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Comparison of media properties between hard/soft stacked composite and capping layer perpendicular recording media

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The effect of soft layer thickness (t_{Soft}) of CoTaZr–SiO_2 and low Pt-containing CoCrPtO layers on media properties in hard/soft (H/S) stacked media is compared to media properties in conventional capping layer (CL) media. Coercivity and coercivity squareness in H/S stacked media continuously decrease with increasing t_{Soft}, while they increase in CL media. H/S stacked media with CoTaZr–SiO_2 layers having higher saturation magnetization and in-plane magnetic anisotropy constant exhibit stronger demagnetization effect. Compared to CL media, H/S stacked media with CoCrPtO soft layers improve signal-to-noise ratio and magnetic write width. However, the use of a relatively soft layer deteriorates adjacent track erasure and does not improve media writeability due to compensation effect between softer and harder layers to be used. These phenomena can be understood as undesirable side effects of a soft layer: higher demagnetization field and larger lattice mismatch.

1. Introduction

Perpendicular magnetic recording (PMR) technology has continuously been increasing areal density by advanced design of media and shielded-pole writer and recently demonstrated 520 Gb/in^2 [1]. In current capping layer (CL) [2,3] and coupled granular/continuous (CGC) media [4], higher intergranular exchange coupling constant (A_{ex}) in a top magnetic layer improved the signal-to-noise ratio (SNR) and thermal stability. However, the increase in A_{ex} also increased magnetic write width (MWW) and transition noise, which limit areal density.

In order to further improve media performance, hard/soft (H/S) stacked composite media are in development with the concept of dynamically tilted switching media by introducing incoherent switching via a soft magnetic layer: exchange-coupled composite (ECC) media [5], exchange spring (ES) media [6] and anisotropy graded media [7]. The exchange interaction through the soft layer acting on the hard layer improves media writeability so that the hard layer with higher magnetic anisotropy constant (K_u) can be used. The origin of SNR improvement was due to the reduction of transition jitter by reducing the angular dispersion of anisotropy field (H_k) [6,8]. Wang et al. [9] demonstrated the possible benefits of ECC media with a structure of CoCrPt–SiO_2 (high Pt)/Pt/CoCrPt–SiO_2 (low Pt) showing SNR comparable to a conventional CL medium. H/S stacked media with a thin soft layer directly coupled on a hard layer showing coherent switching behavior was proposed [10]. Simulation result [11] reported the effect of grain boundary width controlled by oxide content on SNR in a hard(6 nm)/soft(7 nm) structure with strong interlayer exchange coupling strength (J_{IL}) of 10 erg/cm^2 and showed a high potential for 1 Tb/in^2. From the simulated results [5–8,11], SNR improvement and narrower MWW are anticipated while maintaining good media writeability and sufficient thermal stability (K_uV/kT). However, H/S stacked media showed experimental results of positive nucleation field (H_n) [9,12] and relatively low negative H_n [10] compared to CL media. A more negative value of H_n is essential for overcoming adjacent track erasure (ATE) and return field-induced partial erasure (RFPE) [13,14].

The magnetic switching mechanism in H/S stacked media depends on the ratio of K_u of hard and soft magnetic layers, A_{ex}, t_{Soft}, and J_{IL}. Magnetic switching behavior is currently estimated from the angular dependence of the switching field [15]. Existence of reversible magnetization switching can be used as evidence of incoherent rotation as shown in $(Co_{74}Pt_{22}Ni_4)_{73}$-oxide$_{27}$/Ni-oxide stacked media [12]. All the H/S stacked media assume well-isolated grains in the entire magnetic layer but it is hard to get perfectly well-isolated grains. Inaba et al. [16] reported degradation of grain isolation and existence of in-plane magnetization when a soft layer was thicker than a critical thickness of 7 nm in CoPtCr–SiO_2/(Co, CoCr, or NiFe)–SiO_2 stacked media. The large difference in normalized remanent coercivity ($H_{cr\ 45^\circ}/H_{cr\ 0^\circ}$) between theoretical and experimental values in single layer media is currently explained by the angular dispersion of the easy axes [17] and thermal fluctuation [18]. However, high values

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of $H_{cr\ 45^\circ}/H_{cr\ 0^\circ} > 0.67$ are still observed even though very narrow crystallographic *c*-axis distribution of $< 2^\circ$ is achieved in CoCrPt–SiO$_2$ single-layer media. This phenomenon was mostly due to the formation of the highly exchange-coupled initial thin layer on top of Ru [19], which led to significant incoherent switching behavior and large magnetic activation volume. It indicates that the contribution of incoherent switching via a soft top layer can be mixed with the contributions caused by non-uniform microstructure.

The use of a soft top layer in H/S stacked media provides both benefits and undesirable side effects. A soft top layer needs well-isolated grains, magnetic *c*-axis orientation, and hetero-epitaxial growth on a hard layer. It typically has high saturation magnetization (M_s), low K_u, and larger lattice mismatch between hard and soft layers. Values of J_{IL} are particularly sensitive to the degree of hetero-epitaxial growth between hard and soft layers, which can affect switching field distribution and angular dependence of switching field. Stronger J_{IL} and less A_{ex} can maximize benefits for H/S stacked media [8], but a 10% dispersion of J_{IL} led to a loss of 0.7 dB SNR [20]. Higher M_s and A_{ex} and less J_{IL} in a soft top layer will provide strong demagnetization fields, resulting in low H_n. This causes an increase in dc noise and ATE. It was reported [5] that a soft layer with in-plane K_u provides much smaller thermal energy barrier than a soft layer with out-of-plane K_u. In this paper, the effect of t_{Soft} on media properties in H/S stacked media with two kinds of soft top layers of CoTaZr–SiO$_2$ and low Pt-containing CoCrPtO alloys is investigated and compared to media properties in conventional CL media [3].

2. Experiment

Two different H/S stacked media, HS1 and HS2, were prepared for this study as summarized in Table 1 and compared with conventional CL media described elsewhere [3]. HS1 and HS2 start with the same Mag1 bottom layer, 9 nm-thick CoCrPt-oxide with a hexagonal close packed (HCP) structure. This Mag1 layer has $H_c = 7.2$ kOe, $K_uV/kT = 101$, $H_k \sim 15$ kOe, and $M_s \sim 350$ emu/cm^3. These values are significantly higher than $H_c = 4.4$ kOe and $K_uV/kT = 60$ of an 11-nm-thick CoCrPt-oxide bottom layer in CL media [3], because Mag1 in H/S stacked media should have higher K_u than single-layer media for providing equivalent K_uV/kT. Two kinds of soft top layers are used for comparison. For HS1, an amorphous CoTaZr–SiO$_2$ single layer only on top of Ru interlayer shows in-plane $H_k \sim 20$ Oe and $M_s \sim 700$ emu/cm^3. For HS2, a low Pt-containing HCP CoCrPtO single layer only exhibits out-of-plane $H_k \sim 5$ kOe and $M_s \sim 500$ emu/cm^3. Estimated values of $K_{u\ Hard}/K_{u\ Soft}$ are 370 for CoTaZr–SiO$_2$ in HS1 and 2 for CoCrPtO in HS2.

Table 1
Description of the two H/S stacked media types of HS1 and HS2 studied here

Hard/soft stacked media	HS1	HS2
Mag2 (Soft)		
Composition	CoTaZr-SiO$_2$	CoCrPto (low Pt)
Phase	Amorphous	HCP
H_k (kOe)	0.02 (in-plane)	5 (out-of-plane)
M_s (emu/cm^3)	700	500
$K_{u\ Hard}/K_{u\ Soft}$	370	2
Mag1 (Hard)	CoCrPt-oxide-based alloy	
Composition		
Phase	HCP	
H_k (kOe)	15 (out of plane)	
M_s (emu/cm^3)	350	
K_uV/kT	101	

Mag1 and Mag2 are the bottom hard and top soft magnetic layers in H/S stacked media, respectively.

A 9-nm-thick CoCrPt-oxide bottom layer (Mag1) was prepared by reactive sputtering on NiP-plated Al substrates. The thickness of Mag2 (t_{Soft}) varied from 0.0 to 7.5 nm for HS1 and from 0.0 to 12.0 nm for HS2, while all other layer thicknesses were fixed. Ru(24 nm)/Ta(2 nm) was used as an interlayer and anti-parallel coupled soft magnetic underlayer thickness was 90 nm. Microstructure was observed by transmission electron microscopy (TEM). Polar magneto-optic Kerr effect (MOKE) magnetometer, vibrating sample magnetometer (VSM), and alternating gradient magnetometer (AGM) were used to measure magnetic properties. Media recording performance was evaluated on a spin-stand tester at 7200 rpm using a trailing shielded-pole writer/tunneling magneto-resistive reader.

3. Results and discussion

Fig. 1 shows the effect of the CL thickness (t_{Cap}) or t_{Soft} on (a) H_c, (b) coercivity squareness (S^*), and (c) H_n in CL media and H/S stacked media with CoTaZr–SiO$_2$ (HS1) and CoCrPtO (HS2) soft layers. In CL media, H_c uniquely increases with increasing t_{Cap} and then decreases. However, H/S stacked media do not show the peak of H_c with increasing t_{Soft} (Fig. 1(a)). The decrease in H_c is accelerated when a CoTaZr–SiO$_2$ layer with higher M_s and in-plane K_u is used. The increase in H_c with increasing t_{Cap} in CL media was mostly understood by the enhanced K_uV/kT, and it was maximized when the CL had similar K_u as the hard bottom layer [3]. Values of S^* continuously increase with increasing t_{Cap} in CL media, while they decrease in H/S stacked media (Fig. 1(b)). The increase in S^* in CL media was explained by enhancement of A_{ex} in the CL [3]. Compared to a CoCrPtO top layer, a CoTaZr–SiO$_2$ layer maintains similar S^* up to $t_{Soft} = 5$ nm and then S^* significantly decreases. In Fig. 1(c), H/S stacked media initially have high H_n of > -2.5 kOe due to the contribution of the hard layer with high H_c and S^* compared to values in CL media. However, values of H_n continuously decrease with increasing t_{Soft}. A CoTaZr–SiO$_2$ soft layer reduces H_n faster than a CoCrPtO layer and shows positive H_n at $t_{Soft} \geqslant 7.3$ nm due to the significant decrease in H_c and S^* in Fig. 1(c). There is no peaking effect of H_n with increasing t_{Soft} in H/S stacked media.

Values of H_n are determined by contributions of H_k in the soft layer itself, exchange field from the hard layer, lateral A_{ex}, and demagnetization field from grain shape itself and neighbor grains. When demagnetization fields are greater than H_n, magnetizations in a soft layer can be tilted statically and exhibit reversible minor hysteresis loops. The HS1 medium with a 10-nm-thick CoTaZr–SiO$_2$ showing positive H_n was chosen for recoil Kerr measurement. The result in Fig. 2(b) is compared with the results of conventional CL (Fig. 2(a)) and the HS2 medium with a 12-nm-thick CoCrPtO layer (Fig. 2(c)). The HS1 medium with a 10-nm-thick CoTaZr–SiO$_2$ layer clearly shows reversible minor loops, while the HS2 medium with a 12-nm-thick CoCrPtO layer exhibits irreversible minor loops. It suggests that CoCrPtO has less demagnetization field than CoTaZr–SiO$_2$. However, values of negative H_n are still low compared to CL media. Thus, the HS2 media with the CoCrPtO soft layer are chosen for further comparison.

Effect of t_{Cap} or t_{Soft} on K_uV/kT in CL media and HS2 media with a CoCrPtO layer is shown in Fig. 3. The initial value at $t_{Soft} = 0$ nm in HS2 media is significantly increased to 101 compared to 55 in CL media due to contribution of the bottom layer with high H_c. Values of K_uV/kT in HS2 media are not improved at $t_{Soft} \leqslant 4$ nm but considerably increased to ~ 170 at $t_{Soft} \geqslant 10$ nm, while values in CL media are continuously increased from 55 at $t_{Cap} = 0.0$ nm to 92 at $t_{Cap} = 8.3$ nm. Less improvement in K_uV/kT at $t_{Soft} \leqslant 8$ nm can be understood by less contribution of a soft layer with low K_u