Exchange Coupling in Double Layer Systems Using Co-Based Multilayer Thin Films

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Abstract - We have studied the exchange coupling in double-layered structure consisting of the memory and reference layers of e-beam evaporated Co-based multilayer thin films. The structures of the specimens were examined by x-ray diffractometer and the magnetic and magneto-optic properties were measured by VSM and Kerr spectrometer. X-ray diffractometry revealed that all of the specimens had multilayer structure. The exchange coupling between the double layers was so strong that the magnetization reversal of one layer occurred simultaneously with that of the other. The strength of exchange coupling was dependent on the thickness of non-magnetic spacer between the memory layer and the reference layer. It was found that the exchange coupling was blocked when the spacer was thicker than about 50 Å. The existence of exchange coupling was also confirmed by the domain writing experiments.

I. INTRODUCTION

Co-based multilayer thin films have been the subject of considerable investigation because of their technological application to next generation magneto-optical (MO) recording media [1, 2]. The direct overwriting (DOW) should be realized for the practical application of these materials to high performance MO recording media.

One of the current DOW methods is utilizing exchange-coupled double layers (ECDL) which consist of a memory layer (M-layer) having a high coercivity at room temperature and a low Curie temperature, and a reference layer (R-layer) having a low coercivity at room temperature and a high Curie temperature [3, 4]. In this method, both layers are heated above their Curie temperatures using high power laser, the magnetization direction of the M-layer copies, by exchange coupling, that of the R-layer written in the direction of the applied field during cooling. If only the M-layer is heated above its Curie temperature at lower power, the magnetization direction of the M-layer copies that of R-layer initialized by a bias magnet during cooling. Therefore, understanding on exchange coupling between two layers is essential to realize DOW by ECDL scheme in MO recording media. In this paper, we have studied the exchange coupling in double layer systems composing of Co-based multilayer thin films.

II. EXPERIMENTAL

Samples were prepared by e-beam evaporation of Co, Pd, and Pt on glass substrates in a vacuum system. They had double layer structure consisted of Co/Pt (or Pd) multilayer as an R-layer and Co/Pd multilayer as an M-layer. An R-layer was deposited on the glass substrate and then, an M-layer was deposited. The multilayer structure was obtained by alternatively exposing the substrate to two sources via a rotating substrate holder. The thickness of Co sublayer was 3 or 4 Å in an R-layer and 2 Å in an M-layer, whereas the thickness of Pd (or Pt) sublayer was more than 4 monolayers. Typical deposition rates of 0.28 Å/s for Co, 0.25 Å/s for Pt, and 0.30 Å/s for Pd, monitored by corresponding quartz crystal sensors, were kept constant within a 10% fluctuation to achieve the same modulation wavelength.

The multilayer structure was examined by low angle x-ray diffractometry. The M-H hysteresis loop was measured using a vibrating sample magnetometer (VSM). The Kerr hysteresis loop was measured using a Kerr spectrometer at λ = 633 nm. The magnetic domain writing experiments were carried out using a He-Cd laser (λ = 442 nm) and a bias magnet. The samples will be designated (tCo - Co/tPt - Pd (or Pt))n, where tCo and tP are the sublayer thickness of Co and Pd (or Pt) respectively, and n is the number of repeats.

III. RESULTS AND DISCUSSION

Low angle x-ray diffraction studies revealed that all samples had the multilayer structure. In Fig. 1, we demonstrate the Kerr hysteresis loop of a double layer composing of (Q Å Co/11 Å Pd)23 M-layer and (4 Å Co9.2 Å Pt)23 R-layer, together with the loops of M-layer and R-layer. From the figure, one might imagine that a strong coupling between the M-layer and the R-layer is existed so that the magnetization reversal of one layer is occurred simultaneously with that of the other. We have calculated the coercivity of the double layer using Eq.(1) which was derived by Kobayashi [5] under the assumption that there exists an exchange coupling.

\[ H_C = \frac{M_{SR} M_{CR} H_{CM} + M_{SM} M_{CM}}{M_{SR} + M_{SM}} \] (1)
TABLE I
THE COERCIVITIES (Hc) AND SATURATION MAGNETIZATIONS (M_s) FOR R-LAYER, M-LAYER, AND DOUBLE LAYER. (Hc = IS A MEASURED VALUE AND Hc' = IS A CALCULATED ONE.)

<table>
<thead>
<tr>
<th>Samples</th>
<th>M_s (emu/cm^3 Co)</th>
<th>Hc' (Oe)</th>
<th>Hc' (Oe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-layer: (4-A Co/9.2-A Pt)_{23}</td>
<td>2339</td>
<td>143</td>
<td></td>
</tr>
<tr>
<td>M-layer: (2-A Co/11-A Pd)_{23}</td>
<td>2976</td>
<td>1267</td>
<td></td>
</tr>
<tr>
<td>Double layer: (2-A Co/11-A Pd)_{23}</td>
<td>2162</td>
<td>866</td>
<td>849</td>
</tr>
</tbody>
</table>

where M_s, t, and Hc are the saturation magnetization, thickness, and coercivity, respectively. Here the subscripts 'R' and 'M' denote the R and M layers, respectively. The measured coercivity and the calculated one using Eq. (1) for a double layer shown in Fig. 1 are listed in Table I. (In this table, M_s is the (measured) saturation magnetization per unit Co volume.) The theoretical value was found to be well-matched to a measured one within 2% error. Thus, we could infer that the character of coupling between two layers is the exchange one. We have observed a similar result in double layer (2-8 Co/11-8 Pd)_{23} / (3-8 Co/8.8-8 Pd)_{13}, where Co/Pd multilayer thin film was used for an R-layer.

Generally, the exchange coupling between ferromagnetic layers is known to be reduced if they are separated by a non-magnetic spacer [6]. We have observed the fact in our double layer systems where an M-layer and an R-layer were separated by non-magnetic spacer Pd. In Fig. 2, we show the M-H loop of a system where (2-8 Co/11-8 Pd)_{23} M-layer and (3-8 Co/8.8-8 Pd)_{13} R-layer were separated by 50-A-thick Pd. In this system, the strength of exchange coupling between M-layer and R-layer becomes smaller, and therefore the magnetization reversal of one layer occurs almost independently with that of the other. As a result, a stepped M-H loop is obtained. Nevertheless, the exchange coupling between M-layer and R-layer does still weakly exist, and makes the switching field of each constituent layer in the double layer be different from the coercivity of each uncoupled layer. When the exchange coupling between two ferromagnetic layers is weak, the switching fields of an R-layer H_R and an M-layer H_M in the double layer are given by Eqs. (2) and (3), respectively from Kobayashi’s theory [5]:

\[ H_R = -H_{CR} - H_{WR}, \quad H_{WR} = \frac{\sigma_W}{2M_{SR}^R} \]

\[ H_M = -H_{CM} + H_{WM}, \quad H_{WM} = \frac{\sigma_W}{2M_{SM}^M} \]

From these equations, we see that the switching field of the R-layer (or the M-layer) in weakly-coupled double layer is different from that of the R-layer (or the M-layer) itself due to the exchange coupling. This phenomenon has been observed in various ferromagnetic thin films [7-9].

By measuring H_{WR}, one can determine the domain wall energy density \( \sigma_W \) in a weakly-coupled double layer from Eq. (4):

\[ H_{WR} = \frac{\sigma_W}{2M_{SR}^R} \]

The value of \( \sigma_W \) was found to be 6.14 erg/cm^2 for the system discussed in Fig. 2, which is about 100 times larger than that of the magnetostatic coupling.

When an M-layer was weakly coupled with an R-layer owing to non-magnetic spacer, it was found that the location of the step in the M-H loop depends on M_s and Hc of the

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Fig. 1. Kerr hysteresis loops of (2-8 Co/11-8 Pd)_{23}, (4-A Co/9.2-A Pt)_{23}, and (2-8 Co/11-8 Pd)_{23} / (4-A Co/9.2-A Pt)_{23}.

Fig. 2. M-H loop of (2-8 Co/11-8 Pd)_{23} / 50-A Pd / (3-8 Co/8.8-8 Pd)_{13}.
constituent layers. Fig. 3 shows the M-H loop of (2-Å Co/11-Å Pd)8/50-Å Pd/(3-Å Co/8.8-Å Pd)3, where the thickness of the M-layer is one third of that of the M-layer in Fig. 2. The step in this loop exists on the negative magnetization field range when the magnetic field is more than the switching field of the R-layer but less than that of the M-layer is applied in the negative field direction, because the total magnetization of the coupled layer becomes negative owing to a larger $M_s$ of the R-layer than that of the M-layer.

IV. CONCLUSIONS

In this paper, we have studied the exchange coupling in the double layer system consisting of the memory layer and the reference layer made from e-beam evaporated Co/Pd and Co/Pt multilayer thin films. We have confirmed an existence of the exchange coupling between the M-layer and the R-layer in the double layer system from the analysis of the M-H loop. The exchange coupling in the double layer was so strong that the magnetization reversal of one layer occurred simultaneously with that of the other. The existence of an exchange coupling was also confirmed by the domain writing experiments. However, it was observed that the strength of the exchange coupling was distinctively reduced when the M-layer and the R-layer were separated by a 50-Å-thick Pd layer.

ACKNOWLEDGEMENTS

This work was supported by the Korea Science and Engineering Foundation under Grant No. 941-0200-031-2.

REFERENCES