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MAGNETIC DOMAIN STRUCTURE.

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NEUTRON DEPOLARISATION IN CoCr LAYERS TO
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Running title: Neutron depolarisation in
CoCr layers.

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ABSTRACT

Polarised neutrons ($\lambda=0.47$ nm) are transmit-
ted through sputtered CoCr films. From the
measured diagonal elements of the depolarisa-
tion matrix it appears that the effective
thickness h_{eff} of the films is about 50% of
the actual thickness. When a soft magnetic
NiFe film is deposited before or after depo-
sition of the CoCr, h_{eff} is 67 and 60% of the
actual thickness respectively, due to the
disappearance of the flux closure in the CoCr
film. From the angular dependence of the
diagonal elements compared with computer
simulation the "chain of column" model is
supported. Our results indicate that magnet-
ic flux is closed by "branched" spikes at
least in the substrate side of the CoCr film.

Keywords: CoCr-films, domains, neutrons.

1. INTRODUCTION

Sputtered CoCr layers consisting of conically shaped crystals (columns) with hcp c-axis perpendicular to the film plane are at present widely studied because of their unique properties for using them as a perpendicular recording medium with high density [1]. The morphology and crystal structure and therefore the magnetic properties of these films depend strongly on the deposition and growth conditions. In order to understand the magnetisation process, domain studies are of great importance. In particular, the connection between the domain- and column structure of these films is by no means clear.

The domain dimensions predicted in both "particle" models and "continuous" models [2] for such films are too small to have been observed up to now by Kerr microscopy or the Bitter technique. Therefore, we have transmitted polarised neutrons ($\lambda=0.47$ nm) through these films and measured the diagonal elements D_{xx} , D_{yy} and D_{zz} of the depolarisation matrix [3]. The average Larmor precession of the polarisation vector in the spontaneous magnetisation \vec{M}_s inside the domains is a measure for the mean domain size in the transmission direction.

If the domains extend through the thickness (or "height") h of the film (fig.1a) and when the neutrons pass perpendicularly, the precession angle is

$$\varphi = 5.72 \times 10^8 \times (M_s h) \times \lambda, \quad (1)$$

where M_s is in A/m and λ and h are in meters. For CoCr films with $h=1\mu\text{m}$ and $M_s=460$ kA/m one finds $\varphi \approx 5^\circ$, hence $D_{zz} = \cos \varphi \approx 0.996$. This means that transmission through a package of 14 films should give a good measurable effect: $D_{zz} = \cos^{14} \varphi \approx 0.95$.

2. OBSERVATIONS AND INTERPRETATION

The upper part of Table I which was published earlier [4] contains data from films of 4 thicknesses. The values for φ and $\cos^4 \varphi$ are obtained from (M, h) using eq.(1). Dividing $\varphi_{\text{eff}} = \cos^{-1}[(D_{zz})^{1/14}]$ by φ yields h_{eff}/h . It follows that h_{eff} is about half the film thickness, with a tendency to increase for thinner films. This is partly due to flux closure at the domain ends which "consumes" part of the height of the film; furthermore due to the fact that the domain walls are not exactly perpendicular to the plane of the film and due to the different morphology of the so called "initial layer".

To investigate the flux closure, we have sputtered a soft magnetic $0.05\mu\text{m}$ thick $\text{Ni}_{81}\text{Fe}_{19}$ film on top of sample #3 in order to short circuit part of the magnetic flux of the CoCr domains outside the film. Moreover, we have prepared sample #5 consisting of CoCr on top of NiFe. It appears that h_{eff} is significantly bigger than in untreated CoCr films. However, we note that the morphology of sample #5 is quite different from the others.

In non-perpendicular transmission, fig.2 gives the result for D_{xx} and D_{zz} in sample #1 as a function of θ . The average domain section length $\langle \delta \rangle$ of the film may be inferred from the result for D_{zz} by comparison with a computer simulation using the model of fig.1a. As parameters we take:

- (i) the thickness h of the film (taken equal to h_{eff});
- (ii) the average $\langle \delta \rangle$ as seen in a fixed direction in the plane of the film;
- (iii) the distribution of lengths δ .

The average $\langle \delta \rangle$ needs not to be equal to the column diameter. The simulation has been carried out according to a procedure described earlier [5]. The distribution of δ has been found from a photograph of sample #1

made with a TEM replica technique. In a graph of the crystal boundaries derived from this photograph we have assigned + or - magnetisation at random (fig.3a) to individual crystals and measured the intersections along a set of parallel lines through the magnetic domains consisting of crystals of equal sign. This leads to a distribution with a tail and $\langle\delta\rangle=0.218\mu\text{m}$. Maximising the numbers of pairs of neighbouring crystals with opposite sign (i.e. minimising magnetostatic energy) gives fig.3b with $\langle\delta\rangle=0.163\mu\text{m}$. Both represent a "chain of column" model. The outcome of the simulations is plotted in fig.2. It appears that the "random" choice agrees best with the depolarisation results.

3. DISCUSSION AND CONCLUSION

Comparing the measurements with the simulations we conclude that the $\langle\delta\rangle$ value obtained with the random δ distribution is correct within 10%. We have derived that the average thickness of a layer of closure domains with in-plane magnetisation is about $\frac{1}{4}\langle\delta\rangle$, so in sample #1 about $0.05\mu\text{m}$. This gives a reduction of h_{eff} by $0.1\mu\text{m}$, hence h_{eff}/h should be $0.8-0.9$. Such domains cannot fully account for the measured h_{eff}/h (see Table I). It can be derived that the increase in h_{eff}/h after supplying a NiFe layer is about 2 times $\frac{1}{4}\langle\delta\rangle$. This is also found in the experiment after applying the top NiFe layer (Table I, sample #3). The experiment on sample #5 with a NiFe on the substrate side preliminarily indicates that h_{eff}/h is higher than for films with NiFe on top.

As an alternative flux closure structure we consider structure consisting of "spikes" of opposite sign grown from the magnetically charged ends of each domain. Such a structure in effect provides a short circuit of

magnetic flux within the height of the film by the formation of higher order spikes ("branching") [6,7]. It may be shown that h_{eff} can be much lower than in the first model. To evaluate the effect of such spikes we have repeated the simulations with the random δ distribution using the model of fig.1b. On both sides of each domain a wedge shaped area with a top angle $\alpha \cdot \delta/h$ is shaded in fig.1b. In these areas no Larmor precession occurs. Best fit with the experimental data of sample #1 is obtained with $h_{\text{eff}}/h=0.8$ and $\alpha=0.2$ (solid line in fig.2).

In summary we can state that the neutron depolarisation technique measures the domain size perpendicular to the plane in CoCr films with an accuracy in the thinnest films ($\sim 1\mu\text{m}$) up to $0.02\mu\text{m}$. The average domain section length $\langle \delta \rangle$ determined by the "chain of column" model in fig.3 fits quite well with results obtained by the neutron depolarisation experiments giving the same accuracy. Our observations give support for a model by Privorotskii [6] in which magnetic flux is closed by so called "branched" spikes, at least on the substrate side of the film.

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FIGURE CAPTIONS

fig.1:

(a): Domain model of a cross section of the film with domains extending through the thickness (h).

(b): Domain model with (shaded) areas between oblique domain walls where no effective Larmor precession occurs.

fig.2:

Experimental results of sample #1 for D_{xx} and D_{zz} (big symbols) and simulated results for D_{zz} (small symbols) with the model of fig.1a and with $h=h_{eff}$. The circles and triangles correspond to the domain distributions of fig.3a and 3b, respectively. The solid line corresponds to the model in fig.1b with the random δ -distribution with $\alpha=0.2$ and with a height of $0.8 h$.

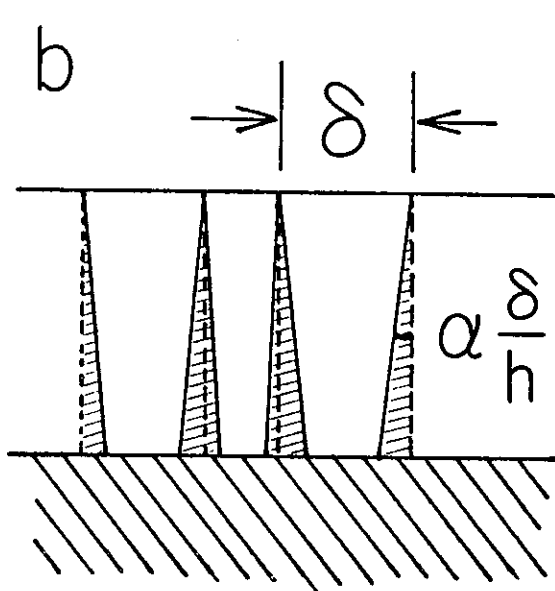
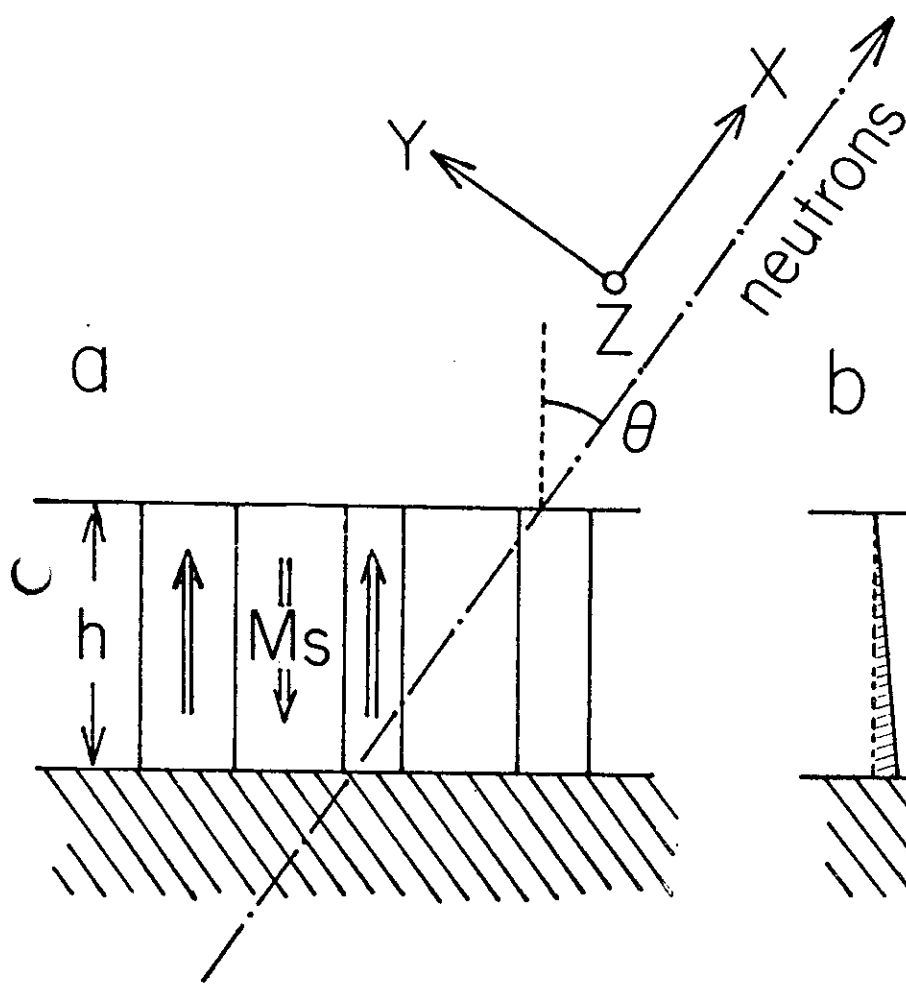
fig.3:

Graph of the crystal boundaries in sample #1 obtained from a TEM replica photograph with + or - magnetisation assigned (a) at random and (b) with maximum number of neighbouring crystals with anti-parallel magnetisation.

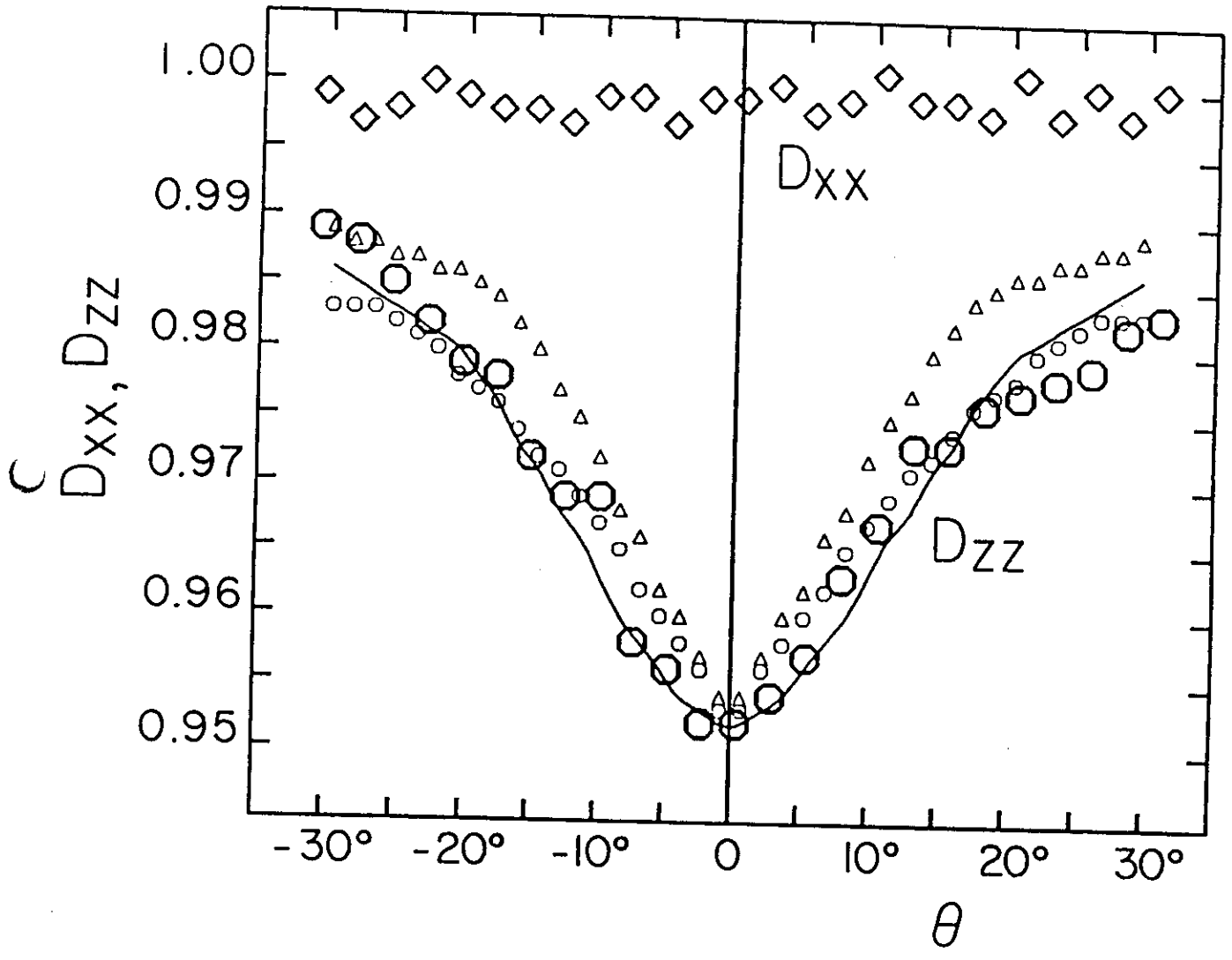
Table I - Comparison of measured D_{zz} with expected $\cos^{14}\phi$,
 expressed in h_{eff}/h for various samples.

Sample (#)	h_{NiFe} (bottom) (μm)	h_{CoCr} (μm)	h_{NiFe} (top) (μm)	$(M_s h)_{\text{CoCr}}$ (A)	$\cos^{14}\phi$	D_{zz}	h_{eff}/h
1	-	0.95	-	0.421	0.913	0.952 ± 0.003	$0.72 \pm 0.04^*$
2	-	1.90	-	0.855	0.686	0.88 ± 0.005	0.58 ± 0.03
3	-	3.81	-	1.737	0.202	0.67 ± 0.01	0.51 ± 0.02
4	-	4.76	-	2.185	0.075	0.57 ± 0.01	0.48 ± 0.02
3	-	3.8	0.06	1.74	0.202	0.50 ± 0.01	0.61 ± 0.02
5	0.04	4.2	-	1.94	0.138	0.42 ± 0.01	0.67 ± 0.02

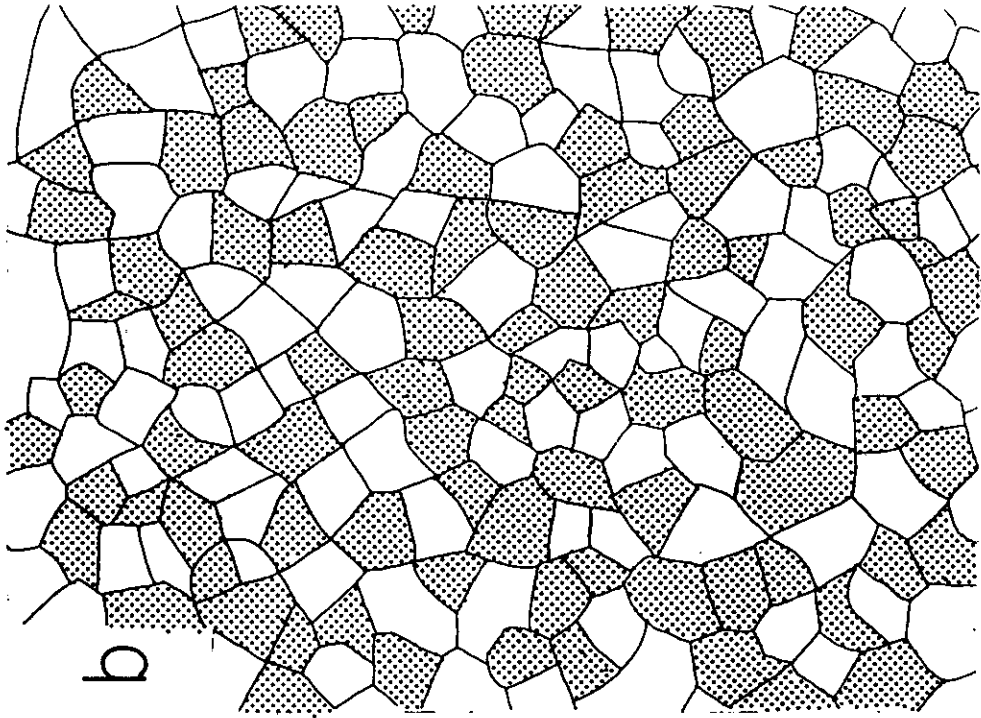
* In ref. [4] we reported 0.61 ± 0.07 . The present figure is obtained after more accurate experiments.



c

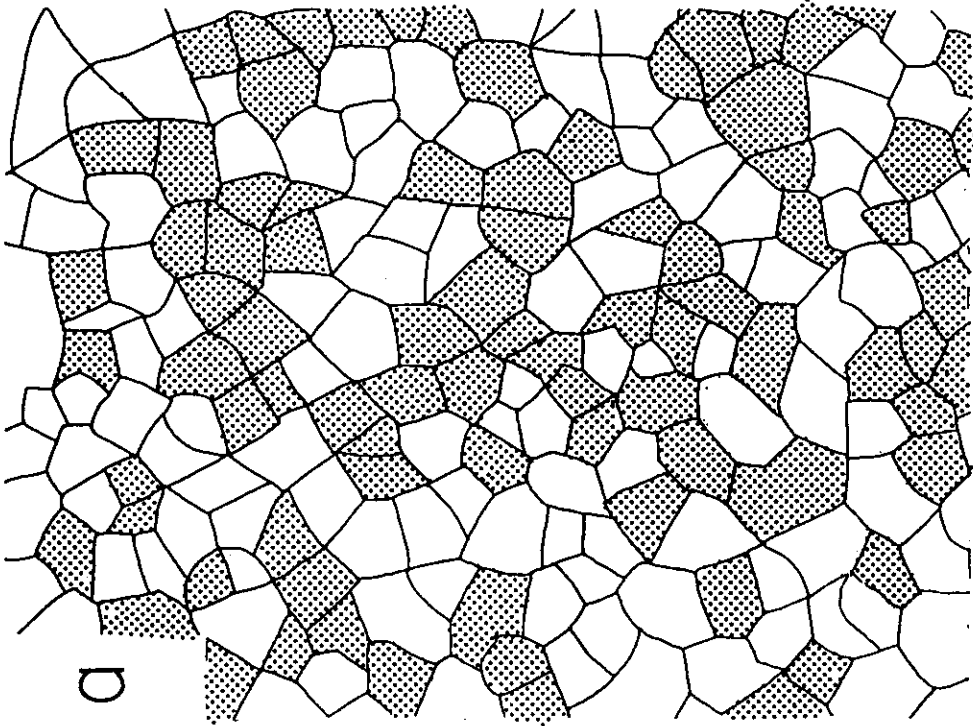


c



b

c



d

1 μ m