the variation of the perpendicular coercivity (H_c) with the amount of additive element for annealed FePtTa and FePtCr thin films. It is found that the addition of Ta and Cr in FePt thin films decreases the perpendicular coercivity. The addition of non-magnetic Ta and Cr in the FePt lattice might have resulted in a net decrease of coercivity in

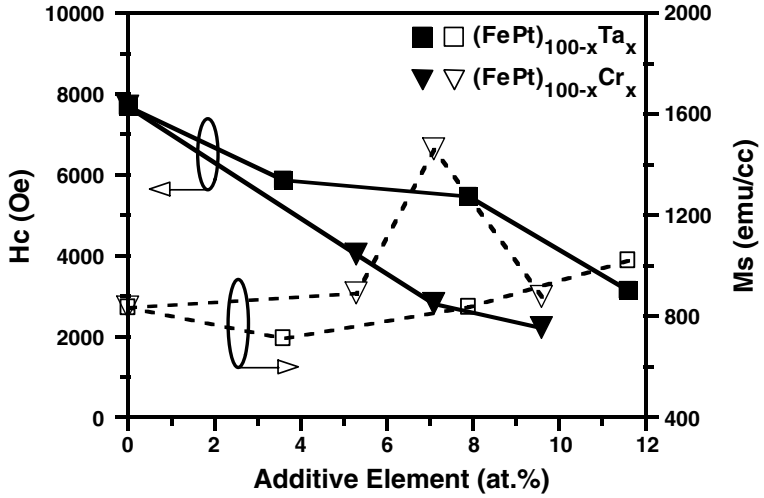

Figure 3. Variations of perpendicular coercivity (H_c) and saturation magnetization (M_s) with the amount of the additive element for annealed $(FePt)_{100-x}Ta_x$ and $(FePt)_{100-x}Cr_x$ thin films.

Table 1. Grain sizes, dominant crystal structure and $(BH)_{max}$ values for annealed $(FePt)_{100-x}Ta_x$ and $(FePt)_{100-x}Cr_x$ thin films (x in at.%).

		$(FePt)_{100-x}Ta_x$ x			$(FePt)_{100-x}Cr_x$ x		
Film composition	Pure $Fe_{50}Pt_{50}$	3.6	7.9	11.6	5.3	7.1	9.6
Grain size (nm)	17.7	16.8	16.0	11.3	15.3	14.6	12.5
Crystal structure	γ_2	γ_2	γ_2	γ	γ	γ	γ
$(BH)_{max}$ (MG Oe)	12.9	18.2	20.8	18.2	21.5	32.1	9.6

FePtTa and FePtCr thin films. Similar behaviour has been reported in CoCrPtTa thin films [6] and FePt bulk alloys doped with Nb and Al [17]. The variation of saturation magnetization (M_s) with additive element content for $(FePt)_{100-x}Ta_x$ and $(FePt)_{100-x}Cr_x$ thin films is also shown in figure 3. For Ta-added films, the saturation magnetization is found to increase with the additive Ta content. The larger Ta atoms (atomic radius 0.149 nm) may inhibit the ordering of the FePt fct phase, which, in turn, increases the M_s value from the disordered phase. This is consistent with the fact that only disordered phase is present for high Ta content of 11.6 at.%. In addition, the refined grain structure resulting from the Ta addition might also have contributed to the increase in M_s. In the case of Cr additive element, the M_s value increases initially with Cr content, and after reaching a maximum value it decreases further with increasing Cr content. The initial increase in M_s is presumably due to the grain-refinement effect of Cr. However, being a non-magnetic material, the addition of more Cr in the FePt film would have diluted the hard phase and resulted in the decrease of saturation magnetization. It has been reported earlier that the addition of Cr in the FePt films has resulted in decreasing the saturation magnetization [12]. The perpendicular M–H loops of FePt thin films doped with various Ta and Cr additive elements are shown in figure 4. All the M–H loops are found to be square-like except for the FePt film doped with 9.6 at.% Cr. In this case, the M–H loop appears with the shape of a concave central area. This suggests reversal of magnetization by domain wall motion arising from a strong magnetic exchange coupling between grains. The

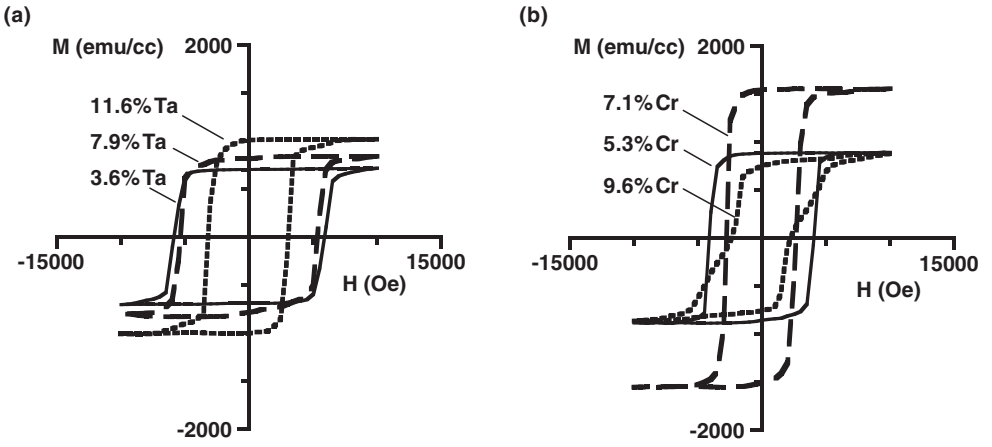

Figure 4. Perpendicular M–H loops of FePt thin films doped with various (a) Ta and (b) Cr additive elements.

large magnetic exchange coupling is the main factor that gives rise to high noise levels in high density recording media. Based on the loops in figure 4, the energy products, $(BH)_{\max}$, are obtained and listed in table 1. The maximum energy products of 20.8 and 32.1 MG Oe are observed for 7.9 at.% Ta-doped and 7.1 at.% Cr-doped FePt films, respectively. The low values of energy product for 11.6 at.% Ta and 9.6 at.% Cr are due to the dilution effect of high non-magnetic contents. The high energy product for 7.1 at.% Cr film is attributed to the combined effect of grain refinement and suppression of ordered phase formation. Nb-doped FePt films with the high energy product ($\sim$30.6 MG Oe) have been reported due to the fact that Nb plays a role as grain refiner and can enhance the formation of disordered γ phase [10].

In summary, FePtTa and FePtCr thin films were magnetron sputtered and, after annealing at 600 °C, characterized for structure and magnetic properties. The addition of Ta and Cr is found to inhibit the grain growth in the films, and Cr is observed to effectively suppress the formation of ordered phase during annealing. Moreover, the additive elements are found to decrease the coercivity in FePt thin films, and increase the saturation magnetization except for the film doped with 9.6 at.% Cr. The high energy product, 32.1 MG Oe, for 7.1 at.% Cr-doped film is obtained as a result of grain refinement and retention of disordered phase. The optimum doping conditions to prepare Ta- and Cr-doped FePt alloy thin films were found to be 7.9 and 7.1 at.%, respectively. The addition of non-magnetic atoms in FePt thin films is expected to enhance the magnetic isolation between grains by effective grain boundary segregation, which leads to noise reduction in high density recording media.

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References

[1] Almasi-Kashi M, Grundy P J, Jone G A, Nadgaran H and Zhao X 2002 *J. Magn. Magn. Mater.* **248** 190
[2] Ide Y, Goto T, Kikuchi K, Watanabe K, Onagawa J, Yoshida H and Cadogan J M 1998 *J. Magn. Magn. Mater.* **177** 1245

[3] Buschow K H J, van Engen P G and Jongebeur R 1983 *J. Magn. Magn. Mater.* **38** 1
[4] Mahalingam T, Chu J P, Chen J H, Wang S F and Inoue K 2003 *J. Phys.: Condens. Matter* **15** 2561
[5] Mahalingam T, Chu J P, Chen J H, Chiang C L and Wang S F 2003 *Mater. Chem. Phys.* **82/2** 335
[6] Lee I S and Kim D W 2001 *Thin Solid Films* **388** 245
[7] Kuo C M and Kuo P C 2000 *J. Appl. Phys.* **87** 419
[8] Inomata K, Sawa T and Hashimoto S 1988 *J. Appl. Phys.* **64** 2537
[9] Chen C, Kitakami O, Okamoto S and Shimada Y 2000 *Appl. Phys. Lett.* **76** 3218
[10] Chen S K, Yuan F T, Chang W C and Chin T S 2002 *J. Magn. Magn. Mater.* **239** 471
[11] Kuo C M, Kuo P C, Hsu W C, Li C T and Sun A C 2000 *J. Magn. Magn. Mater.* **209** 100
[12] Kuo P C, Yao Y D, Kuo C M and Wu H C 2000 *J. Appl. Phys.* **87** 6146
[13] Hong M-H, Hono K and Watanabe M 1998 *J. Appl. Phys.* **84** 4403
[14] Cullity B D and Stock S R 2001 *Elements of X-ray Diffraction* 3rd edn (Englewood Cliffs, NJ: Prentice-Hall) p 167–71
[15] Chen G J, Chang Y H, Lai J H and Chai Y L 2002 *J. Magn. Magn. Mater.* **239** 415
[16] Bai J, Yang Z, Wei F, Matsumoto M and Morisaka A 2002 *Phys. Status Solidi* a **191** 590
[17] Thang P D, Bruck E, Tichelaar F D, Buschow K H J and de Boer F R 2002 *IEEE Trans. Magn.* **38** 2934