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Magnetic properties of FePt nanodots formed by a self-assembled nanodot deposition method

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FePt nanodots dispersed in a SiO2 film (Fe50Pt50 nanodot film) were formed by a self-assembled nanodot deposition (SAND) method in which Fe50Pt50 and SiO2 are cosputtered in a high vacuum rf magnetron sputtering equipment. Fe50Pt50 pellets are laid on a SiO2 target in a sputtering chamber to form the Fe50Pt50 nanodot film in the SAND method. The size and density of Fe50Pt50 nanodots were controlled by changing the ratio of the total area of Fe50Pt50 pellets to that of SiO2 target. The Fe50Pt50 nanodot size decreases and its density increases when the ratio decreases. As-deposited Fe50Pt50 nanodots self-assembled to a face-centered-cubic phase of single-crystal structure. The Fe50Pt50 nanodot films were annealed to evaluate the nanodot size controllability, the magnetic anisotropy, and the thermal stability. Fully ordered L10 face-centered-tetragonal Fe50Pt50 nanodots with high magnetocrystalline anisotropy (𝐾a=8.7×107 ergs/cm3) were obtained by in situ annealing at 600 °C for 1 h in a high vacuum ambience. Furthermore, the Fe50Pt50 nanodot film with a monolayer of Fe50Pt50 nanodots was formed by annealing at 800 °C due to the agglomeration of Fe50Pt50 nanodots in the SiO2 film. © 2006 American Institute of Physics.

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FIG. 1. HRTEM cross-sectional images of as-deposited Fe50Pt50 nanodot film (10 nm) formed on the silicon substrate with thermal SiO2 (10 nm) on its surface. (a) Fe50Pt50 composition of 8%. (b) Fe50Pt50 composition of 12%.

FePt nanodot with L10 face-centered-tetragonal (fct) structure has attracted considerable attention owing to its potentials for new applications in the future including an ultrahigh density magnetic data storage and a novel nonvolatile memory which are produced by its high magnetocrystalline anisotropy. High density metal nanodots can be also employed in single electron devices. For such applications, it is necessary to develop a new formation method for ultrahigh density nanodot layer which enables to precisely control the nanodot size and density.1–8 Recently, Sun et al. reported the magnetic recording properties of self-assembled FePt nanodots having a diameter of 3–10 nm which are synthesized by a chemical method.1 For such FePt nanodots synthesized by a chemical method to give rise to ferromagnetic properties, it is required to convert the nanodot structure from a chemically disordered face-centered-cubic (fcc) phase to a chemically ordered fct phase. It is necessary to anneal FePt nanodots at a temperature higher than 600 °C for the phase conversion of FePt nanodots to a fully ordered L10 fct phase which provides the ferromagnetic properties. However, it is very difficult to control the nanodot size and density in chemically synthesized FePt nanodots after such high temperature annealing due to the agglomeration of FePt nanodots.1–4

In this study, a self-assembled nanodot deposition (SAND) method has been employed for the formation of FePt nanodots.9,10 Fe50Pt50 nanodots dispersed in a SiO2 film (Fe50Pt50 nanodot film) were formed on a silicon substrate with 10 nm thick SiO2 on its surface at room temperature by the SAND method. The sputtering target material with different Fe50Pt50 compositions has been used for controlling the size and density of the Fe50Pt50 nanodots. The Fe50Pt50 composition was controlled by changing the number of Fe50Pt50 pellets having a length of 5 mm, a width of 5 mm, and a thickness of 1.5 mm which are laid on a SiO2 target. The Fe50Pt50 nanodot films were deposited by using a high vacuum rf magnetron sputtering equipment. To obtain uniform dot size and dot density, the silicon substrate was rotated at a rate of 75 rpm/min. Figure 1 shows high resolution transmission electron microscopy (HRTEM) cross-sectional images of as-deposited Fe50Pt50 nanodot film produced with the Fe50Pt50 compositions of 8% and 12%. The Fe50Pt50 composition was defined as the ratio of total area of Fe50Pt50 nanodots.
pellets to the SiO2 target area. It is clearly observed in the figure that the Fe50Pt50 nanodots were dispersed with high density in the sputtered SiO2 film. It is also clear from Fig. 1(b) that as-deposited Fe50Pt50 nanodots self-assemble to a face-centered-cubic phase of single-crystal structures. The sizes of Fe50Pt50 nanodots produced with the Fe50Pt50 compositions of 8% and 12% were 0.9–1.2 and 3.5–4.5 nm, respectively. Moreover, the density of Fe50Pt50 nanodots produced with the Fe50Pt50 compositions of 8% and 12% were 2.5×1013/cm2 and 8.5×1013/cm2, respectively. It was thus found that the nanodot size decreased and the nanodot density increased when decreasing the Fe50Pt50 composition in the target. This indicates that the dot size and density can be controlled well by the Fe50Pt50 composition in SiO2 target. Similar results were obtained in the W–SiO2 nanodot film and the Co–SiO2 nanodot film.

The Fe50Pt50 nanodot film was annealed to improve the crystal qualities and the magnetic properties. Annealing was performed in a high vacuum ambience (1×10−5 Pa) to prevent the oxidation of Fe50Pt50 nanodots. The 0.9–1.2 nm Fe50Pt50 nanodot films show superparamagnetic properties after annealing at 400–800 °C for 1 h. In this study, the 3.5–4.5 nm Fe50Pt50 nanodot films were annealed to evaluate the nanodot size controllability, the magnetic anisotropy, and the thermal stability. Figure 2 shows HRTEM cross-sectional images of Fe50Pt50–SiO2 nanodot films after annealing at various temperatures. As shown clearly in Fig. 2(a), the size of Fe50Pt50 nanodots was 3.5–4.5 nm and the density of Fe50Pt50 nanodots was 8.5×1012/cm2 after annealing at 600 °C for 1 h. It seems that the Fe50Pt50 nanodots do not agglomerate by annealing at 600 °C for 1 h since the nanodot size of as-deposited nanodot film was 3.5–4.5 nm. It was also confirmed that the Fe50Pt50 nanodots formed by the SAND method are thermally more stable when compared to chemically synthesized nanodots. Furthermore, it was confirmed from Fig. 2(b) that the Fe50Pt50 nanodots after annealing at 600 °C for 1 h have a fully ordered L10 fct structure.

FIG. 2. HRTEM cross-sectional images of Fe50Pt50 nanodot films after annealing at various temperatures. The size of as-deposited Fe50Pt50 nanodots was 3.5–4.5 nm. (a) Fe50Pt50 nanodot film after annealing at 600 °C for 1 h. (b) An enlarged image of Fe50Pt50 nanodot after annealing at 600 °C for 1 h. (c) Fe50Pt50 nanodot film with a thickness of 10 nm after annealing at 800 °C for 1 h. (d) Fe50Pt50 nanodot film with a thickness of 6 nm after annealing at 800 °C for 1 h.

Films after annealing at 800 °C for 1 h are shown in Figs. 2(c) and 2(d). The thickness of as-deposited Fe50Pt50–SiO2 nanodot film was 10 nm in Fig. 2(c) and 6 nm in Fig. 2(d). It is clear in Figs. 2(c) and 2(d) that a monolayer of FePt nanodots was produced by annealing at 800 °C due to the agglomeration of Fe50Pt50 nanodots. In addition, it was confirmed by an energy-dispersive x-ray spectroscopy that during the agglomeration of Fe50Pt50 nanodots they have not penetrated into the thermal SiO2 which is formed underneath the Fe50Pt50–SiO2 nanodot films. Consequently it was found that the nanodot size after annealing was defined by the thickness of the as-deposited film.

Figure 3 shows x-ray diffraction (XRD) patterns of Fe50Pt50 nanodot film after annealing at various temperatures for 1 h. As-deposited nanodots exhibited the fcc structure with a broad peak which results from crystal defects in the nanodots. After annealing at 400 °C for 1 h, the fcc phase peak increased, indicating that the crystal defects decreased by thermal annealing. After 500 °C annealing, broad fct peaks of (111), (001), (100), (110), (200), and (112) appeared as the result of the phase transition. After annealing at a temperature of higher than 600 °C for 1 h, all of the fct peaks became clear, indicating that the nanodots converted into a fully ordered L10 phase. Furthermore, annealing at 700 and 800 °C caused the fct (111) peak to narrow and sharpen, indicating that the size of Fe50Pt50 nanodots increased by the agglomeration of Fe50Pt50 nanodots. These XRD results agree with HRTEM results.

Figure 4 shows the annealing temperature dependence of coercivity (Hc) which was measured by vibrating sample magnetometer (VSM). As is shown in the figure, the coerciv-
Fe50Pt50 nanodots dispersed in a SiO2 film (Fe50Pt50 nanodot film) were formed by a SAND method. The Fe50Pt50 nanodot size decreased and the Fe50Pt50 nanodot density increased when decreasing the Fe50Pt50 composition of the target in the SAND method. The as-deposited Fe50Pt50 nanodots self-assembled to a fcc phase of single-crystal structures. Fully ordered L10 fct Fe50Pt50 nanodots with high magnetocrystalline anisotropy ($K_a \approx 8.7 \times 10^7$ ergs/cm$^3$) were produced by annealing at 600 °C for 1 h in a high vacuum ambiance. In addition, the Fe50Pt50 nanodot film annealed at 600 °C exhibited the maximum coercivity of 1.15 T. Furthermore, a monolayer of Fe50Pt50 nanodots was produced by annealing at 800 °C due to the agglomeration of Fe50Pt50 nanodots. The Fe50Pt50 nanodot size in a monolayer could be defined by the Fe50Pt50 nanodot film thickness.

In conclusion, Fe50Pt50 nanodots dispersed in a SiO2 film (Fe50Pt50 nanodot film) were formed by a SAND method. The Fe50Pt50 nanodot size decreased and the Fe50Pt50 nanodot density increased when decreasing the Fe50Pt50 composition of the target in the SAND method. The as-deposited Fe50Pt50 nanodots self-assembled to a fcc phase of single-crystal structures. Fully ordered L10 fct Fe50Pt50 nanodots with high magnetocrystalline anisotropy ($K_a \approx 8.7 \times 10^7$ ergs/cm$^3$) were produced by annealing at 600 °C for 1 h in a high vacuum ambiance. In addition, the Fe50Pt50 nanodot film annealed at 600 °C exhibited the maximum coercivity of 1.15 T. Furthermore, a monolayer of Fe50Pt50 nanodots was produced by annealing at 800 °C due to the agglomeration of Fe50Pt50 nanodots. The Fe50Pt50 nanodot size in a monolayer could be defined by the Fe50Pt50 nanodot film thickness.

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