High Magnetization Exchange-Couple Double-Layer TbFeCo for Magnetic Flux Reading Optical Recording

Chao-Cheng Lin, Chih-Huang Lai, B. M. Chen, and Han-Ping D. Shieh

***Abstract*—High magnetization (Mr) and enhanced coercivity magneto-optical (MO) recording media TbFeCo (TFC) were investigated for hybrid magnetic flux reading/optical recording due to their large magnetic flux. To increase the stability of high Mr TFC media, dual-layer disks composed of TM-rich readout layer with saturation magnetization (Ms) $= 370$ emu/cm^3 and RE-rich memory layer were fabricated. Coercivity and interface energy between double layers as a function of active layer thickness were examined. By simulating thermo-magnetic writing, the dual-layer media were shown to be applicable for optical writing/magnetic flux reading recording.**

***Index Terms*—Coercivity, hybrid magnetic flux reading/optical recording, magnetic flux, magnetization.**

I. Introduction

Amorphous rare-earth transition-metal (RE-TM) films have been considered as a candidate for ultra-high density storage media because of amorphous structure, high perpendicular anisotropy, and simple deposition processes at room temperature. In conventional magneto-optical (MO) recording, to reach higher recording density, shorter wavelength laser beams are needed for detecting small size marks; however, the readout signal level is still low due to small mark size. On the other hand, the GMR readout sensor in hard disk drive has much higher sensitivity in reading small marks. Unfortunately, as the size of recording bits of longitudinal media decreases to several tens nm, the recorded marks become unstable due to super-paramagnetic effect. Combining both advantages of thermo-magnetic writing and magnetic flux detection and using perpendicular MO media, the hybrid recording renders great potential for high-density storage [1], [2].

Higher Mr media are desired to yield larger flux density for GMR sensing. To ensure adequate stability of small size domains, the media for hybrid recording should possess large coercivity. Commonly used single-layer MO film can not meet these requirements since net magnetization of the films must be small at room temperature in order to diminish the influence of demagnetic field in thermo-magnetic writing process.

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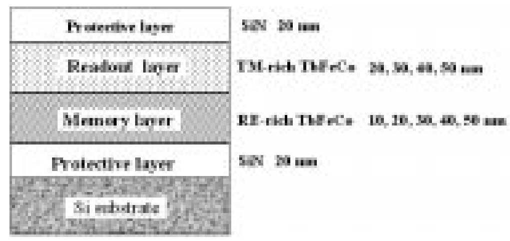

Fig. 1. TFC dual-layer media structure.

Exchange-coupled dual-layer (ECDL) films have been investigated as conventional MO recording media [3], [4]. Yet, Mr and coercivity reported are not adequate to yield higher flux density and to ensure domain stability simultaneously. In this paper, we designed, fabricated, and examined the dual-layer media, composed of high Mr TM-rich readout layer and RE-rich memory layer, with large coercivity for hybrid recording. Furthermore, the enhanced coercivity and interface energy between RE/TM dual layers were examined.

II. Experiments

The dual-layer TFC media are composed of TM-rich readout layer with Ms $= 370$ emu/cm^3, Mr $= 335$ emu/cm^3, $Hc =$ 0.95 kOe, and Curie temperature $(T_{\rm Curie}) = 200$ °C; RE-rich memory with Mr $= 113$ emu/cm^3, $Hc = 4.6$ kOe, and $T_{\rm Curie} =$ 270 °C, shown schematically in Fig. 1. These two layers were sandwiched by SiN protective layers to prevent TFC from oxidation. All of the media were fabricated by magnetron sputtering. The thicknesses of readout and memory layers were varied from 0 to 50 nm. A magneto-optical Kerr effect tracer (MOKE) and a vibrating sample magnetometer (VSM) were used to measure magnetic properties of the fabricated disk media.

III. Results and Discussion

A. Dual-Layer Structure MO Disk Media

The use of dual layer films greatly enhances coercivity of high Mr media because of strong exchange coupling at the interface between two active layers. Fig. 2 depicts the hysteresis loop of single TM-rich layer with saturation magnetization of 370 emu/cm^3 and low coercivity of 0.95 kOe. A VSM measurement on the medium with substrate/SiN(20 nm)/RE-rich memory layer(20 nm)/TM-rich readout layer(20 nm)/SiN(20 nm) is plotted in Fig. 3, where the vertical axis denotes the sum of the products of magnetization

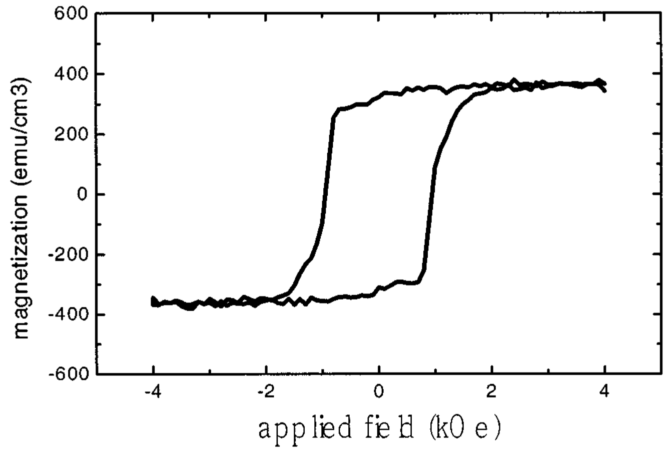

Fig. 2. Hysteresis loop of single TM-rich layer with 20 nm.

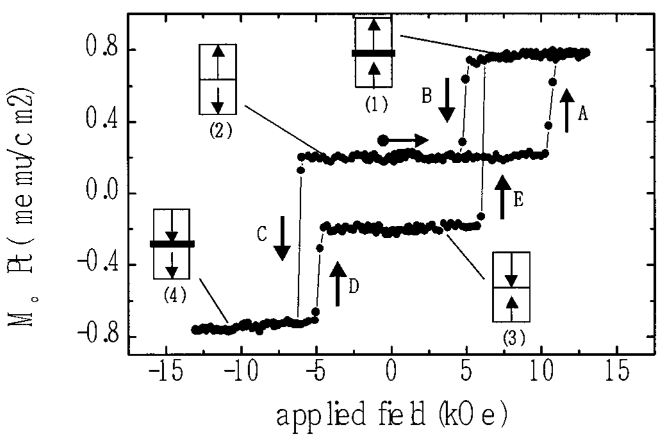

Fig. 3. VSM measurement of exchange coupling film with 20 nm memory layer (RE-rich)/20 nm readout layer (TM-rich). The initial state is in state (2). The field was applied following the ABCDE sequence indicated by the arrows. [The details of moment configurations for state (1) to (4) are shown in Fig. 4.]

and layer thickness $(M \cdot t)$ of both readout and memory layers. Effective coercivity was increased from 0.95 to 6 kOe when a 20 nm memory layer was added. The squareness of hysteresis loop shown in Fig. 3 is larger than that of single-layer medium with high Mr, resulting in Mr equals Ms. According to the measurement, the $\mathrm{Ms} \cdot t$ of dual layers is lower about 20% than the sum of two individual layers because of the interfacial wall formation at the interface. Although net $\mathrm{Mr} \cdot t$ of dual-layer medium is low due to antiparallel magnetization of TM-rich and RE-rich layer, high Mr of upper readout layer effectively enhances readout signal because most magnetic flux sensed by MR/GMR heads is contributed from the upper 20 nm of recording layer, while the bottom memory layer has very little contribution in flux density.

On the other hand, Fig. 3 also reveals strong exchange coupling force in dual-layer films. A micromagnetic model established by Kobayashi *et al.* has been widely employed to analyze magnetization reversal mechanism of RE-TM exchange-coupling dual-layer (ECDL) films [5]. For the RE-rich (readout)/TM-rich (memory) dual layer films of antiparallel type (A-type), there are four possible magnetization states, (1), (2), (3), and (4), shown in Fig. 4. Upon external fields, these

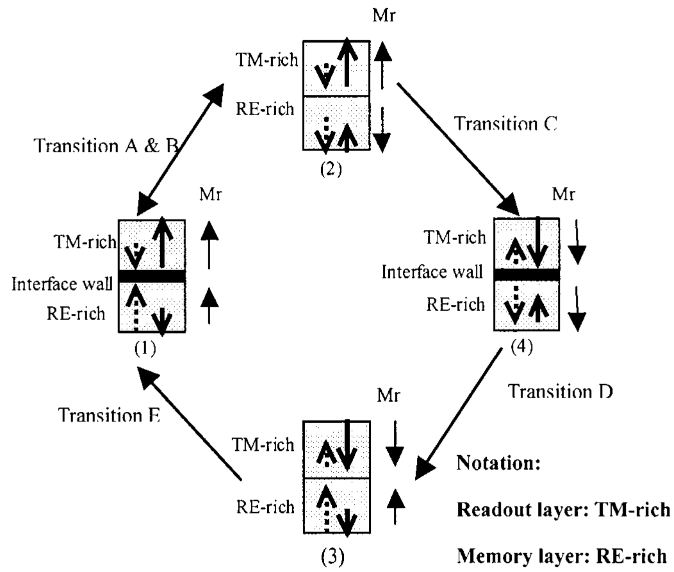

Fig. 4. Switching paths between the four magnetization states of antiparallel type ECDL films. (Transitions A, B, C, D, and E are indicated in Fig. 3.)

states transform each other to reach a minimum magnetostatic energy state, resulting in different magnetization reversal paths. As shown in Fig. 3, when the applied field increases gradually from 0 to 13 kOe, the initial state (2) turns into (1) where the moments of memory layer reverse. If the field decreases from 13 to -13 kOe, the state changes from (1) to (2), and then (4). As the field is applied from -13 to 13 kOe, the state (4) reverses to (3), and then (1). The magnetization reversal path depends on the condition derived from the following equation:

$$Hc_2 + Hc_1 > (\sigma_w/2M_2t_2) - (\sigma_w/2M_1t_1) > Hc_2 - Hc_1 \cdots \tag{1}$$

where

1 and 2	are respectively for readout (TM-rich) and memory (RE-rich) layers,
Hc	is coercive field,
M	is magnetization,
t	is layer thickness, and
σ_w	is interface energy [5].

The coercivity enhancement of high Mr media by using RE-rich/TM-rich dual-layer structure is due to the formation of interface wall at positive and negative saturation fields. As shown in Fig. 3, the effective coercivity of readout layer Hc_R, the absolute magnitude of switching field for transition C and E, is given by:

$$Hc_R = Hc_1 + \sigma_w/2M_1t_1 = Hc_1 + H_{b1} \cdots \tag{2}$$

where exchange bias field (H_b) is equal to $\sigma_w/2M_1t_1$. The switching fields for transition A, B, and D can be derived as:

$$Hc_A = Hc_2 + \sigma_w/2M_2t_2 \cdots \tag{3}$$

and

$$Hs_B = -Hc_2 + \sigma_w/2M_2t_2 \cdots \tag{4}$$

and

$$Hc_D = Hc_2 - \sigma_w/2M_2t_2 \cdots . \tag{5}$$

From (3) and (4), and the Mt value from VSM measurement, the interface energy for 20 nm memory layer and 20 nm readout layer is about 4.1 erg/cm^3.

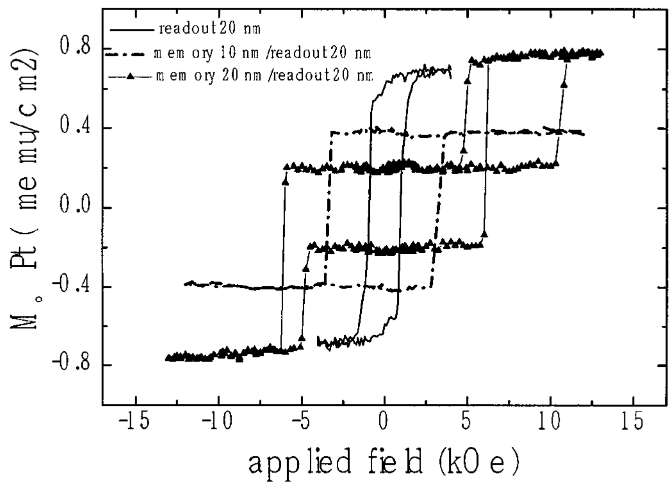

Fig. 5. VSM measurement of dual-layer media with different memory layer thickness.

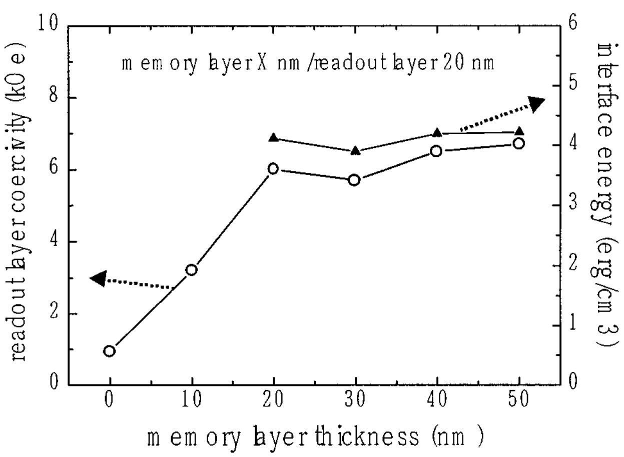

Fig. 6. Memory layer thickness dependence of readout layer coercivity and interface energy.

B. Thickness Dependence of Enhanced Coercivity and Interface Energy

Thickness of active layers affects significantly magnetic properties of ECDL films. To explore how thickness of active layers affects effective coercivity and interface energy, a series of media with different thickness were fabricated and examined. First, with readout layer 20 nm, the magnetization curves for different thickness of the memory layer are shown in Fig. 5. Coercivity and interface energy as a function of memory layer thickness are shown in Fig. 6. Magnetic properties of the above media depend strongly on the thickness of the memory layer (t_m) as revealed in Fig. 5. At $t_m = 10$ nm, the hysteresis loop exhibits larger Hc than that of single readout layer because of biasing effect from the memory layer. When $t_m = 20$ nm, the coercivity of readout layer increases from 0.95 kOe in single-layer medium to 6 kOe in dual-layer media. The enhanced coercivity of readout layer is due to the formation of domain wall at the interface of the double-layer. When $t_m > 20$ nm, readout layer coercivity almost keeps constant as shown in Fig. 6. On the other hand, interface energy exhibits less dependence upon thickness and maintains the value around 4.1 erg/cm^3, implying that the interface energy mainly be related with exchange interaction at the interface for ECDL films. Once the interface wall is formed, further increase in memory layer thickness no longer affects the exchange interaction at the interface. As a result, readout layer coercivity becomes constant because of unvaried H_{b1}. For comparison, readout layer thickness dependence of interface energy and coercivity is plotted in Fig. 7, where readout layer coercivity is smaller for thicker films because H_{b1} is inversely proportional to thickness, but interface energy is independent on readout layer thickness.

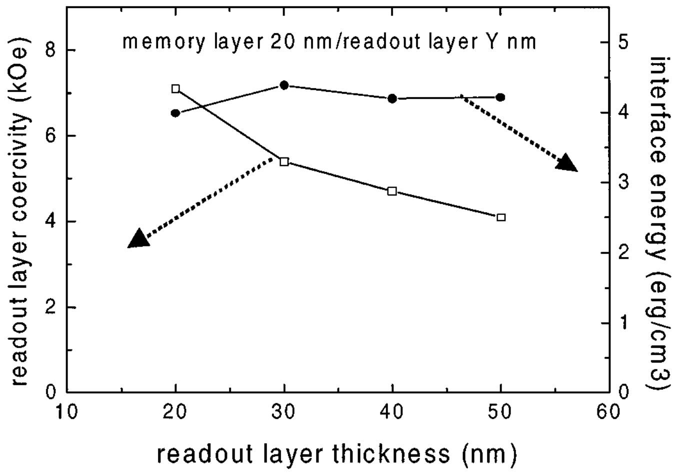

Fig. 7. Readout layer thickness dependence of readout layer coercivity and interface energy.

C. Simulating Writing Process in Experiments

Experiments were performed to simulate thermo-magnetic writing in order to explore the feasibility of dual layer medium for hybrid recording. Mr of the media with dual layer structure, saturated at 230 °C by a magnetic field of 200 Oe and then quenched it down to room temperature without a magnetic field, is the same as that of the media initialized by 10 kOe at room temperature. The result strongly suggests that the magnetization direction of memory layer determined at writing temperature can be effectively exchanged-coupled to readout layer for desired magnetization switching.

IV. Conclusions

RE/TM exchange-couple dual layer media with high Mr of 370 emu/cm^3 and large coercivity were investigated for hybrid recording. Through exchange interaction between TM-rich readout layer and RE-rich memory layer, the coercivity of the high Mr TFC could be greatly enhanced from 0.95 to 6 kOe. In the experiments, the interface energy in ECDL films is less dependent on thickness of readout and memory layer.

Furthermore, the thickness of readout layer with high Mr should be within 20 to 40 nm on the premise of large readout signal and the coercivity higher than 4 kOe. The readout layer coercivity exhibits less dependence upon the thickness of memory layer within 20 to 50 nm. Consequently, the media can be made to be more controllable in magnetization switching processes. The ECDL TbFeCo media with Mr over

370 emu/cm^3 and high stability are potentially applicable for magnetic flux readout.

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