DISTRIBUTION OF HYSTERESIS LOSS IN SPUTTERED CoCr FILMS

J. C. Lodder, Li Cheng-Zhang and Th. J. A. Popma

University of Twente, P.O. Box 217, 7500AB Enschede, The Netherlands

Abstract. – The distribution of the hysteresis loss (ΔWₜ) for films with a high \( H_{c\perp}/H_k \) ratio shows a monotonically decreasing behaviour with applied field \( (H_a) \) while medium and low \( H_{c\perp}/H_k \) exhibit a double peak characteristic. The high field peak agrees with \( H_{cw} \) as determined from domain observations. By changing the direction of \( H_a \) from perpendicular to an in-plane direction, the \( \Delta W_h \) to the in-plane orientation of \( M \) is shown.

1. Introduction

Several experimental methods have been published in order to understand the magnetization process in sputtered CoCr films for perpendicular recording. The domain behaviour has been studied by magneto-optical Kerr effect [1-3], Bitter powder method [4] and colloidal SEM method [5, 6]. The VSM hysteresis loop was studied [7, 9] by means of the initial slope as a function of the angle between the easy axis and applied field \( (H_a) \) [10] and also with the aid of the dependence of the magnitude of \( H_a \) [11, 12]. It has been shown [13] that the normalized hysteresis loss as a function of the orientation of \( H_a \) can be used as a criterion to determine the reversal mechanism in CoCr. We have discussed this by introducing the distribution of the hysteresis loss (ΔWₜ) as a function of \( H_a \) in the VSM loop [14] by:

\[
\Delta W_h = \int_{H_{a1}}^{H_{a2}} d(M_1 - M_2) \frac{dH}{W_h}
\]

(1)

Here \( M_1 \) and \( M_2 \) represent the magnetization of the descending and ascending curves of the VSM loop for a maximum \( H_a = 800 \text{ kA/m} \).

2. Experimental

The relevant properties of the analysed RF magnetron sputtered films are given in table I. The samples

<table>
<thead>
<tr>
<th>No</th>
<th>Sample</th>
<th>( M_s ) kA/m</th>
<th>( h ) nm</th>
<th>( H_{c\perp} ) kA/m</th>
<th>( H_{c\perp}/H_k )</th>
<th>( H_a ) kA/m</th>
<th>( H_{cw} ) kA/m</th>
<th>( H_2 ) kA/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0203 - 1</td>
<td>402</td>
<td>520</td>
<td>8</td>
<td>1.5</td>
<td>320</td>
<td>260</td>
<td>256</td>
</tr>
<tr>
<td>2</td>
<td>0218 - 6</td>
<td>426</td>
<td>650</td>
<td>32</td>
<td>5.5</td>
<td>368</td>
<td>212 - 272</td>
<td>256</td>
</tr>
<tr>
<td>3</td>
<td>0218 - 8</td>
<td>434</td>
<td>700</td>
<td>60</td>
<td>8.9</td>
<td>448</td>
<td>( \sim 188 )</td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>0204 - 2</td>
<td>410</td>
<td>1 230</td>
<td>8</td>
<td>1.4</td>
<td>352</td>
<td>312</td>
<td>296</td>
</tr>
<tr>
<td>5</td>
<td>0211 - 2</td>
<td>441</td>
<td>760</td>
<td>10</td>
<td>1.7</td>
<td>364</td>
<td>236</td>
<td>250</td>
</tr>
<tr>
<td>6</td>
<td>0203 - 8</td>
<td>423</td>
<td>700</td>
<td>18</td>
<td>3.2</td>
<td>352</td>
<td>272</td>
<td>265</td>
</tr>
<tr>
<td>7</td>
<td>0218 - 2</td>
<td>413</td>
<td>1 220</td>
<td>46</td>
<td>7.5</td>
<td>395</td>
<td>248 - 300</td>
<td>245</td>
</tr>
</tbody>
</table>

Fig. 1. – The behaviour of \( \Delta W_h \) vs. \( H_a \) for a low \( H_{c\perp}/H_k \) film (\# 1) at four different orientations of \( H_a \) with respect to the film.

Fig. 2. – The behaviour of \( \Delta W_h \) vs. \( H_a \) for low, medium and high \( H_{c\perp}/H_k \) films for \( H_a \) perpendicular (0°) and in-plane (90°).
are typical representatives of our classification scheme low, medium and high coercivity \( \left( H_{c,\perp}/H_k \right) \) [2]. In the figures 1 and 2 measured data from such samples are given with \( H_{c,\perp}/H_k \) values of 1.5, 5.5 and 8.9 % respectively. From the hysteresis loop we can indicate several characteristic fields such as the nucleation field \( H_n \), which is determined as the field where the first reversed domain is nucleated. This field is experimentally determined by the linear extrapolation of the measured domain density to one domain per square unit area [1, 2]. Another important field is the domain wall coercivity \( H_{cw} \) which is estimated where the stripe-out of the nuclei occurs.

3. Low \( H_{c,\perp}/H_k \) films

The domain photographs are obtained by Kerr microscropy and shown in figure 1 in their relation to \( \Delta W_h \) vs. \( H_n \) for a low coercivity sample (#1) at a direction perpendicular (0°) to the film plane. Coming from saturation the first nucleated domains are observed at an applied field of about 300 kA/m. It is nearly impossible to observe smaller domains because of the limited resolution of the method used [1]. A \( H_{cw} \) value is determined at the \( H_n \) where the first nuclei have been striped-out. From the data it can be seen that a double peak behaviour appears at a lower field \( H_3 \) and at a higher field \( H_2 \). Another field \( H_1 \) can be determined at \( \Delta W_h = 0 \). In figure 1 it can be seen that the peak behaviour changes as the direction of the applied fields varies from perpendicular (0°) to in-plane (90°). In that case \( H_2 \) will gradually move to a higher field while the low field peak is independent of the direction of the field. The amplitude of \( H_3 \) decreases gradually while \( H_3 \) increases. The latter is related to the in-plane magnetization component of the CoCr layer and is observed for all orientations of \( H_n \). In the case of high \( H_{c,\perp}/H_k \) this peak will become more and more pronounced as \( H_n \) is applied at an angle > 20° [14]. All our magnetron sputtered films show the initial-layer effect by the typical jump at zero field in the in-plane hysteresis loop [12]. The orientation of the magnetization of such a layer increases with a decreasing \( H_{c,\perp}/H_k \) ratio [13]. It can be seen in figure 1 that a strong relationship exists between the \( H_{cw} \) (determined from the Kerr photo's) and the value of the high field peak \( H_3 \) determined from the \( \Delta W_h \) vs. \( H_n \) curve. The data of the films with other properties are presented in table I.

4. Comparison low, medium and high \( H_{c,\perp}/H_k \) films

In figure 2 \( \Delta W_h \) vs. \( H_n \) is shown for low (#1), medium (#2) and high (#3) \( H_{c,\perp}/H_k \) films for the perpendicular (black symbols) and in-plane direction (open symbols) of the field applied. For the perpendicular direction the high \( H_{c,\perp}/H_k \) film shows a decreasing behaviour and low field peak is not observed. If \( H_n \) is applied in the plane of the films the low field peak is present for all samples studied. The high field peak is not observed for the high \( H_{c,\perp}/H_k \) films but clearly seen for low coercivity samples if \( H_n \) is applied perpendicular to the sample. The height of the peak at \( H_n \sim 0 \) is larger for low than for high \( H_{c,\perp}/H_k \) films. The medium \( H_{c,\perp}/H_k \) samples show an intermediate behaviour.

The influence of the in-plane orientation of the magnetization is shown by changing the direction of \( H_n \) from perpendicular to an in-plane direction. It is shown (Fig. 1) that for low \( H_{c,\perp}/H_k \) samples the in-plane component is present for all orientations of \( H_n \). It can be concluded from this that the reversal has been considered as the superposition of the domain-wall motion both perpendicular and in-plane orientation of the magnetization (see also [11, 12, 14]).

Acknowledgement

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