Low-temperature ordering of FePt thin films by a thin AuCu underlayer

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We have studied the magnetic and structural properties of AuCu(0–50 nm)/FePt(2–50 nm) films after annealing at various temperatures. The results indicate that, by introducing a thin equiatomic AuCu underlayer, the ordering temperature of FePt films with thickness even down to 5 nm can be significantly reduced to 350 °C, at which a large coercivity is developed. In fact, the coercivity is as high as 4.6 kOe for a 5 nm FePt film on a 10 nm AuCu underlayer after annealing at 350 °C and this value is raised up to 7.5 kOe when annealed at 400 °C, while the corresponding sample without a AuCu underlayer has to be annealed at a temperature beyond 600 °C in order to achieve a coercivity of 4 kOe. The ordering of the thin AuCu film at relatively low temperature and thus coherently inducing the ordering of FePt film led to the formation of the ordered FePt phase at a much lowered temperature. © 2005 American Institute of Physics. [DOI: 10.1063/1.1997268]

L1₀ ordered FePt film with face-centered tetragonal (fct) structure has been commonly regarded as a promising candidate for future ultrahigh density magnetic recording media due to its large magnetocrystalline anisotropy. However, equiatomic FePt alloy films grown near room temperature adopt a disordered face-centered cubic (fcc) structure and exhibit soft magnetic properties. In order to achieve the L1₀ ordered phase and a large coercivity, a high-temperature postannealing process and/or substrate heating during deposition are generally required to overcome the energy barrier for the chemical ordering. From a practical viewpoint, reduction of the ordering temperature of FePt films is an important issue. There have been numerous attempts focusing on this subject for recent years. However, the thickness of FePt films for all these studies is beyond 15 nm with most of them around 50 nm. It has been predicted that the thickness of the recording layer should be around or even less than 10 nm for future magnetic media. Actually it has been demonstrated that the activation energy of the chemical ordering for L1₀ phase increases with the decrease of the film thickness, and the ordering temperature rises up significantly as the FePt thickness decreases. Therefore, it is still a tough task to reduce the ordering temperature for FePt films, especially the very thin films.

Like FePt alloy, in the vicinity of equiatomic ratio, the AuCu alloy also displays a structural disorder-order transformation along with a slight lattice distortion from fcc to fct, but the ordering temperature of AuCu alloy is much lower than that of FePt alloy. Besides, the equiatomic AuCu alloy has lattice constants close to those of equiatomic FePt alloy with either fcc or fct structure. We thus investigated the effect of AuCu underlayer on the ordering of FePt thin film, and expected that the formation of L1₀ AuCu under a relatively low temperature will simultaneously drive the thin FePt film to the ordered structure due to the coherent structure when FePt film deposited on AuCu underlayer.

Films with the structure of AuCu(tₜ nm)/FePt(tₘ nm)/C(5 nm) were deposited on Corning 7059 glass substrates at room temperature by dc magnetron sputtering, where tₜ is from 0 to 50 and tₘ from 2 to 50. The vacuum of the sputtering system is better than 4 × 10⁻⁵ Pa, and Ar pressure is 0.5 Pa during sputtering. The compositions of AuCu and FePt films are near equiatomic ratio (off stoichiometry within 2%) determined by energy dispersive x-ray spectroscopy. Sputtering rate is 0.1 nm/s for AuCu, 0.2 nm/s for FePt, and 0.02 nm/s for C. Films were annealed at temperatures from 300 to 600 °C for 1 h in a vacuum furnace with a pressure lower than 5 × 10⁻⁵ Pa. The magnetic properties were measured at room temperature using a vibrating sample magnetometer and a Quantum Design superconducting quantum interference device magnetometer. Film crystallographic structures were examined by x-ray diffractometers using Cu Kα radiation.

Figure 1 shows the dependence of in-plane coercivity on annealing temperature for several representative samples. One can notice that, without AuCu underlayer, 5 nm FePt film is magnetically soft with the annealing temperature between 300 and 450 °C. Similarly, 9 nm FePt also exhibits small coercivity, which increases very slightly as the annealing temperature rises with the maximum value less than 2 kOe after annealing at 450 °C. We would like to point out that, in order to achieve an appreciable coercivity, e.g., 4 kOe, the annealing temperature for 5 nm FePt is beyond 600 °C and for 9 nm FePt higher than 550 °C (not shown).

FIG. 1. Dependence of in-plane coercivity on annealing temperature for 5, 9, and 50 nm FePt films with 10 nm AuCu underlayer (solid symbols) and without underlayer (hollow symbols).

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As to 50 nm FePt film, the coercivity is drastically raised to 6.7 kOe when the annealing temperature is increased from 300 to 350 °C; then it goes up slightly with the further increase of the annealing temperature. Above results indicate that, the ordering temperature of FePt films indeed strongly depends on the film thickness, and the boomingly increased ordering temperature for FePt films with thickness below 10 nm is a real challenge, which was ignored in all previous studies. With the introduction of 10 nm AuCu underlayer, the coercivity of all FePt films has been greatly enhanced, especially for 5 and 9 nm FePt films (see Fig. 1). Note that, 5 nm FePt film with 10 nm AuCu underlayer has a coercivity of 4.6 kOe after annealing at 350 °C, and 7.5 kOe after annealing at 400 °C, which means that the ordering temperature of 5 nm FePt film is lowered at least 250 °C to a temperature of about 350 °C by 10 nm AuCu underlayer. The effect of AuCu underlayer on the coercivity of 9 nm FePt film is similar, and the corresponding ordering temperature also declines to ~350 °C with a reduction of about 200 °C. For the case of 50 nm FePt, the formation of the ordered phase is still promoted considerably, judging from the large enhancement of the coercivity with AuCu underlayer introduced under various annealing temperatures. Figure 2 presents the change of coercivity as a function of the thickness of FePt film with and without 10 nm AuCu underlayer. The coercivity exhibits a steep rise when \( t_{\text{au}} > 10 \) nm for FePt films without AuCu underlayer, but the abrupt increasing point shifts to FePt thickness \( t_{\text{au}} \approx 2 \) nm along with a great enhancement of the coercivity overall when 10 nm AuCu underlayer is added. Apparently FePt film with thickness below 10 nm has a much higher energy barrier for the disorder-order transformation, and thin AuCu underlayer greatly reduces this barrier and leads to the ordering at a low temperature of about 350 °C with FePt thickness even down to 5 nm.

We further investigated the effect of AuCu underlayer thickness on the ordering of FePt films. All FePt films with thickness from 2 to 50 nm are magnetically soft after annealing at 300 °C with AuCu thickness ranging from 3 to 50 nm, but the variation of AuCu thickness does alter the magnetic behavior of the FePt films when the annealing temperature is beyond 300 °C. Figure 3(a) shows the coercivity behavior of 9 nm FePt film with different thickness of AuCu underlayer after annealing at 350 and 400 °C. One notices that, the coercivity of 9 nm FePt film without AuCu underlayer is below 1 kOe after annealing at 400 °C. However, even a 3 nm AuCu underlayer drastically enhances the coercivity to 7.5 kOe under the same annealing temperature. With the further increase of AuCu thickness, coercivity rises slightly and then saturates at AuCu thickness 8–10 nm, where the maximum coercivity is about 9 kOe after 400 °C annealing. Strange enough, when the thickness of AuCu underlayer exceeds 20 nm, the large coercivity exhibits a decreasing tendency while the coercivity of 5 nm FePt film is lowered at least 250 °C to a temperature of about 350 °C by 10 nm AuCu underlayer. The effect of AuCu underlayer on the coercivity of 9 nm FePt film is similar, and the corresponding ordering temperature also declines to ~350 °C with a reduction of about 200 °C. For the case of 50 nm FePt, the formation of the ordered phase is still promoted considerably, judging from the large enhancement of the coercivity with AuCu underlayer introduced under various annealing temperatures. Figure 2 presents the change of coercivity as a function of the thickness of FePt film with and without 10 nm AuCu underlayer. The coercivity exhibits a steep rise when \( t_{\text{au}} > 10 \) nm for FePt films without AuCu underlayer, but the abrupt increasing point shifts to FePt thickness \( t_{\text{au}} \approx 2 \) nm along with a great enhancement of the coercivity overall when 10 nm AuCu underlayer is added. Apparently FePt film with thickness below 10 nm has a much higher energy barrier for the disorder-order transformation, and thin AuCu underlayer greatly reduces this barrier and leads to the ordering at a low temperature of about 350 °C with FePt thickness even down to 5 nm.

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FIG. 2. Dependence of in-plane coercivity on FePt thickness after 350 and 400 °C annealing. The solid and hollow marks are for FePt films with 10 nm AuCu underlayer and without underlayer, respectively.
AuCu underlayer during the 300 °C annealing process. The coherence length is 15–16 nm for 9 nm FePt film with 50 nm AuCu underlayer in the as deposited state. This value is larger than the thickness of FePt film, but much smaller than that of the AuCu layer. So 50 nm AuCu underlayer itself is definitely not coherently grown throughout the whole layer. It is highly possible that the ordered part of AuCu underlayer during the 300 °C annealing does not extend to the interface between AuCu and FePt layers, thus FePt film remains the disorder structure with small coercivity. Moreover, part of the FePt grains may lose the coherence with AuCu underlayer at the interface, so these FePt grains still need high-temperature annealing for the ordering, thus the coexistence of magnetic hard and soft phases for FePt films were observed during the low temperature annealing, e.g., 350 °C. Finally, we would like to point out that the observation of the ordering of thick AuCu film with FePt being disordered after 300 °C annealing eliminates any possibility that the stress or dynamic stress is the main cause of the low-temperature ordering for FePt films with AuCu underlayer.

In summary, low-temperature ordering of FePt thin films has been achieved by using a thin equiatomic AuCu underlayer. The reduction of the ordering temperature is beyond 250 °C for 5 nm FePt film with the introduction of AuCu underlayer. It is the ordering of AuCu underlayer at relatively low temperature that coherently induces the disorder-order transformation of FePt films.

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20Since the (110) plane of AuCu or FePt is at an angle of about 36° with respect to its (111) plane, the corresponding superlattice (110) peak should be observable by tilting the film normal by 36° with respect to the x-ray incident plane if the (111) textured AuCu or FePt film is ordered.