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FePtCu–C granular film for perpendicular magnetic recording media

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We worked on a FePtCu–C granular film for ultrahigh density perpendicular recording media with the density of 1 Tbits/in^2 or even higher because of the strong anisotropy at FePt $L1_0$-phase. In experiments, a $Fe_{48}Pt_{42}Cu_{10}$–C45% (6.8 nm) film was deposited on a silicon substrate with a MgO (12 nm) interlayer at 490 °C. The perpendicular coercivity of the film is 21 kOe, with a squareness of 1. Bright-field TEM images shows that the FePt granular film has small and uniform grains of 7.2 ± 1.9 nm. More work of high-resolution TEM imaging shows excellent $L1_0$ ordering for this film, consistent with the texture measurement by XRD. The measurement of remnant coercivity proves that it has an energy barrier of 330 k_BT at room temperature, meaning excellent thermal stability. As a result, FePtCu–C granular thin film is a qualified candidate for high-density magnetic recording media.

1. Introduction

It is well-known that modern computers employ magnetic recording for basic storage. In order to improve the data storage efficiency, an important issue in the research and development of hard-disk drives (HDDs) is to increase the recording density, that is to reduce the dimension of a single recording bit. However, for the further increasing density, the super-paramagnetic effect [1] cannot be neglected any more, and it would induce thermal relaxation in the magnetic particles in the storage unit. In order to get excellent thermal stability of recorded information for long time storage like 8–10 years, we should increase the coercivity and anisotropy of the recording materials. Thus, people in magnetic recording industry work hard to search qualified magnetic materials for high-density recording purpose. After long-time efforts, among all possible magnetic materials for recording media, $L1_0$-ordered FePt granular thin films become the best candidates as perpendicular magnetic recording (PMR) media with the recording density of 1 Tbits/in^2 or above, because it has high magneto-crystalline anisotropy ($K_u \sim 6 \times 10^7$ erg/cc) which can reduce the grain size to 4 nm while still thermally stable at room temperature [2–9]. On the other hand, hard recording medium is difficult to "write" at room temperature because no pole material could create so strong field. Researchers solved this trouble by heating the recording medium during heat-assisted magnetic recording (HAMR) [10–14]. In early efforts of other groups, they achieved nanometer grain size FePt thin films with the addition of Ag and C with high coercivity and thermal stability [5]. In their work, carbon is used as the spacer to separate FePt nanograins, and Ag is used to reduce the $L1_0$ ordering temperature. However, their growth temperature is too high (more than 500 °C), which is not welcome for the HDD industry. Also, the squareness of the perpendicular MH loop of their films has to be improved for better recording performance of the media. As we know, the slope of the MH loop at the coercive point, i.e. $\frac{dM}{dH}\big|_{H=H_C}$, has to be increased, so that the magnetization reversal of the recording bits can be executed smoothly during the recording process [11]. On the other hand, several groups reported that the Cu addition to FePt film can reduce the Curie temperature more than the Ag additive [15–19]. Furthermore, the volume of Cu atom is smaller than Ag, so that it is easier to diffuse inside the FePt lattice than Ag. In our work, we worked on a FePt granular thin film with the addition of Cu and C. The growth temperature is reduced to 490 °C, which is easier to accept by industry. By selecting a suitable Ar pressure inside the vacuum chamber, the squareness of the perpendicular MH loop was improved. Then, we displayed detailed work to study the microstructure of FePt grains through high-resolution transmission electron microscopy (TEM) imaging. Finally, we measured the remnant coercivity of the film in different time delay to study the thermal stability of this FePtCu–C granular film.

2. Experiments

We deposit a 6.8 nm thick $Fe_{48}Pt_{42}Cu_{10}$–C45% film on a bare silicon substrate. First step, we grow a 12 nm MgO film interlayer on the top of the silicon substrate, then, FePtCu–C granular film layer on the top of MgO film interlayer, in a high-vacuum magnetron-sputtering chamber. The addition of Cu is to improve the $L1_0$ order of FePt magnetic grains in a low temperature growth [9]. The volume fraction of carbon is 45% in the film. The MgO film layer was grown at room temperature, while the FePtCu–C granular film layer at 490 °C. During film growth, the Ar pressure is 1.1 Pa for MgO, and 0.55 Pa for FePtCu–C, respectively. The deposition rate of

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MgO film layer is about 0.06 nm/s, and FePtCu–C granular film layer is about 0.026 nm/s. The total FePtCu–C granular film was formed by co-sputtering method. In experiments, the base pressure of the vacuum chamber is about 1×10^{-5} Pa. The composition of the FePtCu–C granular film was carefully calibrated based on the deposition rate of each element, Fe, Pt, Cu and C. Furthermore, it is also proved by ICP/OES (inductively couple plasma optical emission spectrometry) examination, which is consistent to the former method. Then, we use XRD (X-ray diffractor) to study the texture of the FePtCu–C granular film with MgO underlayer. We use SQUID (superconducting quantum interferometer device) MPMS (magnetic properties measurement system) to measure the magnetic properties. The field range of SQUID is −55 to +55 kOe. Then, we use a TEM (transmission electron microscope) to study the microstructure of the film, in two modes: bright-field and high-resolution.

3. Results and discussion

In Fig. 1, we display the XRD pattern of the FePtCu–C/MgO/Si film. The index of both MgO and FePt peaks are labeled, while FePt peaks are marked by numbers only. The figure tells us a distinct MgO(200) peak at $2\theta = 43.1°$ and the $L1_0$-ordered fct-FePt(001) (002) peaks, which are mainly created by the MgO(200) texture from the underlayer [5]. Both fcc-FePt(200) and FePt(111) peaks are suppressed. We calculated the degree of the $L1_0$ order of this FePtAg–C granular film, to be 0.83. The above facts indicate excellent $L1_0$ order in the FePtCu–C granular film layer.

Next, we work on the microstructure of the FePtCu–C granular film by TEM. Fig. 2 shows a bright-field TEM image of the plane-view for the film, with the inset of SAED (selected area electron diffraction) pattern and statistic diagram of the grain size distribution. From the image, we can see that the grains in the FePtCu–C granular film are uniformly separated and distributed. After statistical calculation, we obtained the average grain size is 7.2 nm, with a standard deviation of 1.9 nm. The average center-to-center distance of those grains is about 11.2 nm, and so the average spacing is about 4.0 nm for those grains. In the SAED pattern, counted from center to edge, the rings of FePt(001), FePt(110) MgO(200), and FePt(002) peaks are clearly displayed, which agrees with the data in Fig. 1 (XRD pattern). Then we can say that the excellent $L1_0$ ordering is formed in this FePtCu–C granular film. Fig. 3 shows the bright-field TEM image of the cross-sectional view of the FePtCu–C granular film. We see that those FePtCu–C grains form a single-grain layer structure in the film, which can increase the coercivity of the magnetic thin film [7].

After that, we did high-resolution TEM imaging on the FePtCu–C granular film, so that we can understand more details on the microstructure. Fig. 4 displays a plane-view high-resolution TEM image of the FePt grains. We observed some MgO matrix below the $L1_0$-ordered FePt nano-grains. We also can clearly find the boundary of MgO grains in the underlayer. Next, Fig. 5 displays a cross sectional high-resolution TEM image of the FePtCu grains. It

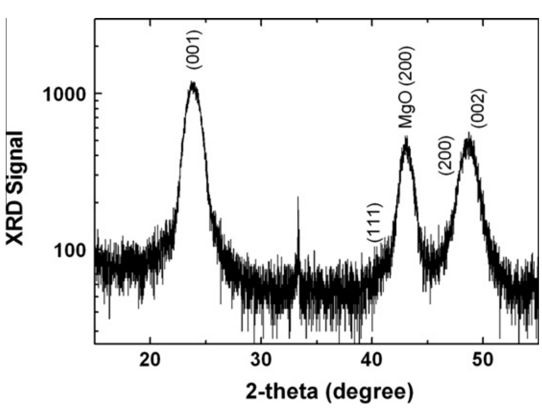

Fig. 1. XRD pattern of FePtCu–C granular thin film.

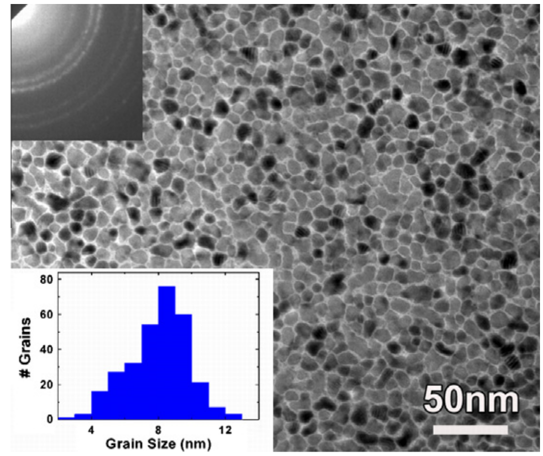

Fig. 2. Bright-field TEM image of the plane-view, with the inset of selected area electron diffraction pattern, and statistics of grain size distribution.

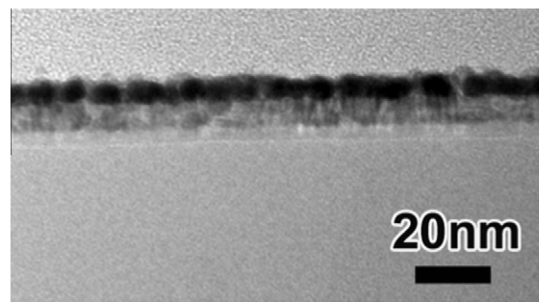

Fig. 3. Bright-field TEM image of the cross-sectional view of the FePtCu–C granular thin film.

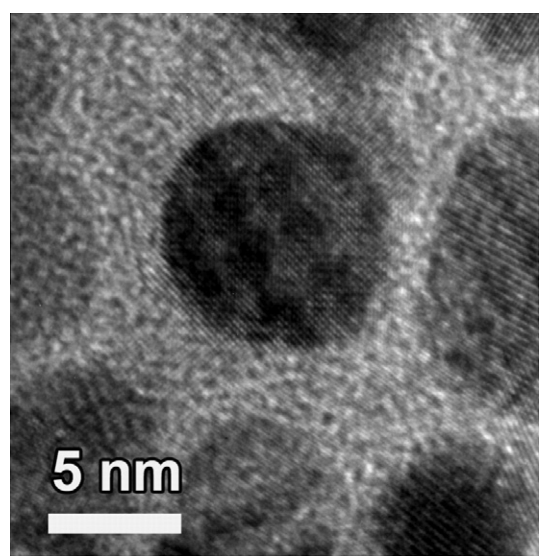

Fig. 4. High-resolution plane-view TEM image of FePtCu–C granular thin film.

seems difficult to find the proof of direct relationship between the FePtCu grains and the MgO grains below. However, we are able to find the epitaxial relationship between FePtCu grains and MgO grains, i.e. $(001)_{FePt}//(002)_{MgO}$. Thus, it demonstrates that the MgO polycrystalline underlayer aids FePtCu grains aligned to (001) orientation normal to the film plane, getting the $L1_0$-order in the FePt granular film.