

ANOMALOUS H_c IN CoCr-FILMS: SURFACE AND BULK MEASUREMENTS.

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Abstract—The major and minor loops of RF sputtered CoCr films in the thickness range of 20 - 1000 nm and the concentration range of 19-24 at. % Cr were measured by Kerr tracer and VSM. Differences between bulk and surface magnetic data are most likely due to a thickness-dependent surface chemical composition. The maximum anomaly of the minor loop coercivity, which depends strongly on the film thickness, appears to be larger at the surface than in the bulk. The anomalous coercivity of the minor loop which is related to a domain pattern change could be caused by repulsive forces between domain walls. It can be concluded that study of the minor loop coercivities is an interesting research tool for micromagnetic behaviour.

INTRODUCTION.

Although much research has been done on CoCr as a material for perpendicular recording, up to now less attention has been paid to the minor loop behaviour. A still largely unknown magnetic reversal mechanism and the non-saturated character of the acting recording process justify this research.

The minor loop behaviour of CoCr, first studied by Li and Lodder [1], deviates strongly from the major loop behaviour. By studying the coercivity as a function of the magnitude and the direction of the applied field amplitude they concluded for their films, that in the low field range the magnetic reversal is mainly due to domain-wall motion while in the high field range the rotation reversal will be dominant.

It was shown by Rupp et al. [2] that minor Kerr loops of CoCr can have a zero magnetization field H_0 which is larger than the coercivity H_{cKerr} of the major loop. They observed that the enhancement of the coercivity ratio ($CR_{Kerr} = H_0/H_{cKerr}$) depends on the magnitude of the applied field amplitude. Domain density studies by M.O. Kerr microscopy led to the conclusion that the enlargement of the coercivity by decreasing the field amplitude is related to an increase of the domain density.

Although Rupp mentioned in his paper the anomalous coercivity of the minor loop as being the bascule effect, in Néel's original article [3], it was introduced as a tilting of the hysteresis curve. It is possible to consider the enhancement of the coercivity as a consequence of this tilting. The model introduced by Néel [3], which is based on negative interactions between the isolated magnetic elements of the ferromagnetic system, however does not easily explain an increase of the coercivity for minor loops.

Bernards et al. [4] measured the CR_{VSM} as a function of the applied field amplitude. Although for their films the measured values deviated from Rupp's [2] results, they observed a comparable relation. They concluded that the smaller slope (dM/dH) of the minor loop at the intersection of the minor and the major curve is in agreement with domain observations. [2,13]

Because the CR larger than one is directly related to a change of the domain pattern it is worthwhile comparing Kerr and VSM minor-loop data. A difference between both measurements could be an indication for a deviation of the domain structure at the surface.

Comparison of surface and bulk magnetic data has been performed by several other researchers. Triggered by Abe et al. [5] and Tsutsumi et al. [6], Smits et al. [7] measured the coercivity of RF sputtered films as a function of the thickness and observed the existence of a critical thickness for which the ratio H_{cKerr}/H_{cVSM} becomes smaller than one. Hemmes et al. [8] also studied the thickness dependency of this ratio and found the critical thickness depended on the sputter method.

In the present paper we compare the minor loops measured by VSM and Kerr tracer of our RF sputtered films as a function of film thickness and composition.

EXPERIMENTAL PROCEDURE.

The films were prepared in a Leybold Heraeus Z400 sputter apparatus. The films were RF-sputtered from an alloyed CoCr 81/19 at. % target under the following optimized conditions determined for the same apparatus by Lodder and Wielinga [9] ($V_{RF} = -1.6$ kV $P_{AR} = 0.4$ Pa). In order to check the influence of the Cr concentration on the observed effects we also sputtered from 79/21 and 77/23 at. % alloyed targets.

The compositions and the thickness of the films were checked with X-ray fluorescence. The at. % Cr of the films sputtered with the 81/19, 79/21 and 77/23 targets amounted respectively 19.5, 20.5 and 23.8.

In order to study the homogeneity of our films the compositions of several samples were determined by AES depth profiling. We found the cobalt concentration to decrease near the surface. This surface inhomogeneity extends to larger depth for the thicker films.

Rocking-curve measurements and 2θ scans were performed to determine the orientations of the films. For all our films $\Delta\theta_{50}$ lies in the range of 2.5 to 4 degrees. In the 2θ scans no other textures were observed.

The films were magnetically characterized by measuring the perpendicular and in-plane hysteresis curves by VSM and the perpendicular hysteresis curve by Kerr tracer. For all samples minor loops were determined by both methods.

The surface hysteresis curves were determined by a Kerr tracer [10] which used HeNe laser light. This means our surface is limited to the upper 15 nm of the films. The accuracy of the M.O. system was better than 0.4×10^{-3} degree (relative error in the major loop of sample #1 is smaller than 0.1 %).

The starting conditions for measuring the minor loops were the same for both methods. After measuring the saturated hysteresis curve, the field was lowered to the new field amplitude ($=H_a$). Before measuring the minor loop the field was changed three times between the values H_a and $-H_a$.

In order to get an idea of the influence of the magnetic history on the coercivities measured, an additional experiment was performed for sample #15. After saturating the film (900 kA/m) and lowering the field we determined the coercivity of the minor curve as a function of the number of field changes. These measurements were only performed by Kerr tracer.

EXPERIMENTAL RESULTS

The most important results are summarized in table 1. For films thicker than 80 nm the VSM coercivity decreases as a function of the film thickness which is in agreement with the data of Wielinga et al. [11]

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Sample	h [nm]	H_c^{\perp} VSM kA/m	H_c^{\perp} Kerr kA/m	θ_s degree	average properties
1	46	79	90	0.163	at.% Cr : 19.5 Ms (kA/m): 440 $\Delta\theta_{50}$: 3-4
2	80	102	88	0.163	
3	110	96	67	0.163	
4	157	88	40	0.149	
5	297	65	9	0.123	
6	611	46	10	0.121	
7	982	40	8	0.117	
8	24	15	-	0.097	at.% Cr : 20.5 Ms (kA/m): 371 $\Delta\theta_{50}$: 3.3
9	80	98	80	0.131	
10	146	83	41	0.113	
11	272	73	36	-	
12	670	42	13	0.111	
13	54	86	-	0.098	at.% Cr : 23.8 Ms (kA/m): 240 $\Delta\theta_{50}$: 3.5
14	312	55	-	0.076	
15	620	37	11	0.073	

Comparing the coercivity measured by VSM and that measured by Kerr tracer we find the critical thickness of the 19.5 at. %Cr films to be 70 nm (see fig.1). This is in agreement with the results of others. [7,8]

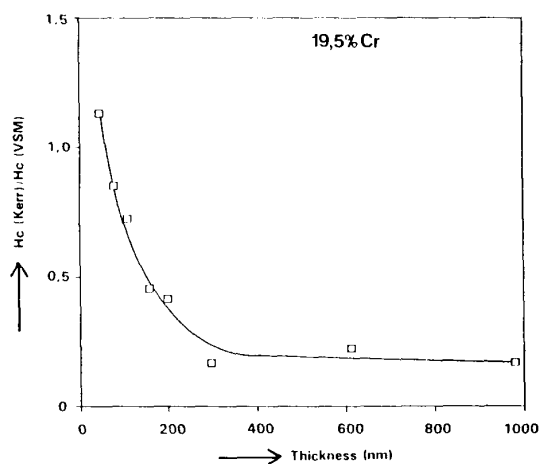


fig. 1: H_{cKerr}/H_{cVSM} as a function of the film thickness for 19.5 at. % Cr films.

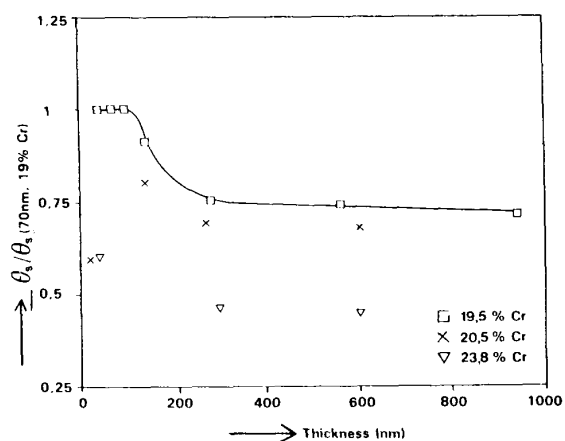


fig. 2: $\theta_s/\theta_s(\#1)$ as a function of the thickness for different concentrations.

In figure 2 the maximum Kerr rotation with respect to the maximum Kerr rotation of sample #1 is plotted as a function of the thickness of the film. Although the change in $\theta_s/\theta_s(\#1)$ and the change in H_{cKerr}/H_{cVSM} take place for about the same thickness, the decrease of the latter parameter seems to be more gradual.

The results of the minor loop measurements of the 19.5 at. % thickness series are given in figures 3 and 4. The CR is plotted versus the amplitude of the applied field for different thicknesses. It is obvious that the data obtained by both methods are not the same. The maximum anomalous coercivity measured by VSM

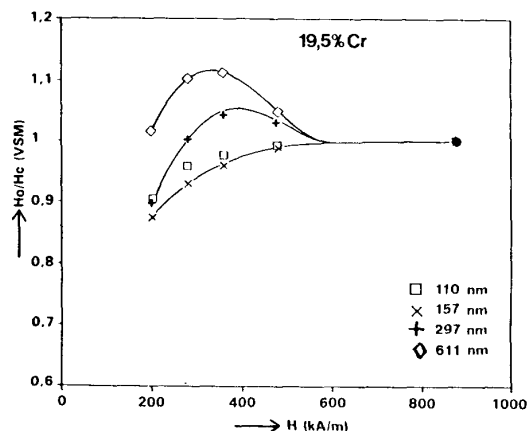


fig. 3: VSM coercivity ratio as a function of the amplitude of the applied field for different film thicknesses (19.5 at. % Cr).

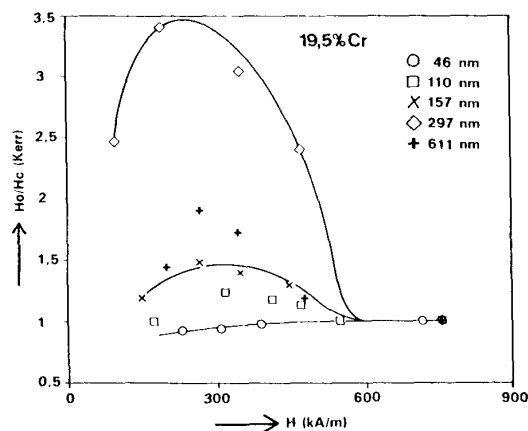


fig. 4: Kerr coercivity ratio as a function of the amplitude of the applied field for different film thicknesses (19.5 at. % Cr).

increases as a function of the thickness. The field amplitude at maximal CR shifts to smaller values for thicker films.

As can be seen from fig. 4 the effect measured by Kerr tracer is much larger. A maximum as function of the film thickness appears to exist. At present, the small number of films prevented us from checking the existence of such a maximum for the 20.5 and the 23.8 at. % Cr films.

The results of the additional experiments to study the influence of the magnetic history on the coercivity are presented in table 2. The measurements were performed on sample #15 ($H_{Kerr} = 11 \text{ kA/m}$)

H_a	$H_{Kerr}(3)$	$H_{Kerr}(6)$	$H_{Kerr}(n)$	kA/m
120	24	24	24	
240	21	27	27	

H_a is the amplitude of the maximum minor loop field. $H_{Kerr}(n)$ is the coercivity of the n th minor loop after coming from saturation.

DISCUSSIONS.

The observed change of the θ_s and H_{Kerr}/H_{VSM} as a function of the thickness is probably due to the change of chemical composition at the surface as measured by AES. Decrease of the Co concentration will lead to a change in magnitude or orientation of the magnetization and as a consequence of θ_s . A smaller anisotropy energy at the surface will influence the coercivity measured by Kerr tracer. Phenomena of the initial sputtering process are probably the cause of the thickness dependence of the surface chemical composition. During sputtering the temperature increases by about 200 degrees with a time constant of 900 seconds. Varying the sputtering methods will show another temperature dependence and as a consequence another thickness is anticipated for which the surface magnetic parameters will deviate from the bulk magnetic data. This is confirmed by the results of Hemmes [8] who also performed Kerr measurements on magnetron sputtered CoCr.

In recent years much research has been done on domain patterns in CoCr. Simsova et al. [12] studied them as a function of the applied field by SEM colloid methods and found hysteresis effects. Schmidt et al. [13] carried out domain observations on CoCr by using a Kerr microscope and found the domain density versus applied field as shown in fig. 5. Lowering the field starting from saturation, the domain density will start to increase at the nucleation field (N), until after stripe-out (S) no measurable change of the domain pattern will take place. Ascending and descending curves are the same for low fields.

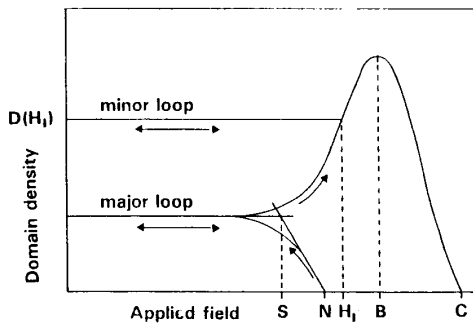


fig.5: Domain density as a function of the applied field after Schmidt [13]. N = nucleation field, S = stripe-out field, C = collapse field, B = bubble field.

Increasing the field will not cause contraction but constriction of the stripe domains. This causes the minor loop to have a higher domain density compared with the saturated hysteresis curve. Although repulsive

forces between the domain walls as suggested by Kaczer [14] can be responsible for this irreversible character, calculations have to be performed to uncover the most important driving forces in this process.

The higher domain densities of the minor loops will exert their influence on the coercivity by means of the above-mentioned repulsive forces. Walls start feeling each others presence if the distance between them is less than 6 times their thickness [14]. Deviation of the anisotropy energy at the surface with respect to the bulk value will result in a change of the wall energy and wall thickness closer to the surface. More research will have to be performed to explain the observed results in more detail.

Figure 5 suggests that by lowering the field from saturation to zero followed by measuring a minor loop with a field amplitude smaller than S will result in a domain density for the minor loop which is equal to that of the saturated curve. No enhancement of the coercivity should be measured. For H_a larger than S fig. 5 also suggests the coercivity to be independent of the number of times the minor loop is measured. Observing table 2 we can conclude that film #15 does not behave like this. We expect that for small fields in major as well in minor loops, a hysteresis in the domain density will occur. Direct domain pattern observations could provide information about the character of the irreversible domain density susceptibility at low fields.

CONCLUSIONS.

The study of the minor loops of thin magnetic layers is not only interesting for (recording) applications but can possibly also provide usable information for explaining the magnetic reversal mechanism in these materials.

REFERENCES.

- [1] Li Cheng-Zhang, Cock Lodder, IEEE Trans. Magn. vol MAG-23 (1987), pp 2260-2261.
- [2] G. Rupp, S. Winkler, G. Neuner, A. Hubert, ICMFS Creusot, TP-24 (1988).
- [3] L. Néel, J. Phys. Rad. 20, (1959) pp 215-221.
- [4] J.P.C. Bernardis et al., J. Magn. Magn. Mat. 78, (1989), pp L119-L121.
- [5] M. Abe, K. Shono, K. Kobayashi, M. Gomi, S. Nomura, Jap. J. Appl. Phys., 21 (1982) L-22-24.
- [6] K. Tsutsumi, Y. Fujii, M. Komori, Y. Sakurai, T. Numata, paper GC-5, Intermag 1983, Philadelp.
- [7] J.W. Smits, S.B. Luitjens, R.W.J. Geuskens, IEEE Trans. Magn., vol MAG-20 (1984), pp 60-62.
- [8] K. Hemmes, W. Lisowski, J.C. Lodder, L.J. Hanekamp, Th. J.A. Popma, Phys. D: Appl. Phys 19 (1986), pp 1311-1320.
- [9] J.C. Lodder, T. Wielinga, IEEE Trans. Magn., MAG-20, 1984, pp 57-59.
- [10] W.J.M.A. Geerts et al., to be published.
- [11] T. Wielinga, J.C. Lodder, J. Worst, IEEE Trans Magn, MAG-18 (1982), pp 1107-9.
- [12] J. Šimšová, J.C. Lodder, J. Kaczér, R. Gemperle, K. Jurek, I. Tomáš, J. Magn. Magn. Mat. 73, (1988) pp 131-135.
- [13] F. Schmidt, A. Hubert, J. Magn. Magn. Mat. 61 (1986) pp. 307-320.
- [14] J. Kaczer, J. Appl. Phys. 29 (1958) pp 569.