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The Influence of Edge Effects on Domain Structure and Coercive Force of Circular Nickel-Iron Films*

A ring-source evaporation system of suitable geometrical arrangement is known to yield a metallic deposit of uniform thickness over a given substrate area. When the material is evaporated through suitable openings in a mask, however, shadowing occurs on the edges of the films. According to Néel's theory,¹ the wall coercive force H_c is inversely proportional to the four-thirds power of the film thickness T . It can therefore be expected that the reduced thickness in the shadowed area will lead to higher coercive forces. If the shadowing is not the same for all films deposited simultaneously, this effect might contribute to a variation of H_c . For most applications, both low and uniform coercive forces are required. The purpose of this note is to show the extent of the influence of this edge effect on the coercive force and the magnetic domain structure.

Experimental procedure

Circular thin films of one-cm diameter were prepared by vacuum evaporation on glass from a nickel-iron alloy ring-source.^{2,3} The source-to-substrate distance was chosen as 1.1 times the ring radius in order to insure a uniform thickness of the deposit over the substrate area employed. During the evaporation process, a dc magnetic field was applied to give a magnetic easy axis in the plane of the films.⁴

From a large number of runs deposited from the same source arrangement, two runs were arbitrarily chosen. These runs will hereafter be called A and B. In both runs, a substrate temperature of 300°C was maintained during the deposition process. The chemical composition of the ring-source wire was 83% Ni, 17% Fe. The substrates were ordinary soft-glass microscope slides which were chemically cleaned like the C series in Ref. 5. The pressures during the deposition of Runs A and B were 8×10^{-6} and 1×10^{-5} mm Hg, respectively; the deposition rates were 1.3 and 1.9 Å/sec.

The film thicknesses of both runs were measured by multiple-beam interferometry.⁶ Run A yielded circular films with an average thickness of approximately 2760 Å and Run B of approximately 1520 Å.

The coercive forces were calculated from measurements taken from a calibrated oscilloscope with a 60-cps B-H loop-tracing apparatus.

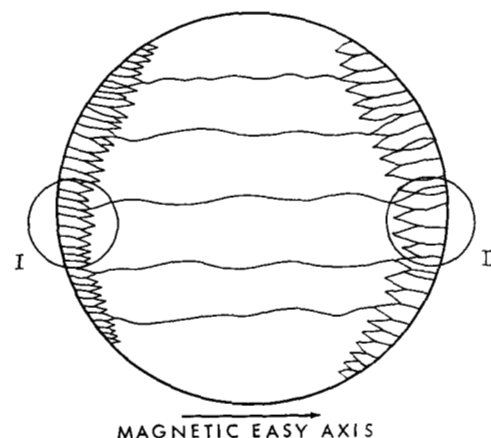
Bitter-technique photographs were made under dark-field illumination with a nonmagnetic microscope. By rotation of the objective stage, overlapping pictures were taken of the perimeter of the circular films at $75\times$ magnification.

Since a rough calculation indicated that a maximum width of the shadowed area of 0.5 mm could be expected, the films were successively etched to 8, 7 and 6 mm diameters using a photo-etch method with appropriate masking. In order to assure that no disturbing effects were introduced, the entire procedure was carried through with the exception of the etching itself. These various steps had no effect on the coercive force or domain structure of the films. In each real etching, only the peripheral edge of the film was removed.

Before etching and after each removal of the border, composite Bitter photographs were taken and the coercive forces measured.

Figure 1 Schematic drawing of domain pattern as observed by composite Bitter photographs.

The numbers indicate the position of the bit with respect to shadowing and correspond to the bit positions in Fig. 3.



Results and discussion

Four circular films were chosen, each from Runs A and B. Composite Bitter photographs showed a peculiar domain structure: numerous spiked domains appeared at the film periphery. In the center portion of the films, only long parallel domains were found.

Frequently, the spiked domains observed on one side of the films were different in length and width from the domains on the other side, as shown in Figs. 1 and 3. The difference is attributed to the unequal shadowing the film suffers because of its position on the substrate with respect to the ring-source (Fig. 2). In all cases, the edge showing the greater degree of shadowing had longer and broader spiked domains than the edges shadowed to a lesser extent. Regardless of the position of maximum shadowing, the spiked domains always formed parallel to the magnetic easy axis.

Bitter photographs taken after removal of the shadowed edge showed that the spiked domains were no longer present. Subsequent etching yielded no further

Figure 2 Representation of shadowing due to evaporation geometry.

(a) Schematic cross section of ring-source, mask, and substrate; (b) schematic cross section of films at positions 1, 2, and 3.

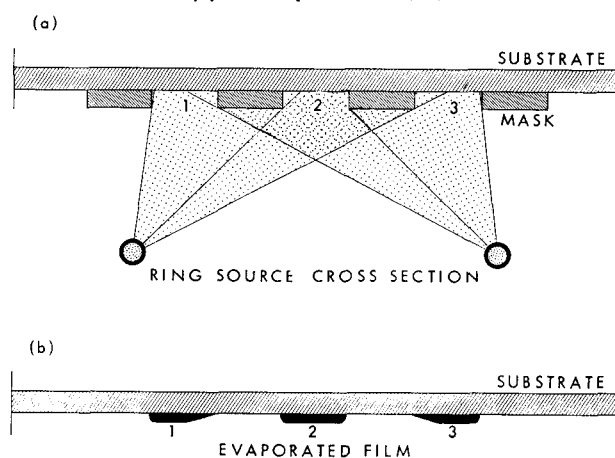


Figure 3 Domain structure as seen by Bitter technique at 130 $\times$ magnification.
Left, Area I in Fig. 1. Right, Area II in Fig. 1.

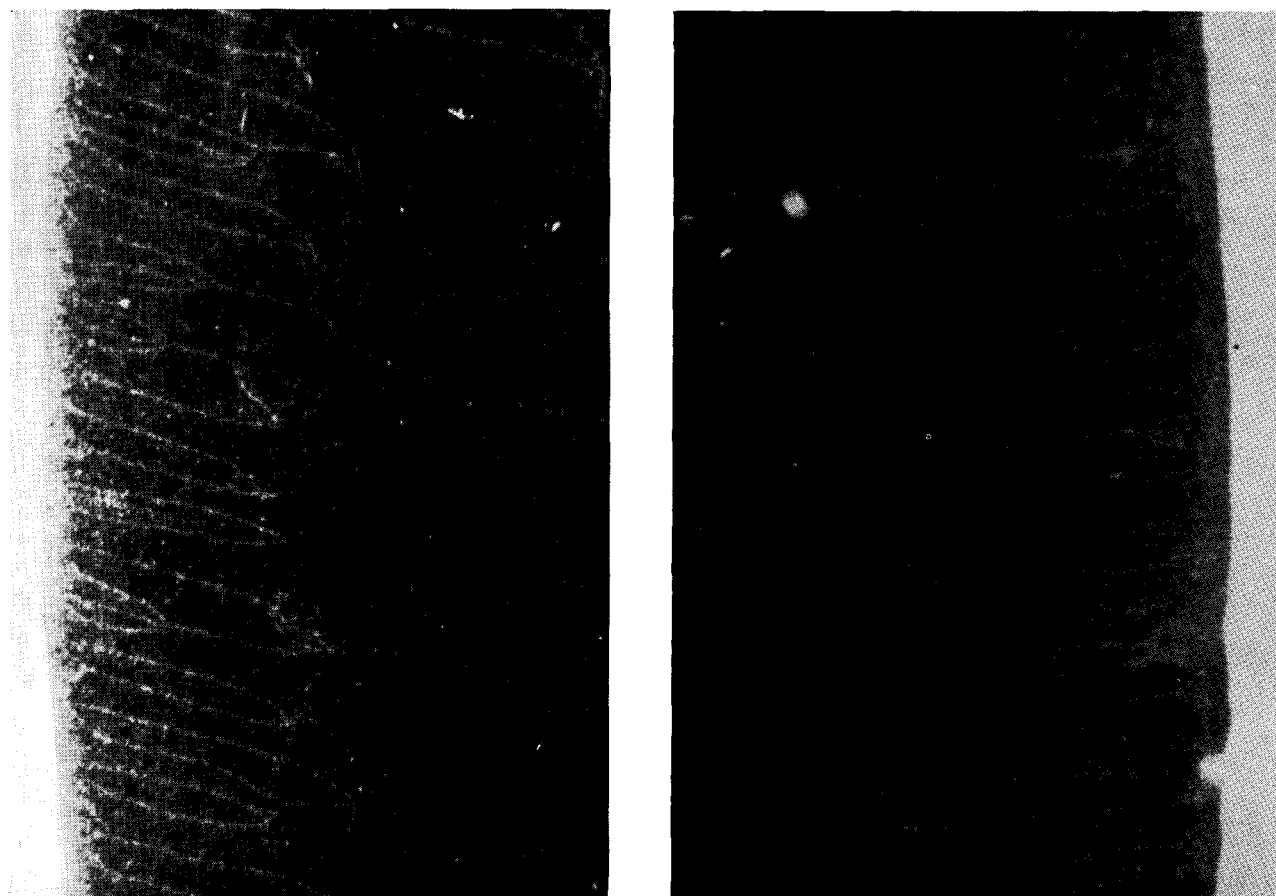


Table 1 Coercive forces of Runs A and B before and after etching.

	Film Number	$d=1.0$ cm Before Etching	$d=0.8$ cm First Etching	$d=0.7$ cm Second Etching	$d=0.6$ cm Third Etching
Run A	1	1.96	1.60	1.59	1.49
	2	2.15	1.46	1.57	1.43
	3	2.54	1.43	1.43	1.43
	4	2.54	1.46	1.61	1.51
Run B	1	2.15	1.80	1.88	1.85
	2	2.15	1.80	2.17	2.19
	3	2.54	1.82	1.87	1.82
	4	2.15	1.77	1.99	2.07

change in the domain structure of the edge. This means that after a sharp edge is once produced, the domain structure is the same throughout the film area, including the periphery, while before etching, the domains in the shadowed zone are distinctly different from those found in the body of the film.

The fact that the film periphery had a smaller thickness than the center of the bit could be verified from the photographs taken of the multiple-beam interference measurements. Figure 4a shows the fringes obtained at the bit edge before etching. It is seen that the step (bit edge, Point A) is not very steep. Thereafter, the fringes are slightly inclined with respect to the fringe direction before the bit edge (Point A). At Point B, there is a slight "knee" in the fringes, marking a change in the fringe direction. Therefore, the profile of the bit has the shape shown schematically in Fig. 4b. The distance between Points A and B is a direct measure of the length of the shadowed zone. After dividing by the power of magnification used for the photograph ($60\times$), one obtains about 0.3 mm for this zone in the case shown in Fig. 4a. In contrast, the film edge is apparently very steep after etching, as is evidenced by the sharp step in the fringes shown in Fig. 4c.

In the method of visual inspection of the films using the Bitter technique and an increasing dc magnetic field along the easy axis, it was noted that the central portion containing the long, regular domains was the first portion to become saturated. At this point only the spiked domains remained at the periphery. A larger field was required to completely saturate the films.

Table 1 is a recording of the coercive forces both before and after etching for Runs A and B. In Run B, pinholes were observed during the etching process of Films 2 and 4. The pinholes appeared during the second etching and produced a sharp change from the pattern followed by films in which there were no pinholes.

Most obvious in both runs (including B before the pinholes) is that there is a decided reduction in coercive force and a step toward greater uniformity of coercive forces within a run. Table 2 shows percent changes in

Figure 4 Photographs of film edge obtained by multiple beam interferometry.

(a) Film before etching; (b) schematic cross section of film as deduced from (a); (c) film after etching.

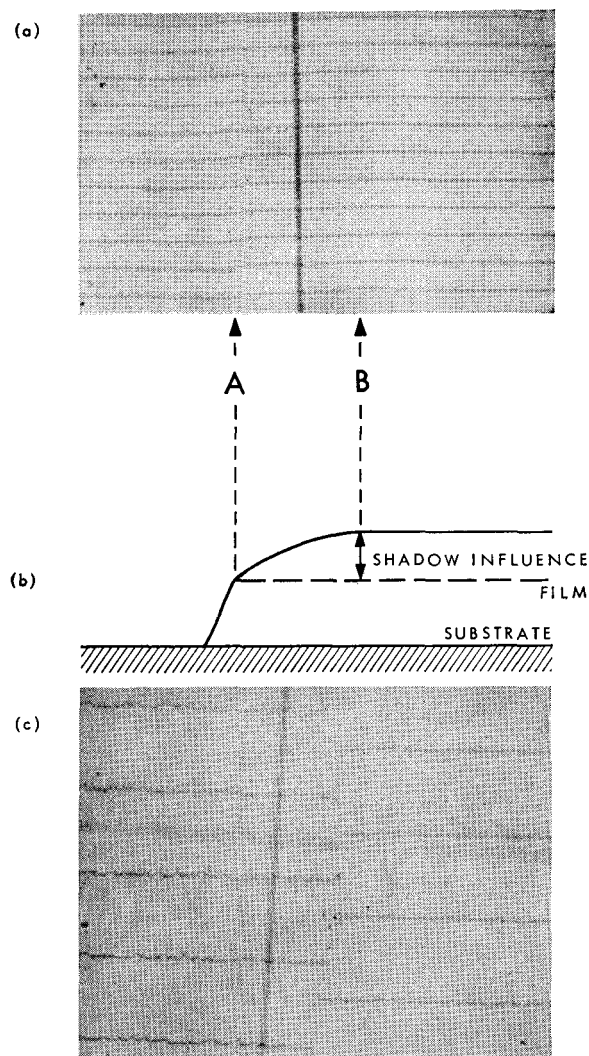


Table 2 Percent reduction in coercive force due to first etching.

	Bit 1	Bit 2	Bit 3	Bit 4
Run A	18.4	32.1	43.7	42.5
Run B	16.3	16.3	28.3	17.7

coercive forces of approximately 18% to 44% for Run A and 16% to 28% for Run B after the first etching. The result of this varied reduction was that the variation of the coercive forces within a run was appreciably reduced.

It should be noted that the percentage reduction for Run A with the larger average thickness is greater than for Run B. If the height of the shadowed area (for definition see Fig. 4b) is proportional to the deposition time and film thickness, then it was larger for Run A. Especially for this run, the percentage reduction of the coercive force is certainly larger than would correspond to the percent of shadowed area — estimated at 19% for worst possible conditions and probably appreciably smaller in most cases. Therefore, it is likely that the height rather than the area of the shadowed zone determines the amount of reduction obtainable.

It can be seen from Table 1 that the variation of the coercive force is appreciably larger before than after etching. Calculations show that before etching there was a standard deviation from the mean of 0.29 oe, or 12.5%. After the first, second and third etchings, the deviations were, respectively, 0.07, 0.07 and 0.04 oersteds. Although it was not possible to carry out the same procedure for

Run B, the trend toward uniformity can be seen in Films 1 and 3 in which no pinholes appeared during etching.

So far the formation of the spiked domains at the film perimeter has been explained by the decreasing thickness in this area. Another factor which might have contributed to this domain configuration should be mentioned: connected with the film thickness is the rate of deposition. The latter has also been smaller in the peripheral area. Since the film structure depends on the deposition rate,^{7,8} it is possible that both structure and film thickness differed in the peripheral zone from the center of the bit. Experiments are being conducted to investigate this question.

Conclusion

It has been shown that the coercive force of thin nickel-iron films evaporated from a ring-source can be decreased by removal of the shadowed edge. In addition, the variation of the coercive forces of the films in a given run is reduced. Once the shadowed edge is removed, however, there is no further appreciable change in variation or reduction.

The higher coercive forces present before etching result from the tapered film edge in the shadowed zone. This reduction in film thickness yields an increase of the coercive force, according to Néel's theory. It has not yet been determined whether the thickness decrease in the peripheral zone is sufficient to explain the value of the coercive force, or whether a change in film structure contributes to the peculiar domain pattern and to the coercive force.

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