TEMPERATURE INDUCED FERRO-ANTIFERROMAGNETIC TRANSITIONS IN EXCHANGE-COUPLED DOUBLE LAYERS WITH MIXED ANISOTROPIES

R. Sbiaa, H. Le Gall, O. Koshkina, S. Yurchenko, J. M. Desvignes, Y. Braik and J. Gouzerh
CNRS, LMIMS, 92195 Meudon, France

Abstract- The temperature dependence of the magnetization processes in mixed exchange-coupled double layers ECDL with a planar GdFeCo film 1 and a perpendicular anisotropy DyFeCo film 2 is analyzed from Faraday rotation measurements. During heating the magnetic state of the ECDL presents strong modifications depending not only on the external field applied along the normal to the layers, but mainly on the ECDL type which can change from a type 1 with an interlayer macroscopic antiferromagnetic (AF) coupling \(-A_{12}M_1M_2\) to a type 2 with a ferromagnetic (F) coupling. From appropriate choice of the deposition parameters the films compositions were adjusted for either \(T_{cpl} < RT < T_{cp2}\) or \(RT < T_{cp2} < T_{cpl}\) where \(T_{cpl,2}\) are the compensation temperatures of the layer 1 and 2 which gives the possibility to obtain at RT ECDL of type 1/AF or type 2/F respectively. Depending on the respective values of \(T_{cpl}\) and \(T_{cp2}\), it is observed by increasing the temperature, F\(\rightarrow\)AF or AF\(\rightarrow\)F type transitions at \(T_{cpl}\) and \(T_{cp2}\). The evolutions with the temperature of the magnetooptical (MO) hysteresis loops of the ECDL are explained at the first order from the parallel change of the individual loops of the layers 1 and 2. However very close to \(T_{cp2}\) more complex MO loops are observed and can be explained from the rise of the hysteresis \(H_{c1}\) in the planar layer 1 induced by a strong increase of the coercitivity \(H_{c2}\) of the perpendicular layer 2 near its compensation temperature.

KEYWORDS: EXCHANGE COUPLING, DOUBLE LAYER, MAGNETOOPTICAL RECORDING, THERMALLY-INDUCED MAGNETIZATION PROCESSES.

Exchange-coupled double layer (ECDL) and multilayers of amorphous rare earth and transition metal (RE-TM) alloys are the subject of strong interest with the possibility to use such structures to increase either the storage density or the data transfer rate in magnetooptical (MO) recording. ECDL with mixed anisotropies corresponding to in-plane magnetization in one layer \((K_u < 0)\) and normal to the film plane \((K_u > 0)\) in the second layer are used to improve either the Kerr rotation in the visible range [1] or the writing sensitivity [2,3]. More recently the readout of submicron bits with near infrared light has been performed from the magnetically-induced super-resolution (MSR) detection process which uses mixed ECDL [4]. The MSR is a thermo-magnetic effect based on a local optical aperture thermally-induced in the planar magnetic layer by the laser spot during the readout process. During heating the magnetic state of the ECDL may present strong modifications depending not only on the external magnetic field applied along the direction perpendicular to the film plane, but mainly on the ECDL type which can change from a type 1 with interlayer macroscopic antiferromagnetic (AF) coupling \(-A_{12}M_1M_2\) to a type 2 with a ferromagnetic (F) coupling. Whatever the F or AF coupling, we have shown in a previous work that the microscopic exchange interaction between the RE and between the TM at the interface induces mutual effects with a reduction of the coercitivity \(H_{c2}\) and the squareness \(M_{s2}/M_{s1}\) of the "perpendicular" layer and a reduction of the saturation field \(H_{s1}\), but an increase of the coercitivity \(H_{c1}\) of the "planar" layer [5]. Such investigation is extended in the present work to the temperature dependence of the magnetization processes in mixed ECDL with a planar GdFeCo film 1 and a perpendicular anisotropy DyFeCo film 2 as measured from Faraday rotation measurement.

MODEL OF MIXED ECDL

Our results have been analyzed from the extension of the model of Kobayashi et al [6] from perpendicular anisotropy ECDL \((K_{u1}, K_{u2} > 0)\) to bilayers with planar \((K_{u1} < 0)\) and perpendicular \((K_{u2} > 0)\) anisotropies as described in Fig. 1 for two typical bilayers A and B. In Type 1 bilayer at room temperature (RT) the TM moments are dominant in the planar film 1 and RE moments are dominant in the perpendicular film 2. In Type 2 bilayer, on the other hand, the TM moments, or the RE moments are dominant in both film 1 and 2. Since, as discussed by Kobayashi, the coupling in the bilayer is induced at the interface by exchange interactions...
Sbiaa, R. et al.: TEMPERATURE INDUCED FERRO-ANTIFERROMAGNETIC TRANSITIONS IN EXCHANGE-COUPLED DOUBLE LAYERS WITH MIXED ANISOTROPIES

RESULTS AND DISCUSSION

To induce magnetic exchange rather than a magnetostatic coupling the two films of the bilayers were deposited one after another without breaking vacuum in the rf sputtering chamber. Two ECDL corresponding to the bilayers A and B were grown under the same rf power (P_w=200W) applied on 10 cm diameter targets. The ferromagnetic (antiferromagnetic) coupling associated with the type 2 (1) bilayer depends on the respective value of the T_cp1 and T_cp2 which can be choosen from the layers composition adjusted by appropriate value of the sputtering parameters. The RE (TM) content increases (decreases) by increasing the argon pressure P_ar during deposition which gives at RT either ECDL type 1 or type 2. The composition of the perpendicular DyFeCo layer was first adjusted from the optimal choice of P_ar in order to obtain T_cp2 in the range RT < T_cp2 < +100°C as shown in Fig. 2. This is required to produce magnetic domains homogenous in shape and size with respect to the fluctuations of the laser power and writing field during the recording process [7]. T_cp2 is lower in sample A (65°C) compared to sample B (89°C) due to a small difference of Dy content as reported in Table 1. High squareness and coercitivity up to 15kOe can be obtained in the memory layer DyFeCo near the compensation temperature as shown in Fig. 3. The GdFeCo films have always in-plane magnetization whatever the argon pressure in a wide range. On the other hand T_cp1 can change from low to high values as shown in Fig. 4 from temperature dependence of the Faraday rotation in samples deposited between 2.10^{-3} and 20.10^{-3} mbar. Two ECDL corresponding to the samples A and B (Tab. 1) have been deposited with similar T_cp2 but with strong difference between T_cp1 and T_cp2 in order to investigate precisely the type transitions F(AF) → AF(F) from the change, at the compensation temperature, of the MO hysteresis loops of the bilayers.

A typical transition from type 1/AF to a type 2/F is observed in the bilayer A when the temperature increases from RT to T > T_cp2 = 65°C as shown in Fig. 5 from the Tab. 1. ECDL type depending on the compensation temperatures induced from the sputtering argon pressure by the respective composition of the bilayer.

<table>
<thead>
<tr>
<th>Sample</th>
<th>P_ar (x10^{-3} mb)</th>
<th>bilayer</th>
<th>T_cp1 (°C/K)</th>
<th>T_cp2 (°C/K)</th>
<th>ECDL type and coupling at RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8</td>
<td>Gd_{25}Fe_{62}Co_{13}</td>
<td>&lt; RT</td>
<td>65/338</td>
<td>1/AF</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Dy_{27}Fe_{60}Co_{13}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>Gd_{27.5}Fe_{59}Co_{13.5}</td>
<td>202/475</td>
<td>89/362</td>
<td>2/F</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Dy_{28}Fe_{60}Co_{13}</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Faraday rotation (FR) at 1.15 micron wavelength as a function of the magnetic field applied normal to the films plane. The changes of the shape and amplitude of the MO loops with T are associated with the thermal dependences of the magnetization processes in each layer which depend on the composition between the different energies in the two layers (anisotropy, magnetostatic and Zeeman) and with the ferro- or antiferromagnetic type exchange energy $-A_{12}M_1M_2$ between the layers as summarized for instance in Fig. 6 for the sample A in a type 1/AF at T = 25°C. The FR of the bilayer is not algebraic addition of the MO loops of the single layers.
GdFeCo and DyFeCo. Whatever the F or AF coupling, the exchange interaction between the RE and between TM at the interface induces mutual effects corresponding in the planar layer to a reduction of the saturation field (from $H_{S1} = 9.5\text{kOe}$ to $H_{S3} = 6\text{kOe}$ at $T=25^\circ\text{C}$) and in the perpendicular layer to a reduction of both the squareness and the coercitvity (from $H_{c2} = 2\text{kOe}$ to $H_{c3} = 1.5\text{kOe}$ at RT), but to an increase $\beta$ of the remanent FR associated with the spatial rotation out of plane of the magnetic moment in the planar GdFeCo layer. Since $T_{cp1} < RT$, the MO loops of the planar layer are always positive (or direct) for $T>25^\circ\text{C}$, which is not the case for the perpendicular layer with a sign change from negative (or inverse) to positive at $T_{cp2} = 65^\circ\text{C}$. Near $T = 150^\circ\text{C}$ the MO loop of the DyFeCo layer vanishes near its Curie temperature and only the GdFeCo hysteresis is detected.

Different magnetization processes with complex shape are observed by increasing the temperature from 50 to 95°C as reported from the bilayer B in Fig. 7. The change of the shape of the MO loops can be understood from the evolution with the temperature of the shape (coercivity amplitude and saturation field) and the sign of the individual loops as described in this figure by the schemes of the hysteresis in the layers 1 and 2. It is to be noted the strong change of the magnetization processes in a very short range of temperature near $T_{cp2} = 89^\circ\text{C}$. The more complex MO loop of the bilayer B observed at a temperature very close to $T_{cp2}$ is explained from the rise of an hysteresis in the planar layer induced by a strong increase of the coercitivity $H_{c2}$ of the perpendicular layer near its compensation temperature. Similar T-dependences of MO loops have been observed with RE-rich or TM-rich compositions for both layers 1 and 2 or with RE-rich for one layer and TM-rich composition for the second layer.

REFERENCES