(001) FePt graded media with PtMn underlayers

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(001)-oriented FePt graded media are obtained by using PtMn underlayers. The PtMn underlayer not only behaves as the (001) structural template but provides the diffusion source of Mn. The diffusion of Mn into FePt reduces its anisotropy but, on the other hand, the exchange coupling between antiferromagnetic PtMn and ferromagnetic FePt enhances the anisotropy. Hysteresis loops taken from x-ray magnetic circular dichroism confirm the competition between these two effects, leading to the lowest anisotropy in the middle of FePt. © 2011 American Institute of Physics. [doi:10.1063/1.3664129]

To achieve high-density magnetic recording, high anisotropy materials are required to maintain thermal stability; however, an affordable writing field is limited. To address this issue, graded media with continuously varied anisotropy are proposed and show that the switching field can be significantly reduced while the thermal stability of media remains the same.1

FePt has been identified as the most promising high anisotropy material for next-generation media. The fabrication methods have been extensively studied to obtain uniform granular FePt films with small grain sizes and to acquire fully ordered structure at relatively low temperature.2,3 It is known that doping a third element into FePt, such as Cu, Ni4, Au, Ag5, or Mn6, can change the ordering temperature, curie temperature, or the anisotropy constant of FePt. By doping varied amount of Cu, the anisotropy of FePt can be reduced and thus graded media by the concentration gradient can be obtained.7 However, these films are not (001) oriented. The FePt-C graded media using a graded composition were reported to decrease the required switching field and at the same time maintain the perpendicular anisotropy.8 So far, to fabricate perpendicular FePt graded media is still a big challenge.

In this letter, we demonstrate that the (001) FePt graded media can be achieved by the graded composition profile and exchange coupling strength. The PtMn underlayer is used for achieving (001)-growth of FePt films and serves as the diffusion source of Mn for the composition gradient. The ordered phase (L10) of antiferromagnetic PtMn is the same as FePt and the a-axis lattice constants of the ordered PtMn and FePt are compatible. Furthermore, the exchange coupling between antiferromagnetic PtMn and ferromagnetic FePt introduces extra anisotropy, and thus enhances coercivity of FePt.9 The extra anisotropy originating from the exchange coupling decreases with the distance away from the interface of FePt/PtMn. On the other hand, during the high temperature deposition, the Mn atoms may diffuse from the PtMn underlayer into the FePt layer, leading to the formation of the Fe1-xMnxPt ternary alloy with a composition gradient of Mn. By the competition between exchange anisotropy and Mn alloying, the anisotropy of FePt is varied along the film thickness.

Samples with the structure of FePt (25 nm)//MgO (001) and FePt (25 nm)/PtMn (50 nm)//MgO(001) were prepared at the deposition temperature of 500°C. FePt and PtMn were deposited by co-sputtering two elemental targets. The compositions were controlled by the deposition power and verified by inductively coupled plasma mass spectrometer (ICP-MS). The compositions of the single layer of FePt and PtMn are Fe52Pt48 and Pt49Mn51, respectively. X-ray diffraction (XRD) patterns reveal that all samples show (001) epitaxial growth. This proves that the PtMn underlayer maintains the (001) orientation and the diffusion of Mn into FePt films does not destroy the (001) epitaxial growth.

Fig. 1 shows the perpendicular and in-plane hysteresis loops of as-deposited and annealed samples of FePt (25 nm)/PtMn (50 nm)//MgO, measured by a vibrating sample magnetometer (VSM). Annealing was performed at 550°C for different periods of time. The perpendicular coercivity decreased as the annealing time increased. Furthermore, the magnified in-plane loop, shown in the inset of Fig. 1, shows significant kinks at small fields after 1 h annealing, implying the presence of soft phases due to Mn diffusion. According to previous reports, the presence of Mn in the FePt leads to the reduction of the anisotropy.6 The depth profile of Auger electron spectroscopy (AES) of the as-deposited sample of FePt (25 nm)/PtMn (50 nm)//MgO, shown in Fig. 2, clearly shows intermixing of Mn and Fe. For the annealed samples, AES depth profiles reveal enhanced interdiffusion. The composition depth profile combining with hysteresis loops suggest that the existing Mn composition gradient may lead to anisotropy gradient in FePt.

To further investigate how the diffusion of the Mn atoms affects the density-dependent magnetization reversal, we on purpose doped small amount of Co (so-called Co-marker of 1 nm) at the different depth positions of the FePt layer and performed x-ray magnetic circular dichroism (XMCD) measurements with the fluorescence yield mode (probing depth ~100 nm). Because the XMCD loop is element-specific, the
loop taken at Co L3 edge only shows the hysteresis loop of Co-marker. Since the Co-marker is strongly coupled to the local FePt, the perpendicular loops of the Co-marker can be used as the indicator of local magnetization reversal in FePt.\textsuperscript{10} By varying the position of the Co-marker, we can get the anisotropy profile of the FePt along the depth direction. We prepared three samples of FePt (25 nm)/PtMn (50 nm)/MgO in which Co was co-sputtered with FePt at the designated depth, away from the most top surface, of 21 nm (bottom), 14 nm (middle), and 5 nm (top), respectively. The schematic diagram of the sample structure is shown in the inset of Fig. 3(b). The nominal thickness of the Co-marker was 1 nm and the estimated composition, based on the deposition rate, was (Fe\textsubscript{80}Co\textsubscript{20})\textsubscript{0.52}Pt\textsubscript{0.48}. Since the thickness of the Co-marker is thin and Co-marker is strongly coupled to the adjacent FePt layer, the effect of Co doping on the magnetic properties of FePt is almost negligible. The hysteresis loops of the samples with or without the Co-marker, measured by VSM, indeed do not show observable differences. Fig. 3 shows hysteresis loops for the samples with a Co-marker at different depth measured by VSM and XMCD. The VSM loops, which give the total magnetic signal from the sample, for three samples are almost the same. Although XMCD loops from the Co-marker only are relatively noisy due to quite limited amount of Co, they reveal that the middle FePt shows the lowest coercivity rather than the bottom FePt in which more Mn atoms existed. On the other hand, the reference samples without the PtMn underlayer (FePt (25 nm)/MgO) showed identical Co loops measured by XMCD regardless of the positions of the Co-marker. Two effects from the PtMn layer have to be taken into consideration. The diffusion of Mn, confirmed by AES profile (Fig. 2), may lead to the formation of the (Fe\textsubscript{1-x}Mn\textsubscript{x})Pt alloy. The more the Mn composition is, the smaller the anisotropy of the ferromagnetic (Fe\textsubscript{1-x}Mn\textsubscript{x})Pt is.\textsuperscript{6} Another effect is the presence of antiferromagnetic layer, which can provide an extra exchange coupling to stabilize the ferromagnetic layer.\textsuperscript{9,11,12} Although the interdiffusion exists in the region near the interface of FePt/PtMn, the Mn content is high enough to form antiferromagnetic (Mn\textsubscript{1-x}Fe\textsubscript{x})Pt\textsuperscript{13}; consequently, exchange coupling still exists. Notice that the exchange coupling is an interfacial phenomenon so its strength decreases with increasing the distance away from the interface of FePt/PtMn.

To further confirm the existence of the exchange coupling between PtMn and FePt, we fabricated samples with a structure of PtMn (x nm)/FePt (25 nm)/MgO. We on purpose put PtMn on the top of FePt to assure the properties of FePt are not changed by varying the thickness of PtMn. All the samples with PtMn layers show enhanced coercivity compared to the sample without PtMn. The dependence of FePt coercivity on the PtMn thickness, shown in Fig. 4, is quite similar to the thickness dependence reported in the...
The FORC distribution shown in Fig. 5(b) is the typical case measurement can refer to Refs. 16 and 17. Families of FORCs the reversal behavior of the sample. The detail of FORCs annealing, the last 5 nm FePt (hard layer) was deposited. to promote the Mn diffusion and to reduce the anisotropy. Af-

and the corresponding FORC distribution are shown in Fig. 5. enhancement without the exchange bias field as observed in the competition between Mn alloying and exchange coupling: at the bottom of FePt layer, the anisotropy is enhanced by the exchange coupling to (Mn1-xFe)xPt. For the middle of the FePt layer, the exchange coupling strength is weakened and the anisotropy is reduced by the existence of Mn, so the effective anisotropy is the smallest. At the top of the FePt layer, due to the less content of Mn, the anisotropy is increased. For the application of graded media, the field of the formation of reversed domain should be lowered to help the magnetization reversal. Although the FePt/PtMn shows larger coercivity than FePt due to the existence of the exchange coupling (Fig. 4), the coercivity of the middle FePt in the sample of FePt/PtMn (Fig. 3(b)) is still smaller than that of pure FePt films due to Mn diffusion. Since the reversed domain occurs in the region with the lowest anisotropy, our proposed structure can not only possess a low filed to form the reversed domains but provide an extra tuning knob to manipulate the anisotropy profile.

Since our proposed structure of FePt graded media is to utilize the Mn concentration profile and exchange coupling from the PtMn layer to adjust anisotropy profile of FePt, we can achieve desired anisotropy profile and further reduce the field to form reversed domains by post-annealing. For example, we used the same layer structure (FePt (25 nm)/PtMn (50 nm)/MgO) but after depositing FePt 20 nm layer at 500°C, the sample was in-situ annealed at 550°C for 30 min to promote the Mn diffusion and to reduce the anisotropy. After annealing, the last 5 nm FePt (hard layer) was deposited. We employed the first order reversal curves (FORCs) to study the reversal behavior of the sample. The detail of FORCs measurement can refer to Refs. 16 and 17. Families of FORCs and the corresponding FORC distribution are shown in Fig. 5. The FORC distribution shown in Fig. 5(b) is the typical case for soft-hard coupled layers reported in the graded media. A single and highly localized peak along with a pair of negative-positive tails was observed in the FORC distribution for the reversal field of \( H_R < -2500 \text{ Oe} \), suggesting the existence of both soft and hard phases. It should be noted that no appreciable feature is observed in the reversal field of \( H_R > -2500 \text{ Oe} \), which demonstrates the reversible reversal contributed from the soft phase coupled to the hard phase.

In summary, we demonstrate (001) FePt graded media by using the PtMn underlayer. The PtMn underlayer not only exchange-couples to FePt but serves as a Mn source. The anisotropy of FePt is varied along the thickness direction by the effects of the exchange coupling to the antiferromagnetic (Mn1-xFe)xPt and the formation of ferromagnetic (Fe1-xMn)xPt alloy.

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