Domain structure of Co–Cr films on minor loops

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Domain periods in low coercivity Co–Cr films were measured on minor and major loops and the differences are correlated with the observed coercivity enhancement on minor loops.

The enhanced coercivity of minor loops [1] of Co–Cr films is an effect of both practical and theoretical interest. Its discovery was accompanied by the observation of a domain structure on the minor loop, and on the major loop near the nucleation field; higher domain densities on the minor loop appeared to be the main cause of enhanced coercivity, generally due to domain interaction effects [1]. Bernards et al. [2] studied the conditions for enhanced minor loop coercivity (and remanence) in more detail, and pointed out that differences in the loop tilting, depending on domain density, are expected even in the anhysteretic equilibrium theory. Another systematic study, comparing VSM and Kerr minor loops, was recently reported by Geerts et al. [3] for Co–Cr films with differing Co contents and coercivities.

The aim of the present paper is to correlate the coercivity enhancement [3] in low coercivity Co–Cr films with differences in the periods of domain structure measured on major and minor loops and in anhysteretic states.

The colloid-SEM method (e.g. ref. [4]) enabled us to measure the domain period with a resolution of about 100 nm using JEOL JXA 733 SEM. For simultaneous observation of domain structure and morphology of the surface of low coercivity Co–Cr films, the ISI DS 130C SEM was used. The low voltage SEM image shows very clearly the domain structure (fig. 1a) and at larger magnification (fig. 1b) also the much finer columnar structure (diameter of columns of about 20 nm) confirming the magnetically continuous character [5] of the

Fig. 1. Simultaneous observation of the dried Bitter patterns (a) and the column size at the surface (b) (at larger magnification also the much finer columnar structure is seen in the “dark domains”; sample no. 1; $H_m = 80$ kA/m minor loop).

film. No indications of spike domains have been observed.

The domain structure of three low coercivity Co–Cr films (79/21 at% Cr), obtained earlier on the descending branch [6,7] of the major loop, on the virgin ascending branch (following demagnetization at $H = 0$ [6]), and in the anhysteretic states after demagnetization at a fixed dc bias [6] were compared with the domain structures observed on the minor loops obtained after three (H_m , $-H_m$, H_m) cycles (for sample no. 1 see fig. 2). Domain periods were measured in all these regimes. Table 1 presents some of these results. In all 3 samples,

Table 1

Domain periods p_r^{maj} at remanence (descending branch on the major loop), $p_r(H_m)$ at remanence on minor loops with different cycling fields H_m and p_0 in the anhysteretic zero field state [6]; (the error of measurement of p is 30–80 nm)

Sample no.	h [nm]	p_r^{maj} [nm]	$p_r(H_m)$ [nm] (for H_m [kA/m])					p_0 [nm]
			80	160	200	224	264	
1	520	630	450	445	445	450	480	390
2	770	730	500	505	510	—	—	450
3	1230	870	625	610	645	640	675	570

Fig. 2. Domain structure of sample no. 1: (a) on the descending branch of major loop [7], (b) in the anhysteretic state [6], (c) on different minor loops (H_m : 160; 200; 224 kA/m).

the remanent minor-loop period $p_r(H_m)$ is significantly lower than the remanent major-loop period p_r^{maj} , and close to anhysteretic zero field period p_0 [6]. Further, the periods $p(H_m)$ measured at the minor-loop maxima (H_m) are very close to periods measured at $H = H_m$ on

the virgin ascending branch and/or in the anhysteretic states (for sample no. 1 see fig. 3).

Hysteresis curves on minor and major loops were measured by a Kerr tracer based on the polarizer/multiple-reflection on sample/rotating analyzer principle

Table 2

The enhancement of coercivity of minor loop H_c^{min} in comparison with the value of H_c^{maj} of major loop determined by VSM and (in the brackets) by Kerr tracer [8]. The stripe-out field H_s and the nucleation field H_n were determined by the Kerr method [9]

Sample no.	H_c^{maj} [kA/m]	H_c^{min} [kA/m] for H_m [kA/m]:						H_s [kA/m]	H_n [kA/m]
		80	160	200	240	280	318		
1	9.5 (4.3)	–	11.5 (5.9)	– (5.9)	– (5.9)	10.7	– (5.2)	260	320
2	11.5	13.3	13.5	14.3	–	13.1	–	236	364
3	7.9 (5.0)	9.4	10.3 (6.5)	10.2	–	9.8 (6.1)	–	312	352

Fig. 3. Normalized domain period p/p_0 (stripes) and b/p_0 (bubbles) [6] vs normalized field H/M_s in sample no. 1: $\blacktriangledown$ – descending (CSEM); $\times$ – descending (Kerr); $\blacksquare$ – virgin ascending; anhyseretic state: $\square$ stripes; $\circ$ bubbles; $\triangle$ – $p(H_m)/p_0$ (measured at the maximum magnetic field H_m of different minor loops).

[8] and by a VSM. Slightly larger enhancement of the coercivity on Kerr minor loops in comparison with VSM minor loops was obtained for samples no. 1 and no. 3 (see table 2). The flat maximum of the enhancement extends from 100 to 200 kA/m. The values of H_s (stripe out field) and H_n (nucleation field) [9] are also shown in table 2.

Our former results [6] reproduced in fig. 3 clearly show that the domain periods on the descending branch are significantly larger than the anhyseretic equilibrium values, and strongly decrease with decreasing H (cf. also fig. 2a). This shows that domain growth at stripe

tips, or additional stripe branching is an important process on the descending branch, which is likely to contribute significantly to the relatively low coercivity of the major loop (beside lateral wall motion, easier in large-period structures, quoted by Bernards et al. [2]). This argument is in full accordance with that given by Rupp et al. [1]. Qualitatively, the major loop structure needs lower external pressure (measured by H_c) because of the interaction forces which aid reversed domain growth. Such an internal pressure is absent on the minor loop where, according to our $p_r(H_m)$ measurements, reversal occurs in configurations much closer to anhyseretic equilibrium.

The full H_c enhancement on minor loops is only observed for $H_m < H_s$; for larger values of H_m the minor loop domain period increases above the anhyseretic (nearly constant) value due to contraction and break-up of the stripes tending to energetically more favourable bubble structure [4] (cf. also fig. 2b). These results also show that the domain density per unit area, which peaks above H_s on the ascending major branch [5,3] due to stripe contraction and break-up, is a parameter with no direct relation to the processes discussed.

References

- [1] G. Rupp, S. Winkler and A. Hubert, 12 ICMFS (1988) TP-24.
- [2] J.P.C. Bernards, G.J.P. van Engelen, C.P.G. Schrauwen and H.H. Stel, J. Magn. Magn. Mater. 78 (1989) L119.
- [3] W.J.M.A. Geerts, J.G.Th. te Lintelo, J.C. Lodder and Th.J.A. Popma, IEEE Trans. Magn. MAG-30 (1990) 36.
- [4] J. Šimšová, R. Gemperle, J. Kaczér and J.C. Lodder, IEEE Trans. Magn. MAG-26 (1990) 30.
- [5] F. Schmidt and A. Hubert, J. Magn. Magn. Mater. 61 (1986) 307.
- [6] J. Kaczér, J. Šimšová, R. Gemperle, L. Murtinová and J.C. Lodder, J. de Phys. 49 (1988) C8-1993.
- [7] J.C. Lodder, D. Wind, Th.J.A. Popma and A. Hubert, IEEE Trans. Magn. MAG-23 (1987) 2055.
- [8] K. Hemmes, W. Lisowski, J.C. Lodder, L.J. Hanekamp and Th.J.A. Popma, J. Phys. D 19 (1986) 1311.
- [9] Li Cheng-Zhang and J.C. Lodder, J. Magn. Magn. Mater. 72 (1988) 22.