A FORMALISM TO DETERMINE THE DOW AND MSR CAPABILITY OF EXCHANGE COUPLED LAYER SYSTEMS

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Abstract - The storage media for the magneto-optic (MO) recording technology available on the market today consist of thin ferrimagnetic films of amorphous rare earth/transition metal (RE/TM) alloys. Because the writing speed is limited by the need to erase entire sectors before writing new data, great effort has been made to develop direct overwrite (DOW) techniques, where the light intensity modulation technique appears to be the most promising method. This technique involves the use of exchange coupled layer systems as storage media. On the other hand, exchange coupled layer systems can also be used to increase the storage density without changing the optical arrangement introducing the so called magnetically induced superresolution process (MSR). Both methods, however, suppose a detailed knowledge of the switching behaviour of the exchange coupled films.

Therefore, exchange coupled double layers (ECDLs) were produced and their magnetization reversal behaviour was analyzed yielding a characteristic switching field diagram for each investigated sample. Using this switching field diagram, a formalism was deduced, which enables to prove the DOW or MSR capability of exchange coupled layer systems using data only obtained from macroscopic investigations (Kerr measurements).

KEYWORDS: DOW; EXCHANGE COUPLING; INTERFACE WALL (ENERGY); KERR MEASUREMENT; MAGNETIZATION REVERSAL PROCESS; MSR; RE/TM FILMS; STORAGE DEVICES; SWITCHING FIELD

INTRODUCTION

Erasable magneto-optical (MO) disks available on the market today require erasing of entire sectors before writing new data. To increase the writing speed, great effort has been made to develop direct overwrite (DOW) techniques, where the light intensity modulation technique appears to be the most promising method [1]. Having only one magnet in the MO drive, this technique involves the use of exchange coupled quadrilayers as storage media [2].

In this paper, a formalism based on a switching field diagram is developed yielding all information necessary to achieve a reliable and practicable writing process. It gives, for example, the data stability ranges during the initialization process and demonstrates the need of "negative switching fields" for the writing temperature cycles of the DOW process.

On the other hand, exchange coupled layer systems can be used to increase the storage density of MO media without changing the optical arrangement introducing the so called magnetically induced superresolution (MSR) process [3]. Using the deduced formalism, it is possible to predict the characteristic switching behaviour of an exchange coupled double layer (ECDL) capable for MSR.

EXPERIMENTS AND RESULTS

To analyze the DOW process of quadrilayers, only the exchange coupled memory and reference layer have to be considered, because the initialization layer is magnetically decoupled from the ECDL by the intermediate layer at the writing temperatures. In the following, the memory layer and the reference layer are denoted as layer ① and ②, respectively. ECDLs consisting of one TM (①) and one RE dominated layer (②) were prepared by rf sputtering, where each sublayer had a characteristic coercivity as shown in fig. 1.

![Coercivity](chart.png)

**fig. 1:** Characteristic $H_{c}(T)$ dependence of each sublayer of the investigated ECDLs.
Very often, fig. 1 is used to evaluate the DOW capability of MO films. This procedure, however, leads unambiguously to wrong predictions, because the $H_C$-curves do not take into account the coupling by the exchange energy. This coupling energy causes a shift of the coercivities and leads to effective fields (denoted in the following as "switching fields" $H_s$), which are necessary to reverse each of the sublayers in the stack [4].

These switching fields $H_s$ can be determined experimentally by partial magnetization reversal processes, where only one sublayer is reversed. In the following, this procedure will be described using an antiparallel coupled double layer.

If an antiparallel coupled bilayer is saturated in a negative field (−), a horizontal interface wall exists, where the coupling energy $\sigma_{WiJ}$ is stored. When the applied field is changed into the positive direction, eventually one sublayer will switch and the wall will be annihilated. For the following discussion, it is assumed, that layer 1 reverses first. (The reversal sequence depends on the applied temperature. If, for instance, a temperature range is chosen, where layer 2 switches first, an analogous discussion would be required).

When layer 1 switches first, the horizontal interface wall will be annihilated and therefore, the corresponding switching field is denoted as $H_{S1}$ (the − represents wall annihilation). From energy balances, $H_{S1}$ can be deduced to be $H_{S1}^- = H_{C1}^- (\sigma_{WiJ}/2M_{S1}t_1)$ with $M_{S1}$ magnetization and $t_1$ thickness [5].

When the applied field is turned back and the sample is again saturated in the negative direction (−), layer 1 switches back by wall creation at the switching field $H_{S2}^- = H_{C1}^- (\sigma_{WiJ}/2M_{S2}t_2)$, and therefore, $H_{S1}$ is determined. If, on the other hand, the sample is saturated in the positive direction (1) after layer 1 switches by wall annihilation at $H_{S1}$, layer 2 will also be reversed by wall creation and $H_{S2}^+$ is determined.

Because it was assumed, that layer 1 switches first (by wall annihilation) after saturating the sample, the last missing switching field $H_{S2}$ cannot be determined experimentally. Nevertheless, the switching field $H_{S2}$ as well as the coercivities $H_{C1}$ and $H_{C2}$ can be calculated using the determined switching fields and the values of $M_s$ and $t$.

To determine and evaluate the described reversal processes, VSM magnetometry and Kerr measurements were used. The VSM measurements yield the product $M_{st}$ of the samples, whereas the Kerr measurements give the switching fields of each sublayer separately, because these measurements were performed on both sides of the samples. Applying the described magnetization reversal processes on different temperatures, the bold $H_S^\pm$-curves in fig. 2 are obtained (thin lines: $H_s$-curves).

Note, that in a certain temperature range (in fig. 2 from 100 to 160°C), layer 1 switches before the applied field is reversed, which is represented by a "negative switching field". This is only possible, when the interface wall energy $\sigma_{WiJ}$ is larger than the coercivity energy $E_C = 2H_C M_d$ of layer 1 [5]. In the next section, it will be shown, that this behaviour is a necessary prerequisite for a successful DOW performance.

At $T=T_{CI}$, the $H_{S2}^+$-switching curves run into the $H_{C2}$-curve, because for $T \geq T_{CI}$, only layer 2 switches during the magnetization reversals and, therefore, no interface wall is created or annihilated.

When all the described magnetization reversal processes were performed again but starting from a saturation in a positive field (1), the symmetrically downward orientated $H_{S1}^+$-switching fields are obtained (the dashed lines in fig. 2).

![Switching field diagram](image)

**fig. 2:** The complete $H_s(T)$ diagram showing all switching fields considering every possible magnetization configuration.

All these switching curves can be regarded as phase boundary lines, because they indicate the switching from one stable configuration to another one. For a particular configuration, only one curve per sublayer is relevant. Which one depends on the magnetization...
direction of each layer and on the question, whether
an interface wall is created (\(+)\) or annihilated (\((-)\)) during
the next switching. For an upward directed magnetization (\(\uparrow\)), the switching occurs when the applied field is
changed to a value below the critical switching line and vice versa. If, for instance, layer \(1\) is upward (and layer \(2\) is downward) magnetized, no interface wall exists.

Because switching of one layer, therefore, requires wall creation, the relevant switching fields are a downward oriented \(H_{Si}^-\) -curve (the dashed \(H_{Si}^-\) -curve in fig. 2) and an upward oriented \(H_{S2}^-\) -curve (the bold \(H_{S2}^-\) -curve in fig. 2). To change this configuration, an applied field has to be below the dashed \(H_{Si}^-\) - or above the bold \(H_{S2}^-\) -curve.

To show the benefit of this formalism, in the following this procedure will be applied on the high temperature writing cycle of the DOW process (\(T_{H}\)-cycle).

Applying the \(T_{H}\)-cycle, the sample is heated to the temperature \(T_{H}\), which is close to the Curie-temperature of the reference layer (layer \(2\)) and far above the Curie-temperature of the memory layer (layer \(1\)). At this temperature, the reference layer is magnetized parallel to the permanent bias field \(H_b\). The problem is, that a successful \(T_{H}\)-cycle needs a magnetization direction of the memory layer antiparallel to that of the reference layer at the end of the \(T_{H}\)-cycle. That means: layer \(1\) has to magnetize during cooling down against \(H_b\). The details, which were responsible for this behaviour, are given in fig. 3.

As shown in fig. 3, layer \(1\) has, in principle, two possibilities to magnetize:

(i) the direction parallel to \(H_b\) (\(\downarrow\)). Then, an interface wall exists and the relevant switching field is the upward orientated \(H_{Si}^-\) -curve (switching requires wall annihilation). When \(H_b\) is above \(H_{Si}^-\) (as shown in fig. 3 for \(T<T^*\)), layer \(1\) will reverse. That means:

A (\(\downarrow\))-magnetized memory layer is not stable during cooling down from \(T_H\) for the chosen parameters and will reverse to the direction (\(\uparrow\))!

(ii) the direction opposite to \(H_b\) (\(\uparrow\)). No wall exists and the relevant switching field is a downward orientated \(H_{Si}^-\) -curve. Because for \(T<T^*\), \(H_b\) is not below the \(H_{Si}^-\) -curve, the magnetization direction (\(\uparrow\)) of layer \(1\) is not affected by \(H_b\) and remains stable. That means:

After applying the temperature \(T_{H}\), a (\(\uparrow\))-magnetized memory layer is stable during cooling down for the chosen parameters!

The result of (i) and (ii) is, that at the end of the \(T_{H}\)-cycle, both situations will lead to the desired magnetization direction of layer \(1\) (\(\uparrow\)), provided that the parameters are chosen appropriately (as shown in fig. 3). In particular, a sufficiently high coupling energy \(\sigma_{w,2}\) is required, which allows a negative switching field \(H_{Si}^-\), so that the \(H_b\)-line crosses the \(H_{Si}^-\) -curve (figurative: a sufficiently large "bulge" of the \(H_{Si}^-\) -curve).

These findings were additionally verified experimentally by writing performances, where laser modulated written domains were imaged and demonstrated a successful DOW performance [6].

Investigations of the initialization process by means of a similar switching field diagram indicate, that the data stability ranges are limited by the strength of \(\sigma_{w,2}\). Considering a quadrilayer structure, a successful initialization process requires a proper adjustment of the exchange coupling between all sublayers. Using the described formalism, this range can be estimated precisely for each interface. Therefore, the DOW capability of the films can be proved by macroscopic experiments in combination with an appropriate discussion of the switching field diagram as described.
Another field of application is the MSR technique, where bits smaller than the light spot area can be read by front- (FAD) or rear aperture detection (RAD) [7]. In the FAD-process, for instance, the following basic requirements have to be fulfilled: The readout layer (1) has to switch for \( T>T_r \) parallel to the readout field \( H_r \), but has to be stable for \( T<T_r \) (\( T_r \); hot region of the laser spot). The recording layer (2) must not be affected by this process. This configuration has to be stable until the film is cooled down to the working temperature \( T_w \) of the drive, where layer (1) has to switch back to a direction given by layer (2). All these requirements can be translated into a switching field diagram, which results in a characteristic switching behaviour as shown in fig. 4.

![Switching field diagram](image)

**fig. 4:** \( H_x(T) \) diagram of an ECDL capable for the "MSR by FAD" process.

If an ECDL shows a characteristic switching behaviour as shown in fig. 4, this film is capable for the "MSR by FAD" process:

- Provided, that a \( H_r \) field was chosen as shown in fig. 4, the shown coarse of the \( H_{x,T} \)-curves in the range of the temperature \( T_r \) guarantees the creation of the desired magnetization configurations during the read-out procedure (the \( H_r \)-line and the \( H_{x,T}^- \)-curve have to cross exactly at the temperature \( T_r \)).

- The "switching back" process of layer (1) is represented by a \( H_{x,T}^- \)-curve below the "zero-line" \( H=0 \) in a temperature range \( T_{sw} \).

**SUMMARY**

The DOW or MSR capability of exchange coupled layer systems depends on a characteristic switching behaviour of the films. This switching behaviour can be experimentally determined by macroscopic magnetization reversal processes. As an example, the switching behaviour of an antiparallel coupled double layer is determined.

To demonstrate the DOW capability of the bilayer, a formalism is deduced based on the experimentally determined switching fields. Using this formalism, it is possible to prove the various magnetic requirements of the film, which have to be fulfilled for a successful DOW performance. As an example, the details necessary for a successful high temperature cycle of the DOW process were deduced. The formalism also yields the data stability ranges for given writing parameters.

Finally it is shown, that this formalism also works to investigate the MSR capability of exchange coupled layer systems.

**REFERENCES**