A novel crystalline soft magnetic intermediate layer for perpendicular recording media

Soyoung Park,[1,2,a)] Jian-Gang Zhu,[1,2,3] and David E. Laughlin[1,2,3]
[1]*Data Storage Systems Center, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*
[2]*Department of Materials Science and Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*
[3]*Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*

(Presented 11 November 2008; received 18 September 2008; accepted 21 January 2009; published online 16 March 2009)

In order to improve the recording efficiency in current perpendicular recording media, it is important to reduce the distance from the head to soft underlayer. In this paper, a soft magnetic intermediate layer is proposed to partially replace the presently used Ru intermediate layer. The new soft magnetic intermediate layer serves two purposes, which are as follows: (1) to decrease the thickness of the nonmagnetic Ru intermediate layer by providing a proper crystalline texture and surface morphology for the optimal crystalline grain growth of the magnetic storage layer on top and (2) to act as an additional soft magnetic underlayer that is closer to the head air bearing surface to enhance the recording performance. The prototypes of the soft magnetic intermediate layer consists of CoIr:SiO_2/CoPt:SiO_2/NiW multilayer structure. CoIr and CoPt were chosen because both have the hcp structure but the opposite sign for K_1. A zero effective magnetoanisotropy of a composite grain is accomplished by varying the thickness ratio of each layer of CoIr and CoPt. The developed multilayer film shows the hcp (00.2) orientation with a dome morphology for facilitating the growth of the top magnetic storage layer as well as soft magnetic properties ($K_1 = 6.8 \times 10^5$ erg/cc). © *2009 American Institute of Physics*. [DOI: 10.1063/1.3079899]

I. INTRODUCTION

In perpendicular recording media, minimizing the switching field distribution to reduce the transition noise of the magnetic storage layer and enhancing the writing field gradient are crucial to increase the recording areal density.[1–4] Currently, a nonmagnetic hcp Ru intermediate layer (IL) with sufficient thickness is used in perpendicular granular media (1) to acquire high K_u with small switching field distribution and (2) to minimize intergranular exchange coupling. The thicker Ru IL tends to have a smaller *c*-axis distribution and better defined dome morphology.[5] The small *c*-axis distribution of the Ru IL allows hcp Co-alloy grains in the recording layer to have smaller switching field distribution with high K_u. The dome morphology of Ru IL enhances the intergranular exchange decoupling because the Cr/oxide in the recording layer tends to deposit in the Ru valley between domes (grain boundaries) isolating the magnetic grains. However, the large distance between the recording head and the soft underlayer (SUL) due to the thick nonmagnetic Ru IL deviates the writing field.[6,7] In this paper, practical designs of a soft magnetic crystalline IL are proposed to decrease the thickness of the nonmagnetic Ru IL without sacrificing the small switching field distribution or intergranular decoupling. This novel layer is inserted between the conventional Ru IL and the amorphous SUL so that images the head field closer than the SUL allows in the conventional design; thus, the head field gradient and amplitude can be increased, as illustrated in Fig. 1. The principles of the design can be explained as follows. First, this crystalline soft magnetic IL has the hcp (00.2) texture with a dome morphology so it serves as a seedlayer for Ru IL. Thus, the Ru IL can grow with the required texture/morphology in the initial growth stage so that the thinner Ru IL is only necessary for magnetic exchange decoupling of the SUL with the recording layer. Second, this IL is magnetic. This means that this layer images the head field in shorter distance (d') due to the reduced Ru IL thickness than in the case of only an amorphous SUL with a thick nonmagnetic Ru IL does (d). Third, the proposed soft magnetic interlayer can be seen as an assembly of magnetically isolated, soft granules, as illustrated in the orange color in Fig. 1(b). Each isolated zero anisotropy cube images the head field more efficiently than the continuous amorphous SUL by switching immediately and independently so that it sharpens the head field gradient, as illustrated in Fig. 1(b). In addition, the combination of the complete softness and shortened exchange length prevents this soft IL from forming magnetic domain walls, which can be a source of noise.

In order to achieve required microstructure and magnetic properties, two different hcp Co alloy materials with opposite signs of their magnetocrystalline anisotropy (K_1) were selected. It is known that above Co-7at.% Ir has negative K_1.[8] Co-17at.% Ir was chosen for the largest negative crystalline anisotropy for the design and deposited on top of $CoPt_{20}$ with positive K_1, as illustrated in Fig. 1(c). The mag-

a)Electronic mail: soyoung1@andrew.cmu.edu.

 © 2009 American Institute of Physics

Downloaded 01 Apr 2009 to 128.2.132.41. Redistribution subject to AIP license or copyright; see http://jap.aip.org/jap/copyright.jsp

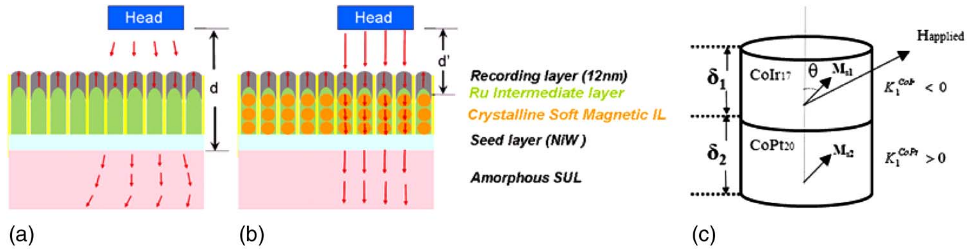

FIG. 1. (Color online) A schematic illustration of (a) a conventional perpendicular recording media having a large head field deviation and (b) a new proposed media with the reduced nonmagnetic Ru IL used due to the crystalline soft magnetic IL. The head field gradient and the amplitude are increased. Note that the soft IL consists of magnetically isotropic granules. (c) A composite grain of easy plane material (CoIr with negative K_u) and perpendicular anisotropy material (CoPt with positive K_u)

netic energy consideration in Eq. (1) describes how a composite grain of CoIr and CoPt obtains the magnetic energetically isotropic structure,

$$E(\text{erg/cm}^2) = (K_1'\delta_1 + K_1''\delta_2)\sin^2\theta. \quad (1)$$

This equation assumes the magnetization of each layer is fully exchange coupled since the films are thin and consider only the first order magnetocrystalline anisotropy constants (K_1', K_1'') of CoIr and CoPt. The magnetostatic energy of the whole magnetic composite grain is negligible since the magnetic grains are designed as cubed shape in which the aspect ratio is 1. The Zeeman potential energy is also negligible when the composite is soft. By varying the thickness of each layer (δ_1, δ_2), one can find the magnetic energy angle independent condition. In this study, the assembly of magnetic zero anisotropy cubes was achieved by laminating [CoIr:SiO_2/CoPt:SiO_2/NiW interlayer] unit layers on top of Ru or NiW seedlayer. Nonmagnetic SiO_2 and NiW interlayers are used for the intergranular and interlayer magnetic exchange decoupling, respectively. An hcp (00.2) Ru or fcc (111) NiW seedlayer provides the epitaxial/dome morphological template for the CoIr/CoPt magnetic composite layer.

II. EXPERIMENT

The films were deposited on a Ta adhesion layer/Si substrates by rf sputtering (Leybold Z-400). The soft magnetic films were fabricated by sputtering CoPt and CoIr alloy targets modified with SiO_2 chips. X-ray diffractometer (XRD) (Phillips X'Pert) and transmission electron microscopy (TEM) (JEOL 2000EX) were used to study the texture and microstructure of the films. A vibrating sample magnetometry (Lake Shore) with the capability of 18 kOe field was used to measure the magnetic properties.

III. RESULTS AND DISCUSSION

A. A multilayer design

An fcc (111) NiW seed layer was sputtered at low Ar working pressure. Both CoPt:SiO_2 and CoIr:SiO_2 films deposited on the NiW seedlayer were confirmed to have hcp (00.2) texture. The measured *MH* loop supports that CoPt:SiO_2 and CoIr:SiO_2 films have easy axis in perpendicular direction (positive K_u) and in the plane (negative K_u), respectively. TEM micrographs showed that NiW grows with a columnar structure and both CoPt:SiO_2 and CoIr:SiO_2 on top follows the NiW columns. The oxide is isolated in the grain boundaries. The average grain size of the deposited layers from the plan view is approximately 6–7 nm. The magnetic films of CoIr:SiO_2 and CoPt:SiO_2 were deposited with different thickness ratios. Figure 2(a) shows when the thickness is 3 nm for each layer, the effective K_1 becomes zero. Having this zero anisotropy condition, the soft magnetic [3 nm CoIr/3 nm CoPt] unit bilayers were repeated five times with and without 2 nm nonmagnetic NiW interlayers. The magnetic layers were sputtered at high Ar working pressure to form the well segregated dome morphology. XRD θ-2θ scan in Fig. 2(b) shows this multilayer structure to have a hcp (00.2) texture and its lattice mismatch is about 4.8% with Ru. The rocking curve on hcp (00.2) peak has full width at half maximum of 4.7°. It is expected to be better than the measured texture because it is underestimated due to their overlapped peak positions. A cross-sectional TEM micrograph confirms a clear columnar structure with dome morphology as thick Ru IL, as shown in Fig. 3(a). The dome morphology improves as the layers are repeatedly laminated. The black cubes describe magnetic zero anisotropy granules that are magnetically isolated horizontally and vertically with

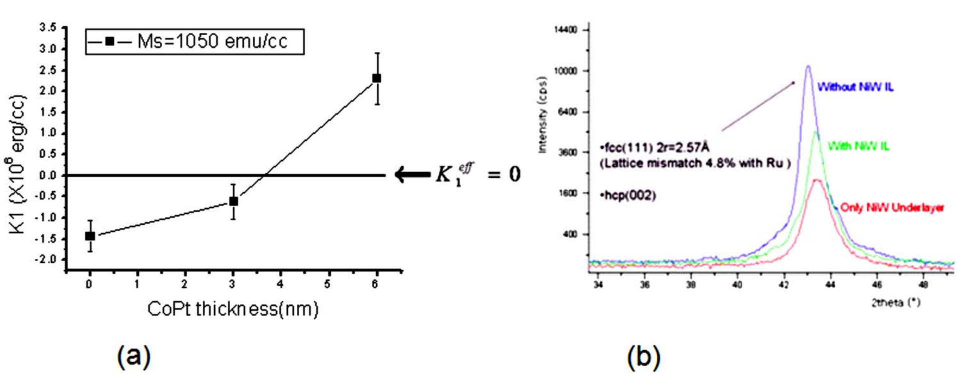

FIG. 2. (Color online) (a) Calculated K_1 from the fitted curve to the simulated *MH* hard axis loop of seed layer /CoIr:$SiO_2$3 nm/CoPt:SiO_2 *x* nm. (b) XRD θ-2θ scan.

Downloaded 01 Apr 2009 to 128.2.132.41. Redistribution subject to AIP license or copyright; see http://jap.aip.org/jap/copyright.jsp

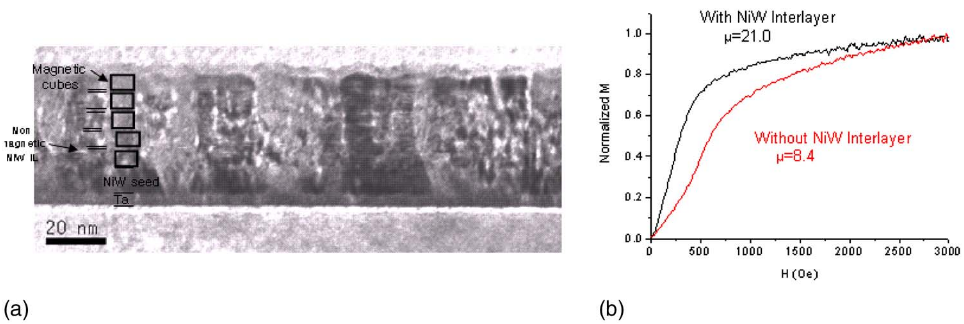

FIG. 3. (Color online) (a) TEM cross-sectional image (b) In-plane initial *M-H* curve for NiW seed/ $[\mathrm{CoIr:SiO_2}3\ \mathrm{nm/CoPt:SiO_2}3\ \mathrm{nm/NiW\ interlayer}\ 0,2\ \mathrm{nm}]_5$ showing the effect of interlayer isolation with NiW interlayers.

nonmagnetic SiO_2 and NiW interlayer, respectively. Figure 3(b) shows the effect of the interlayer magnetic isolation on the soft properties of multilayer structure. The permeability of multilayer with nonmagnetic NiW interlayers ($\mu=21.0$) is larger than the case without NiW interlayers by a factor of about 3, and the measured K_1 was 6.8×10^5 erg/cc. The presence of NiW interlayer helps the structure magnetically softer.

B. A single layer design

For practicality in the fabrication process, a single layer design was devised and fabricated. For better oxide segregation in the initial growth, the double layer design was studied. First, fcc (111) NiW seedlayer 1 (seed 1) was deposited at low Ar working pressure, and Ru or NiW seedlayer 2 (seed 2) was deposited at high Ar pressure to create the dome morphology. A 7 nm CoPt:SiO_2 film was deposited as above to evaluate the degree of oxide segregation. The measured *MH* perpendicular loops (not shown) shows the Ru seed 2 results in a higher H_c, which means Ru seed 2 helps to obtain better crystalline texture (less stacking faults) in CoPt:SiO_2 than NiW seed 2 does. However, the effect on the intergranular exchange decoupling is not evident in that the slope at H_c is not improved by having Ru seed 2. If the oxide segregation is improved by having Ru seed 2, it can be explained that the dome structure is created by the competition between the lateral diffusion and the shadowing effect during the growth. When the diffusion is dominant, the film is rather continuous, while when the shadowing effect is dominant, a rough domelike morphology is developed. Since the diffusivity of Ru is lower than NiW, Ru can create a more distinct dome structure, resulting in the better oxide segregation. However, the contradictory result leads us to conclude that the further optimization study for better oxide segregation is necessary in the future.

A single magnetic composite layer of CoIr:SiO_2 and CoPt:SiO_2 was deposited at high Ar pressure on the double NiW seed layer. The total thickness is fixed as 7 nm in order to keep the aspect ratio of magnetic cube as 1, to minimize the magnetostatic energy. Figure 4 shows the measured *M-H* perpendicular field loop of composite film stack, Ta/NiW seedlayer/CoPt:SiO_2 $(7-x)$ nm/CoIr:SiO_2 x nm. The calculated K_1 of individual CoPt:SiO_2 and CoIr:SiO_2 films are approximately 6.0×10^6 and -5.6×10^6 erg/cc, respectively. In agreement with the zero anisotropy criterion of Eq. (1) and consistent with the condition of a multilayer design, the anisotropy of the composite layers approaches zero when the thickness of each layer is 3–4 nm.

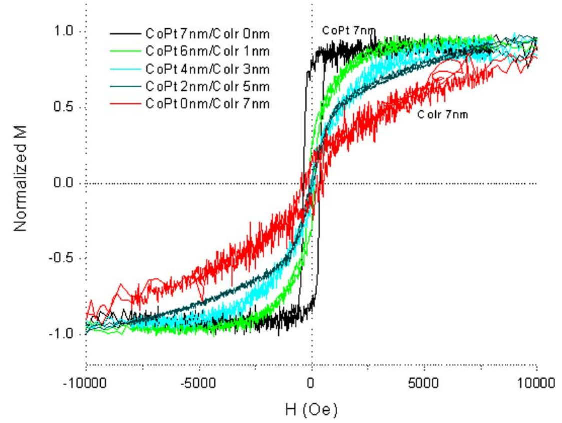

FIG. 4. (Color online) *M-H* perpendicular field loop of composite film stack, Ta/double NiW seed/CoPt:SiO_2 $(7-x)$ nm/CoIr:SiO_2 x nm.

IV. CONCLUSION

To reduce the nonmagnetic Ru IL, various designs of a soft magnetic crystalline interlayer were fabricated. The multimagnetic layer design, $[\mathrm{CoIr/CoPt/NiW\ interlayer}]_n$, and the single magnetic layer design on the double seedlayers were fabricated and evaluated to ascertain if the required crystalline/magnetic properties were achieved. Further fine tuning with design optimization is necessary to achieve better oxide segregation and crystalline texture in magnetic layers.

ACKNOWLEDGMENTS

This work was supported by Williams Advanced Materials, the Data Storage Systems Center, and the Nanofabrication Facility at Carnegie Mellon University.

[1]K.-Z. Gao and H. N. Bertram, IEEE Trans. Magn. **39**, 2995 (2003).
[2]Y. Shimizu and H. N. Bertram, IEEE Trans. Magn. **39**, 1846 (2003).
[3]M. Mochizuki, M. Hara, A. Nakamura, and M. Igarashi, IEEE Trans. Magn. **41**, 3082 (2005).
[4]K. Miura, H. Muraoka, and Y. Nakamura, IEEE Trans. Magn. **37**, 1926 (2001).
[5]G. Choe, M. Zheng, E. N. Abarra, B. G. Demczyk, J. N. Zhou, B. R. Acharya, and K. E. Johnson, J. Magn. Magn. Mater. **287**, 159 (2005).
[6]S. Khizroev and D. Litvinov, J. Appl. Phys. **95**, 4521 (2004).
[7]S. Khizroev, Y. Liu, K. Mountfield, M. Kryder, and D. Litvinov, J. Magn. Magn. Mater. **246**, 335 (2002).
[8]N. Kikuchi, O. Kitakami, S. Okamoto, Y. Shimada, A. Sakuma, Y. Otani, and K. Fukamichi, J. Phys.: Condens. Matter **11**, L485 (1999).

Downloaded 01 Apr 2009 to 128.2.132.41. Redistribution subject to AIP license or copyright; see http://jap.aip.org/jap/copyright.jsp