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# Magnetic and structural properties of RTA-processed L<sub>10</sub> FePt-Mn thin films

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**Abstract.** In this study, we have investigated the effect of Mn addition on texture, phase formation, and magnetic properties of L<sub>10</sub> FePt thin films. FePt/Mn/FePt trilayers were processed by rapid thermal annealing in the temperature range of 650 – 800°C for 30 s in N<sub>2</sub> atmosphere. It is shown that Mn addition up to 10 at.% supports L<sub>10</sub>(001)-texture formation resulting in large perpendicular magnetic anisotropy. However, it is observed that Mn is only partially incorporated into the FePt lattice. It was found that Mn diffuses through the FePt top layer to the sample surface, promoting the ordering process and forming a Mn oxide layer.

## 1. Introduction

Chemically ordered L<sub>10</sub> FePt(001) thin films exhibit strong perpendicular magnetic anisotropy (PMA) and make it the most promising material for heat assisted magnetic recording (HAMR) [1, 2]. It was reported that addition of third elements to FePt allows controlling its magnetic properties [1-3]. For instance, a reduction of the Curie temperature and saturation magnetization  $M_s$  with Mn addition is accompanied by a moderate decrease in PMA [4] required for HAMR application. In that case, stoichiometric Fe<sub>1-x</sub>Mn<sub>x</sub>Pt alloy thin films were prepared by epitaxial growth on MgO(001) at elevated temperatures [5].

In this work, we are focusing on the influence of Mn addition on the phase and texture formation in FePt thin films processed by rapid thermal annealing (RTA) on thermally oxidized silicon substrates.

## 2. Experimental part

Fe<sub>52</sub>Pt<sub>48</sub>/Mn/Fe<sub>52</sub>Pt<sub>48</sub> trilayers with a total thickness of about 10 nm were deposited by dc magnetron sputtering at room temperature on SiO<sub>2</sub>(100 nm)/Si(001) substrates. A Fe<sub>52</sub>Pt<sub>48</sub> alloy target was used for deposition. Variation of the Mn content is achieved by altering the thickness of the Mn and FePt layers. Detailed information about the sample compositions is listed in Table 1. Post-annealing was performed by

**Table 1.** Layer thicknesses and compositions of the Fe<sub>52</sub>Pt<sub>48</sub>/Mn/Fe<sub>52</sub>Pt<sub>48</sub> sample series

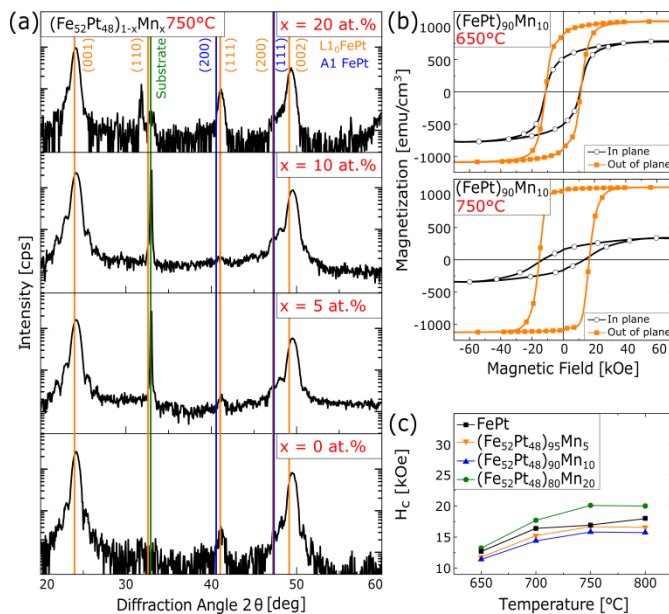
	Layer 1	Thickness	Layer 2	Thickness	Layer 3	Thickness	Expected composition
<b>1</b>	Fe <sub>52</sub> Pt <sub>48</sub>	4.9 nm	Mn	0.23 nm	Fe <sub>52</sub> Pt <sub>48</sub>	4.9 nm	(Fe <sub>52</sub> Pt <sub>48</sub> ) <sub>95</sub> Mn <sub>5</sub>
<b>2</b>	Fe <sub>52</sub> Pt <sub>48</sub>	4.8 nm	Mn	0.46 nm	Fe <sub>52</sub> Pt <sub>48</sub>	4.8 nm	(Fe <sub>52</sub> Pt <sub>48</sub> ) <sub>90</sub> Mn <sub>10</sub>
<b>3</b>	Fe <sub>52</sub> Pt <sub>48</sub>	4.6 nm	Mn	0.87 nm	Fe <sub>52</sub> Pt <sub>48</sub>	4.6 nm	(Fe <sub>52</sub> Pt <sub>48</sub> ) <sub>80</sub> Mn <sub>20</sub>



RTA in the temperature range of 650 – 800°C for 30 s in N<sub>2</sub> atmosphere [6]. Structural properties were investigated with x-ray diffraction (XRD) and for selected samples cross-section transmission electron microscopy (TEM) studies were performed. For the characterization of the magnetic properties, superconducting quantum interference device - vibrating sample magnetometry (SQUID-VSM) was carried out at room temperature.

### 3. Results

XRD  $\theta/2\theta$ -scans of FePt films RTA processed at 750°C with different Mn content are presented in Fig. 1a. All film samples exhibit a pronounced L1<sub>0</sub> (001)-texture. In addition, a significant (111)-reflection is observed for the pure FePt film. The intensity of the (111) reflection decreases with addition of Mn up to 10 at.%. Further increase of the Mn content up to 20 at.% alters the film orientation as indicated by a reduced (001)-reflection intensity as well as the reappearance of the (111)- and (110)-reflection (Fig. 1a). Thus, a nominal Mn content of 10 at.% seems to be the optimum in terms of (001)-texture formation.



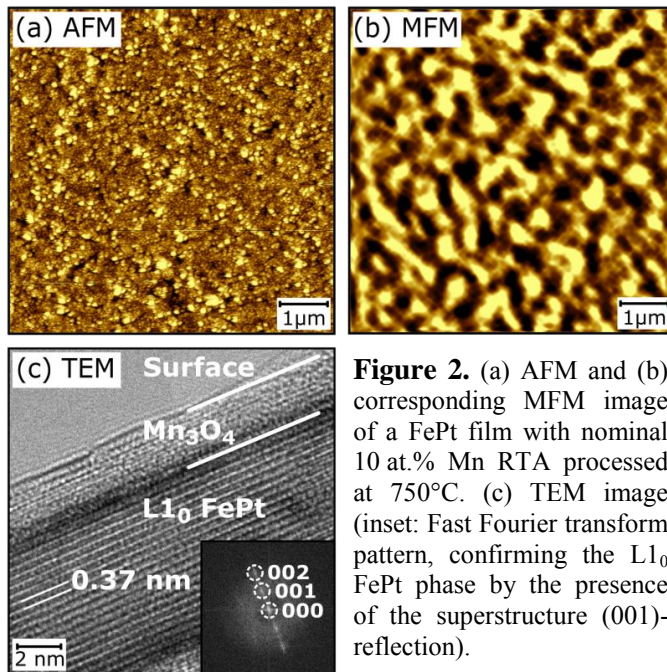
**Figure 1.** (a) XRD ( $\theta$ - $2\theta$ ) scans of FePt films with different nominal Mn content RTA processed at 750°C. (b) Out-of-plane and in-plane hysteresis loops for the FePt film with 10 at.% Mn annealed at 650°C and 750°C. (c) Annealing temperature dependence of the coercivity (out-of-plane).

between Mn and Fe magnetic moments was observed experimentally in epitaxially grown Fe<sub>1-x</sub>Mn<sub>x</sub>Pt thin films [5]. There, a linear reduction in  $M_s$  with Mn content was found. For instance, for a Fe<sub>0.92</sub>Mn<sub>0.08</sub>Pt sample, which corresponds in our case to a Mn content of 4 at.%, a saturation magnetization of 930 emu/cm<sup>3</sup> was observed. This leads to the conclusion that for our RTA processed FePtMn sample with nominal Mn content of 20 at.% only a small amount of about 4 at.% Mn is in fact incorporated into the FePt lattice.

Coercivity values in out-of-plane direction are slightly increasing with annealing temperature and remain almost unchanged up to 800°C (Fig. 1c). Films with a nominal Mn content of 10 at.% annealed at 750°C show a continuous film morphology with a root-mean-square roughness of about 1.8 nm as shown in the atomic force microscope (AFM) image of Fig. 2a. The corresponding magnetic force microscope

Exemplarily, magnetic hysteresis loops taken in out-of-plane and in-plane geometry for FePt films with 10 at.% Mn after RTA processing at 650°C and 750°C are shown in Fig. 1b. Increasing the annealing temperature leads to an increase in remanent magnetization due to the formation of a high fraction of L1<sub>0</sub>-ordered (001) grains. In the in-plane direction, a reduced remanence is observed, which confirms its hard-axis character. Furthermore, the occurrence of a significant coercivity in the in-plane direction indicates the presence of (111)-oriented grains. Please note that the magnetic moments cannot be fully saturated even with 70 kOe field in the in-plane direction, which makes it difficult to extract the magnetic anisotropy values. Nevertheless, the PMA shows a strong increase with annealing temperature, achieving values in the range up to 3.5 MJ/m<sup>3</sup>.

Furthermore, only a small reduction in  $M_s$  value from 1125 to 900 emu/cm<sup>3</sup> by adding 20 at.% of Mn is observed for RTA processed samples at 750°C (not shown). This behavior is rather unexpected as an antiparallel coupling



**Figure 2.** (a) AFM and (b) corresponding MFM image of a FePt film with nominal 10 at.% Mn RTA processed at 750°C. (c) TEM image (inset: Fast Fourier transform pattern, confirming the  $L1_0$  FePt phase by the presence of the superstructure (001)-reflection).

(MFM) image (Fig. 2b) shows bright and dark contrast, revealing magnetic domains in the size range of about 500 nm pointing up and down, respectively. This is consistent with the strong PMA. The addition of 20 at.% Mn leads to an enhanced coercivity (Fig. 1c) due to increase in roughness and formation of small holes in the film, which act as defect sites for domain wall pinning (not shown).

In Fig. 2c, a cross-section TEM image for the film with 10 at.% Mn annealed at 750°C is shown, revealing large and well-ordered  $L1_0$  FePt(001) grains. Interestingly, we observe the presence of a non-continuous Mn oxide layer (most likely  $Mn_3O_4$ ) at the free surface. This result suggests that most of the Mn diffuses through the top FePt layer towards the free surface and is not incorporated into the FePt lattice during RTA processing. This behavior is consistent with the observation of a rather unaffected saturation magnetization with Mn content,

as discussed before. Please note that an additional study on RTA processed stoichiometric  $Fe_{1-x}Mn_xPt$  thin films did not improve the texture formation and revealed rather soft magnetic properties.

#### 4. Conclusions

FePt/Mn/FePt thin films with a total thickness of about 10 nm were deposited at room temperature on  $SiO_2(100\text{ nm})/Si(001)$  substrates. In order to transform them into the  $L1_0$  FePt phase, RTA post-processing at different temperatures was carried out. For films with a nominal Mn content up to 10 at.%, the (001)-texture formation is enhanced, resulting in strong PMA. Larger Mn contents up to 20 at.% lead to a degradation of the (001)-texture in particular at high annealing temperatures.

However, only a small amount of Mn will be actually incorporated into the FePt lattice. Most of the Mn diffuses through the FePt layer, promoting the ordering process, and forms a Mn oxide layer at the free surface. Additional studies on RTA processed stoichiometric  $Fe_{1-x}Mn_xPt$  thin films did not lead to strong (001) texture or PMA. These findings are in contrast to  $Fe_{1-x}Mn_xPt$  films prepared by epitaxial growth on  $MgO(001)$  at elevated temperatures, where up to 68 at.% of Mn can be incorporated into the FePt lattice [5].

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