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A soft magnetic underlayer with negative uniaxial magnetocrystalline anisotropy for suppression of spike noise and wide adjacent track erasure in perpendicular recording media

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The suppression of spike noise and wide adjacent track erasure (WATE) are important technical issues in the development of a perpendicular recording medium (PRM). As a solution to both of these problems, this paper presents a type of soft magnetic underlayer (SUL) with negative uniaxial perpendicular magnetic anisotropy. The magnetic anisotropy is achieved by employing a material with negative uniaxial magnetocrystalline anisotropy (K_u^{grain}). WATE is suppressed in the SUL by realizing wide distribution of magnetic flux below the edge of the return yoke, while spike noise is eliminated by ensuring the formation of a Néel wall instead of a Bloch wall in SUL domains. CoIr with the disordered hcp structure is selected as a negative K_u^{grain} material, and *c*-plane-oriented CoIr films with various Ir contents are prepared for experimental evaluation. Among the films tested, the CoIr film with 22 at. % Ir is found to provide the minimum K_u^{grain} value of -6×10^6 ergs/cm^3. Under a field applied parallel to the film plane, this film exhibits soft magnetic properties, attributable to the high crystallographic symmetry of the *c*-plane sheet texture. A PRM fabricated using the CoIr SUL is confirmed to display substantially lower spike noise and WATE compared to conventional structures. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2177126]

I. INTRODUCTION

In a perpendicular recording medium (PRM), a soft magnetic underlayer (SUL) with thickness (d_{SUL}) of greater than 50 nm is indispensable considering a magnetic circuit in writing. Thick SULs introduce serious technical problems: spike noise and wide adjacent track erasure (WATE). Spike noise is random noise in the readout signal in the time domain, and WATE occurs over a range of several micrometers in the off-track direction. For suppressing spike noise, the formation of a single-domain structure over the whole disk-shaped SUL stacked on or under an antiferromagnetic layer is known to be effective by preventing the formation of a Bloch wall in the SUL in the zero-field state.[1] On the other hand for suppressing WATE, a multilayered SUL with magnetic moments aligned antiparallel by the Runderman-Kittel-Kasuya-Yoshida (RKKY) coupling has been reported to be effective.[2] However, the combination of these two solutions[3] requires a larger number of fabrication processes and results in degradation of heat resistance by interlayer atomic diffusion. This paper examines a SUL material that can be fabricated by a simple process and which suppresses both spike noise and WATE.

II. DESIGN CONCEPT

For the suppression of both WATE and spike noise, a SUL with negative perpendicular magnetic anisotropy energy ($K_{u\perp}$) is considered. Here, $K_{u\perp}$ refers to the uniaxial magnetic anisotropy energy with symmetric axis perpendicular to the film plane and does not include self-energy caused by the demagnetization field.

First, mechanism of suppression of WATE is discussed. Figure 1 illustrates the local magnetic moments in SUL composed of a conventional soft magnetic material ($K_{u\perp}=0$) and the proposed material ($K_{u\perp}<0$). The recording layer is omitted for clarity. Judging from the erasure region, WATE appears to originate from the concentration of the magnetic flux on the edge of the return yoke in writing [see area α in Fig. 1(a)]. Therefore, it should be possible to suppress WATE by realizing wide distribution of magnetic flux around the return

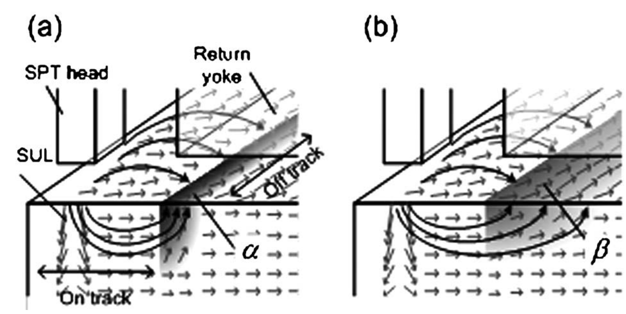

FIG. 1. Schematic of local magnetic moments in a SUL composed of materials with (a) $K_{u\perp}=0$ (conventional SUL) and (b) $K_{u\perp}<0$ (proposed SUL). The gray and black arrows denote local magnetic moments and magnetic flux, respectively.

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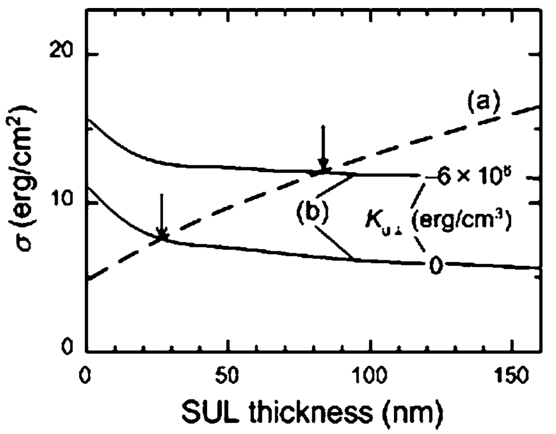

FIG. 2. Dependence of energy density of domain wall (σ) on SUL thickness for (a) Néel-type walls (broken line) and (b) Bloch-type walls (solid line) in films with negative $K_{u\perp}$. The arrow denotes the maximum SUL thickness for Néel wall formation ($d_{\rm crt}$) for the case of $K_{u\perp}=0$ and -6×10^6 ergs/cm^3.

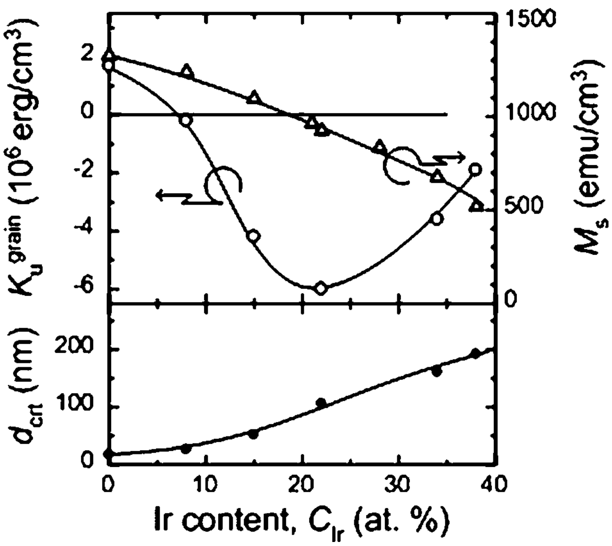

FIG. 3. (Upper) M_s and $K_u^{\rm grain}$ and (lower) $d_{\rm crt}$ for c-plane-oriented CoIr films as a function of $C_{\rm Ir}$.

yoke, which can be achieved by reducing the local susceptibility of the SUL in the film-normal direction ($\chi_\perp$) [see area β in Fig. 1(b)]. Assuming a self-energy of $2\pi M_s^2$ and a homogeneous external field, $\chi_\perp$ for the proposed SUL can be expressed as $\chi_\perp = M_s/[2(2\pi M_s^2 - K_{u\perp})]$. The distribution of magnetic flux can thus be controlled by changing $K_{u\perp}$.

Next, elimination of spike noise is discussed focusing on a structure of 180° domain wall. In general, the dominant origin of spike noise is considered to be the leakage flux from the Bloch wall toward the reading head. Therefore, even if a 180° domain wall exists in a SUL in the zero-field state, the formation of a Néel wall instead of a Bloch wall will effectively reduce leakage flux. Figure 2 shows calculations of the dependence of $d_{\rm SUL}$ on the energy density of domain walls with Néel (σ_N) and Bloch (σ_B) types. σ_N and σ_B are calculated by

$$\sigma_N = dK_u^{\rm inp}/2 + \pi^2 A/d_{\rm wall} + d_{\rm wall} d_{\rm SUL}\pi M_s^2/(d_{\rm wall}+d_{\rm SUL}), \quad (1)$$

$$\sigma_B = d(K_u^{\rm inp} - K_{u\perp})/2 + \pi^2 A/d_{\rm wall} + d_{\rm wall}^2 \pi M_s^2/(d_{\rm wall}+d_{\rm SUL}), \quad (2)$$

where $d_{\rm wall}$, $K_u^{\rm inp}$, and A denote the domain-wall thickness, in-plane uniaxial magnetic anisotropy energy, and exchange stiffness constant, respectively. The values of $K_u^{\rm inp}$ and A used in the calculation were 5.0×10^3 ergs/cm^3 and 1.0×10^{-6} ergs/cm, respectively, which are typical values for soft magnetic materials. σ_B for $K_{u\perp}=0$ and -6×10^6 ergs/cm^3 can be easily calculated (solid lines in Fig. 2). Since a negative $K_{u\perp}$ term appears in Eq. (2) for σ_B, the decrease in $K_{u\perp}$ to negative values leads to an increase in σ_B. In the small $d_{\rm SUL}$ region, the value of σ_N is smaller than σ_B, indicating that a Néel wall is formed stably in a thin SUL. Here, the maximum thickness of a SUL in which a Néel wall will form stably ($d_{\rm crt}$) is defined from the intersection of the lines for σ_N and σ_B. With decreasing $K_{u\perp}$ from 0 to -6×10^6 ergs/m^3, $d_{\rm crt}$ increases from 25 to 80 nm, demonstrating that a Néel wall can be formed in the thickness range of practical SULs.

III. USE OF COIR TO REALIZE A SUL WITH NEGATIVE $K_{U\perp}$

To realize a SUL with negative $K_{u\perp}$, a negative $K_u^{\rm grain}$ material with c-plane sheet texture is employed. The materials with uniaxial crystallographic anisotropy, such as α'-Fe-C,[4] dhcp-CoFe,[5] NiAs-type $Mn_{50}Sb_{50}$,[6] and hcp-CoIr,[7] are known to exhibit negative $K_u^{\rm grain}$ at room temperature. In this study, CoIr with the disordered hcp structure was selected due to its high M_s, phase stability, and suitability for film preparation. The CoIr films were fabricated by dc cosputtering with Co and Ir targets. The compositions of the CoIr films were controlled by adjusting the discharge power for each target and were checked after preparation by x-ray fluorescence (XRF) analysis. To obtain a c-plane sheet texture, a Ta(10 nm)/Pt(10 nm)/Ru(10 nm) layer sequence was sputtered on the glass substrate in advance as seed layers. $K_u^{\rm grain}$ was evaluated from the saturated torque coefficient of the twofold components obtained by extrapolating the coefficient versus $1/H$ curves to $H\to\infty$.[8] Figure 3 shows the change in saturation magnetization (M_s) and $K_u^{\rm grain}$ for the c-plane-oriented CoIr films as a function of Ir content ($C_{\rm Ir}$). As $C_{\rm Ir}$ increases from 0 to 38 at. %, M_s decreases monotonically from 1350 to 700 emu/cm^3 and $K_u^{\rm grain}$ reaches a minimum value of -6×10^6 ergs/cm^3 ($C_{\rm Ir}$=22 at. %). Note that $K_u^{\rm grain}$ is negative in the region of $C_{\rm Ir}\geqslant 7$ at. %. This result indicates that the $K_{u\perp}$ of CoIr SUL is tunable by changing $C_{\rm Ir}$ according to the specification of the write head. Figure 3 also shows the calculated values of $d_{\rm crt}$ using the experimentally obtained values of M_s, $K_u^{\rm grain}$, and an exchange stiffness constant (A) of 1.0×10^{-6} erg/cm. With increasing $C_{\rm Ir}$, $d_{\rm crt}$ increases monotonically to 50 nm at $C_{\rm Ir}$=10 at. % and 192 nm at $C_{\rm Ir}$=38 at. %. These results indicate that the Néel wall is more stable than the Bloch wall even in films thicker than 50 nm when this c-plane-oriented negative $K_u^{\rm grain}$ material is employed. The coercivities measured in the easy- and hard-magnetization directions (in the film plane) are 28 and 20 Oe at $C_{\rm Ir}$=18 at. %, respectively, indicating a relatively soft magnetic material. This soft magnetism is considered to be due to the sheet texture with high crystallographic symmetry. To realize even softer magnetism in the film-plane direction of such *c*-plane-oriented CoIr films, further reductions in grain size will be necessary, approaching the scale at which nanocrystalline effects may be utilized.[9]

IV. VERIFICATION OF WATE SUPPRESSION

As the suppression of spike noise in CoIr SULs with thickness below d_{crt} has already been reported,[10] the present paper will focus on WATE suppression. For evaluation, a film with a stacking structure of glass substrate/Ta(5 nm)/Pt(6 nm)/SUL/Ta(5 nm)/Pt(6 nm)/Ru(20 nm)/$CoPtCr-SiO_2$(10 nm) was fabricated by dc magnetron sputtering. The composition of the SUL was varied by changing the alloy target composition ($Co_{95}Ir_5$, $Co_{90}Ir_{10}$, and $Co_{85}Ir_{15}$). The effective thickness of the SUL ($B_s d$) was fixed at 120 T nm. For the media examined in this study, the hysteresis loops measured by the Polar Kerr equipment show that the magnetic properties of the recording layer are largely independent of the Ir content of the SUL (H_c=3 kOe, H_n=−1.3 kOe). WATE was measured by the following procedure: a 133 kfci signal was recorded with a write current (I_w) of 58 mA over 50 tracks, a 500 kfci signal was then rewritten 10 000 times only at the center track, and the off-track profile of the 133 kfci differential signal was measured. When rewriting the 500 kfci signal, I_w was varied from 24 to 40 and 58 mA. These writing conditions are enough for saturation recording. In the off-track profile, WATE and ATE phenomena overlap: ATE occurs near the center track due to saturation of the writing head and WATE occurs over a range of several micrometers. To evaluate these two erasures separately, the ATE ratio (ATER) and WATE ratio (WATER) are defined as ATER$=Y/(Y-Z)$ and WATER$=Y/X$, where X is the integral signal power prior to 500 kfci recording, Y is the uniformly erased signal power in the range of several micrometers after 10 000 times recording of the 500 kfci signal, and Z is the erased signal power around the center track after 10 000 times recording of the 500 kfci signal (see Fig. 4 inset). Figure 4 shows the change in ATER and WATER as a function of C_{Ir} for various I_w. ATER is independent of C_{Ir}, yet decreases from 15% to 3% as I_w decreases from 58 to 24 mA. On the other hand, WATER decreases monotonically with increasing C_{Ir}. Especially in the case of I_w=24 mA, WATER is reduced extremely from 20% to 7% as C_{Ir} increases from 6 to 18 at. %. These results clearly indicate that negative K_u^{grain} is effective for suppressing WATE.

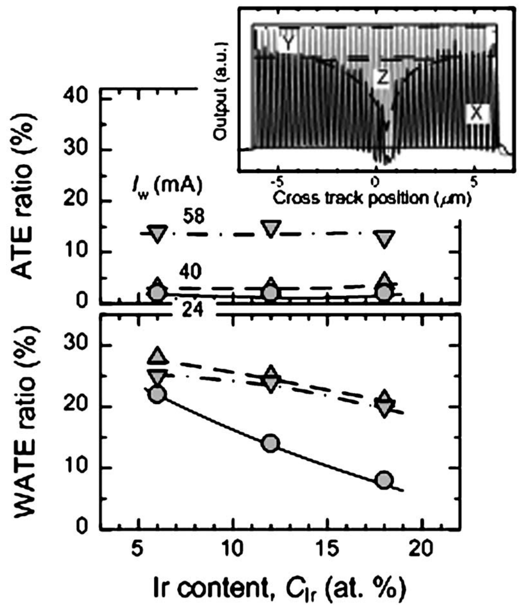

FIG. 4. Change in (upper) ATER and (lower) WATER as a function of C_{Ir} for PRM with CoIr SUL under write currents (I_w) of 24 (○), 40 (△), and 58 mA (∇). (Inset) Typical off-track profile. The gray and black lines denote initial signal power and signal power after rewriting center track, respectively.

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[1] S. Takahashi, Y. Yamakawa, and K.Ouchi, J. Magn. Soc. Jpn. **23**, 19 (1999).
[2] B. R. Acharya, J. N. Zhou, M. Zheng, G. Choe, E. N. Abarra, and K. E. Johnson, IEEE Trans. Magn. **40**, 2383 (2004).
[3] K. Tanahashi, R. Arai, and Y. Hosoe, IEEE Trans. Magn. **41**, 577 (2005).
[4] M. Takahashi, Y. Takahashi, and H. Shoji, IEEE Trans. Magn. **37**, 2179 (2001).
[5] M. Takahashi and S. Kadowaki, J. Phys. Soc. Jpn. **48**, 1391 (1980).
[6] T. Okita and Y. Makino, J. Phys. Soc. Jpn. **25**, 120 (1968).
[7] N. Kikuchi, O. Kitakami, S. Okamoto, Y. Shimada, A. Sakuma, Y. Otani, and K. Fukamichi, J. Phys.: Condens. Matter **11**, L485 (1999).
[8] S. Saito, D. Hasegawa, F. Hoshi, D. D. Djayaprawira, and M. Takahashi, Appl. Phys. Lett. **80**, 811 (2002).
[9] M. Takahashi and T. Shimatsu, J. Magn. Magn. Mater. **101**, 11 (1991).
[10] A. Hashimoto, S. Saito, and M. Takahashi, J. Magn. Soc. Jpn. **30**, 135 (2006).