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# Magnetic and Microstructural Properties of FePt $L1_0$ Nanoparticle Films Fabricated by Self-Assembled Deposition Method

J. C. Bea[1], C.-K. Yin[2], M. Nishijima[3], T. Fukushima[2], T. Sadoh[4], M. Miyao[4], and M. Koyanagi[1]

Japan Science and Technology Agency (JST)[1], Dept. of Bioengineering and Robotics, Tohoku University[2],
01 Aza-Aramaki, Aoba-ku, Sendai 980-8579, Japan
Institute for Materials Resarch,Tohoku University[3], Katahira 2-1-1, Aoba-ku, Miyagi 980-8577, Japan
Dept. of Electronics, Kyushu University[4], Fukuoka 812-8581, Japan
Phone:+81-22-795-6906, Fax:+81-22-795-6907, E-mail: sdlab@sd.mech.tohoku.ac.jp

## 1. Introduction

In recent year, a face-centered tetragonal $L1_0$ structure FePt nanoparticle, which has a high bulk magnetocrystalline anisotropy energy density [$K_u$ ~$6.6\times10^7$ ergs/cm3] and a relatively high magnetization at the equiatomic composition, has attracted much attention from both scientific and application viewpoints [1-3]. For the application of ultrahigh-density recording media and spintronic devices, it is necessary to disperse ferromagnetic particles with the size of less than 10nm in a nonmagnetic matrix. To achieve the nano-sized particles of $Fe_{(1-x)}Pt_{(x)}$ (with x~50%) with a high magnetic anisotropy, a number of techniques including solution phase chemical synthesis(SPCS) [1], molecular beam epitaxy(MBE), cosputtering of Fe and Pt target [2], and sputtering of multilayer have been investigated. In the most cases, coercivity values over 10 kOe were reported for the film with the magnetic grain size of around 10nm. Theoretically, it shows low coercivity values compared with those predicted by the Stoner-Wohlfarth model for isolated single domain particles ( < 20nm) [2, 3]. Thus, it is indicated that the nanoparticles give rise to insufficient phase transformation. Hence, a novel metal-nano-dot (MND) formation technique, which achieves a ultrahigh density of metal in oxide, thermal stability of the films, and controllability of microstructure, was reported by M.Takata, *et al*. [4]. In this work, we fabricated FePt nanoparticle films by self-assembled deposition method. These FePt nanoparticles give rise to concurrent ordering at the elevated annealing temperature which results in coalescence and diffusion of the particles and magnetic coupling of the ferromagnetic particles. Magnetic and microstructure properties of these FePt nanoparticles are investigated to realize the full potential of FePt nanoparticle arrays.

## 2. Experiment

FePt nanoparticle films were formed on $Si_3N_4$(5nm)/ $SiO_2$(10nm)/silicon substrates and $SiO_2$(10nm)/silicon substrates at room temperature by using RF magnetron sputtering method with a special target as shown in Fig. 1. The FePt nanoparticle film consists of silicon oxide matrix where FePt nanoparticles are dispersed with high density. In order to attain uniform composition and thickness of the film, the silicon substrate was rotated at 75rpm. The as-deposited films were annealed in vacuum ambience at various temperatures by using rapidly thermal annealing system (RTA) for 10min. And then, the orientation and microstructure of these films was examined by X-ray diffractometry (XRD) with Cu-K$\alpha$ radiation and a transmission electron microscope (TEM) with high resolution. The magnetic properties of the FePt nanoparticle films were examined by a superconducting quantum interference device (SQUID) magnetometer.

## 3. Results and discussion

Figure 2 shows XRD patterns of the as-deposited FePt nanoparticles and after annealed by RTA at temperature ranges from 400 to 750 °C for 10min. The as-deposited FePt nanoparticle film shows broad peaks which are consistent with fcc structure. In the film annealed at 500 °C, there are initial signs of (002), (201), and (112) $L1_0$ peaks. The overlaid XRD patterns show the appearance of the $L1_0$ (100), (110), and (201) superlattice peaks with increasing annealing temperature and the splitting of the (200) and (002) peaks at 600, 650, and 750 °C, indicating a highly ordered $L1_0$ phase. Cross-sectional TEM images of FePt nanoparticle film on $SiO_2$/Si substrate is shown in Fig. 3 (a) for unannealed sample and (b) for that annealed at 650 °C for 10min by RTA. From Fig. 3 (b), it is found that the coalescence of FePt nanoparticles in oxide was synchronized with diffusion of FePt nanoparticles into bottom oxide. It is considered that infrared thermal energy supplied by RTA is selectively absorbed by FePt nanoparticles in oxide. This enhanced the diffusion of FePt nanoparticles, caused to increase the FePt nanoparticle size up to 16nm, and deteriorated the uniformity of nanoparticle size. Figure 4 shows the magnetization characteristics of FePt nanoparticle films which were annealed RTA at 500, 600, and 650 °C by RTA. As is obvious in Fig. 4, any magnetic hysteresis was not observed in the as-deposited and 500 °C annealed samples indicating that they are essentially superparamagnetic. On the other hand, the samples annealed at 600 °C and 650 °C showed clear hysteresis loops in the magnetization characteristics indicating the coercivities of 1.6 kOe and 5 kOe, respectively. In order to suppress the anomalous diffusion of FePt nanoparticles into the bottom oxide, we inserted the $Si_3N_4$ buffer layer between the FePt nanoparticle film and the bottom oxide. Figure 5 shows the TEM cross-sectional images of the samples where the FePt nanoparticle film is formed on $Si_3N_4$(5nm)/$SiO_2$(10nm)/Si substrate. It is clear in Fig.5 (b) that the anomalous diffusion of FePt nanoparticles into the bottom oxide is suppressed and the uniformity of nanoparticle size is dramatically improved even after RTA at 650 °C for 10min. The FePt nanoparticle size was about 6 nm after RTA. Thus, it was confirmed that thermal stability is dramatically improved by inserting the $Si_3N_4$ buffer layer. Figure 6 shows the magnetization characteristics of the FePt nanoparticle film formed on $Si_3N_4$(5nm)/$SiO_2$(10nm)/Si substrate and annealed at the temperature from 500 to 650 °C. As is clear in the figure, large coercivity with the maximum value of 22 kOe was obtained at room temperature after annealed 650 °C. Figure 7 shows the temperature dependence of the coercivity for the FePt nanoparticle film formed on $Si_3N_4$(5nm)/$SiO_2$(10nm)/Si substrate and annealed at 650 °C. The maximum coercivity of 27 kOe was obtained at 10K due to the decrease of the magnetic interaction of each FePt nanoparticle in isolated matrix and the existence of the single domain in nanoparticle.

## 4. Conclusions

The FePt nanoparticle films were successfully formed by using the self-assembled deposition method. A highly ordered $L1_0$ phase face-centered tetragonal structured FePt nanoparticles with the size of less than 6nm were obtained after annealing at 650 °C by forming the FePt nanoparticle film on $Si_3N_4$(5nm)/$SiO_2$(10nm)/ silicon substrates. The uniformity of FePt nanoparticle size was dramatically improved by inserting the $Si_3N_4$ buffer layer between the FePt nanoparticle film and the bottom oxide. In addition, it is found that the coercivity of FePt nanoparticle film formed on $Si_3N_4$(5nm)/$SiO_2$(10nm)/Si substrate (~22 kOe at room temperature) is four times larger than that of FePt nanoparticle film formed on $SiO_2$(10nm)/Si substrate (~5 kOe at room temperature).

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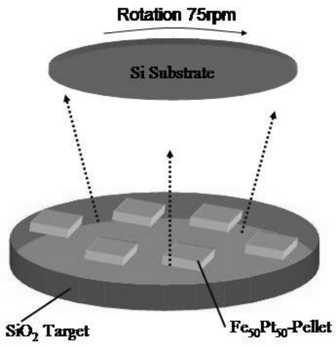


Fig. 1 Self-assembled deposition method with a special target to form FePt nanoparticle film.

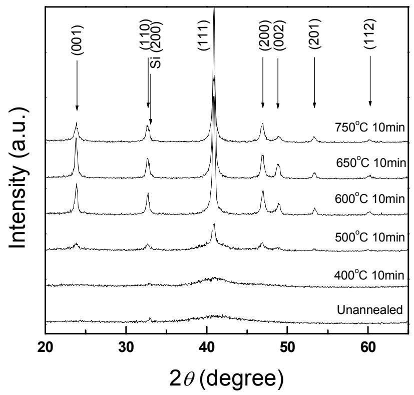


Fig. 2 X-ray diffraction patterns of FePt nanoparticle film annealed at various temperatures for 10min.

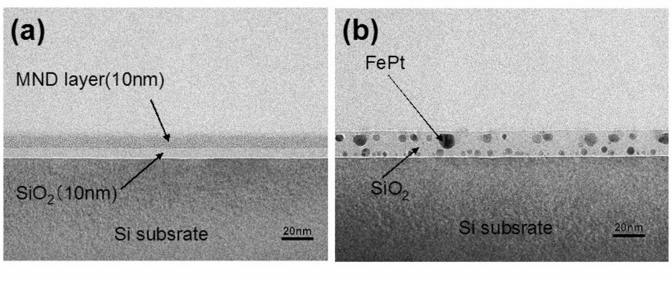


Fig. 3 TEM cross-sectional images of FePt nanoparticle film (10nm) formed on $SiO_2$(10nm)/Si substrate: (a)unannealed and (b) annealed at 650 °C for 10min.

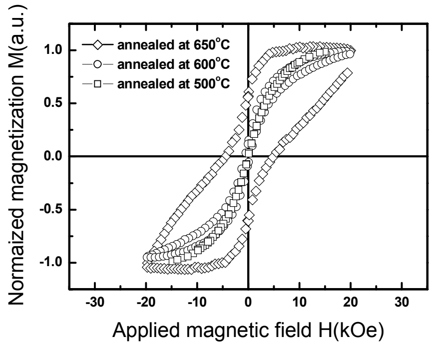


Fig. 4 Magnitization characteristics measured using SQUID in the FePt nanoparticle film formed on $SiO_2$(10nm)/Si substrate and annealed at 500, 600, and 650 °C for 10min using RTA method.

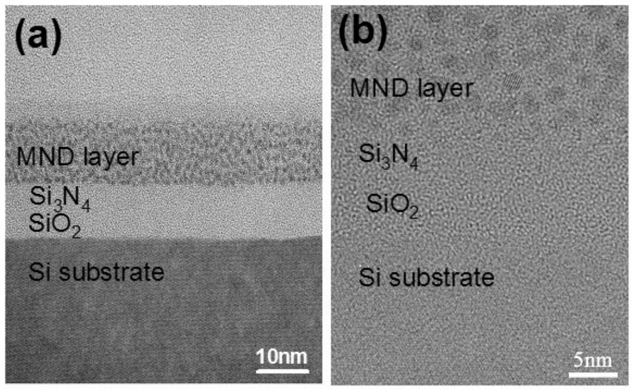


Fig. 5 TEM cross-sectional images of FePt nanoparticle film formed on $Si_3N_4$(5nm)/$SiO_2$(10nm)/Si substrate: (a) unannealed and (b) annealed at 650 °C for 10min.

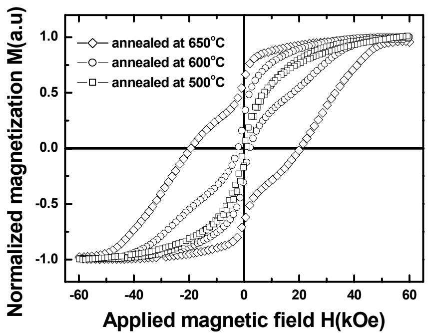


Fig. 6 Magnitization characteristics measured using SQUID in the FePt nanoparticle film formed on $Si_3N_4$(5nm) /$SiO_2$(10nm)/Si substrate and annealed RTA at 500, 600, and 650 °C for 10min using RTA method.

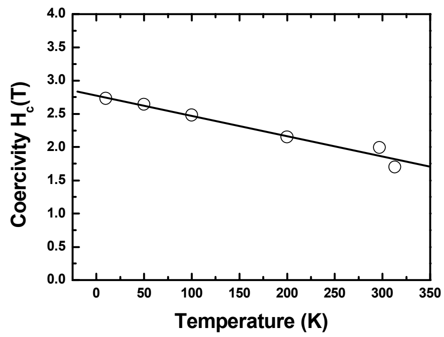


Fig. 7 Temperature dependence of coercivity in FePt nanoparticle film annealed at 650°C for 10min.