S. Middelhoek

Peculiar Domain Behavior in Thin, Magnetic Ni-Fe Double Films

In a previous letter[1] it was shown that in double Permalloy films, consisting of two Permalloy layers separated by a nonmagnetic layer, wall structures occur which differ from those observed in single films. In particular, in a double film (400 Å Ni-Fe, 200 Å SiO, 400 Å Ni-Fe) Néel walls and perturbation walls were observed instead of the cross-tie walls normally occurring in Ni-Fe layers of 400 Å.

This communication reports on Kerr and Bitter observations that show that in double films not only wall behavior, but also domain behavior, differs from that observed in single films.

When a conventional single Ni-Fe film is subjected to a field in the easy direction, magnetization reversal occurs by wall motion[2], which starts from nuclei of reversed magnetization at the edges of the film. As the applied field increases, these nuclei grow over the whole film, forming long, drawn, tapered domains, the surrounding walls of which are roughly parallel to the easy axis.

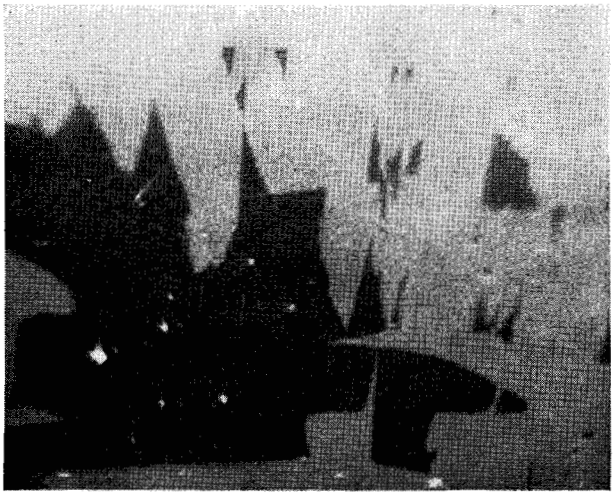
This domain behavior is not observed in double films in the case where the thicknesses of both Ni-Fe layers are roughly equal. Figure 1 is a Kerr photograph obtained from a Ni-Fe double film (300 Å Ni-Fe, 300 Å SiO, 300 Å Ni-Fe). In this and all the following Figures the easy axis is horizontal. Figure 1, when compared with the Kerr photographs of normal single films, shows a striking difference—the occurrence of many walls that are perpendicular to the easy direction. Also, many small tapered domains occur with their tips pointing in the hard direction. It seems that the bases of the tapered domains lie on a line parallel to the easy axis. In addition, at the bottom right-hand corner of the picture should be noted the horizontally tapered domain, of which the tip and a vertical stripe are missing.

Careful analysis of Kerr photographs taken of both sides of the film, which was evaporated on a glass substrate, revealed that two kinds of domain interactions are responsible for the peculiar domain behavior in double films.

Type I domain interaction

Figure 2 schematically indicates the development, in double films, of vertical walls, missing domain tips and stripes. When the double film is subjected to a field in the easy direction, a small tapered domain is nucleated at the left edge of Layer 1 (Fig. 2a). When the field is increased slightly, the domain grows until the tip reaches a spot in the film that has, locally, a higher coercive force (Fig. 2b). In the case of a regular single film, this means that the applied field has to be increased again, so that the tip of the domain can overcome this obstacle.

Figure 1 Kerr photograph of a double film (300 Å Ni-Fe, 300 Å SiO, 300 Å Ni-Fe).



In double films it appears that another solution is possible, namely, the domain terminates in Layer 1 and continues in Layer 2 (Fig. 2c, g). Apparently the domain in Layer 1 can grow only in a vertical direction, so that only vertical domain walls occur. In Layer 1, a domain without a tip becomes visible, whereas in Layer 2 only the tip is observed in a Kerr photograph.

When the tip of the domain is again blocked by an obstacle, but this time in Layer 2 (Fig. 2g), the domain configuration of Fig. 2d,h appears, which is similar to the domain structure visible at the bottom right-hand corner of Fig. 1. Good flux closure between the two layers occurs. This is demonstrated in Fig. 3, which shows a cross section of the double film taken at the location indicated by the arrows in Fig. 2d. It can be seen that the magnetization in the domains in both layers is antiparallel at all points.

Figure 4 is a Bitter photograph of the upper layer of a double film (450 Å Ni-Fe, 500 Å SiO, 450 Å Ni-Fe) showing similar domain structures. It is interesting to note that the vertical walls, visible with the Kerr effect, do not show up in the Bitter photograph. This is probably due to the fact that the stray field distribution above the vertical walls is similar to that above Bloch walls; Bloch walls, as is well known,[3] also are not easily visible, in contrast to Néel walls.

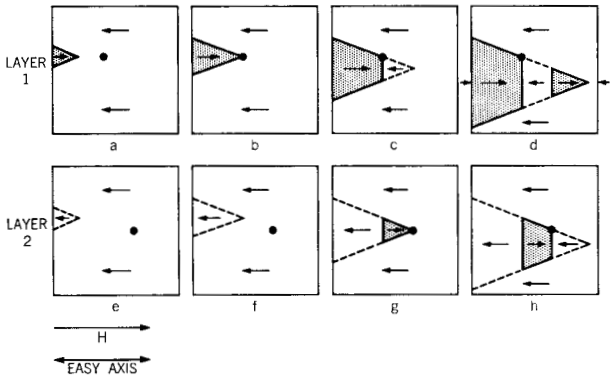
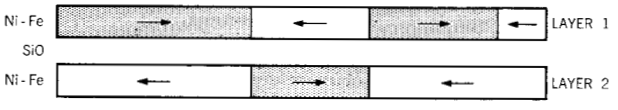


Figure 2 Schematic drawing indicating the occurrence of vertical walls, missing domain tips and stripes. Solid lines represent Néel walls; dashed lines, quasi-Néel walls.[1]

Figure 3 Cross section of the double film of Fig. 2d (see arrows) showing flux closure between the domains.



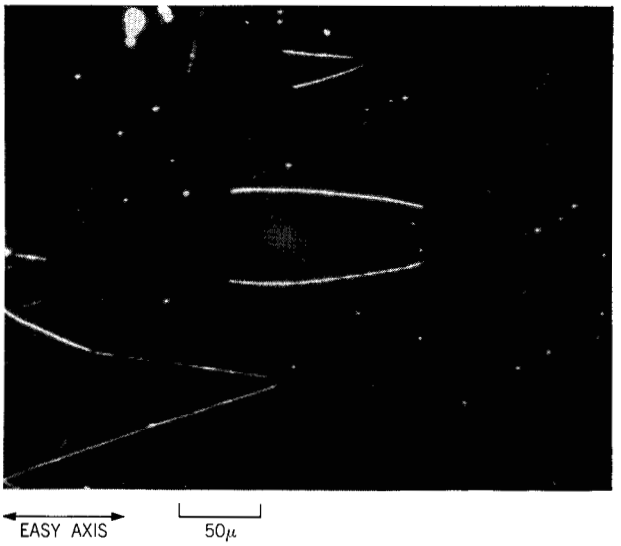
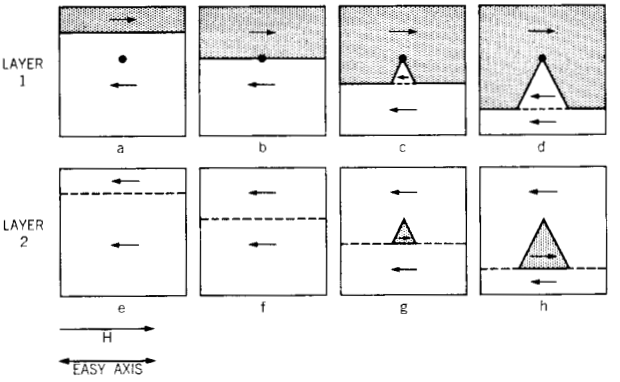


Figure 4 Bitter picture of the upper layer of a double film (450 Å Ni-Fe, 500 Å SiO, 450 Å Ni-Fe), showing vertical walls and missing domain tips.

Figure 5 Schematic drawing indicating the occurrence of triangular domains with horizontal base.



Type II domain interaction

Figure 5 shows how domains tapered in the hard direction, with the bases on a horizontal line, might be formed. When a field is applied in the easy direction, magnetization reversal also occurs by the horizontal displacement of horizontal walls. When such a wall is blocked by an obstacle, for instance a hole, a triangular domain is then reversed in Layer 2 and omitted in Layer 1. With the Kerr effect in Layer 2, a large number of such tapered domains can be observed, the bases of which all coincide with the horizontal domain wall in Layer 1.

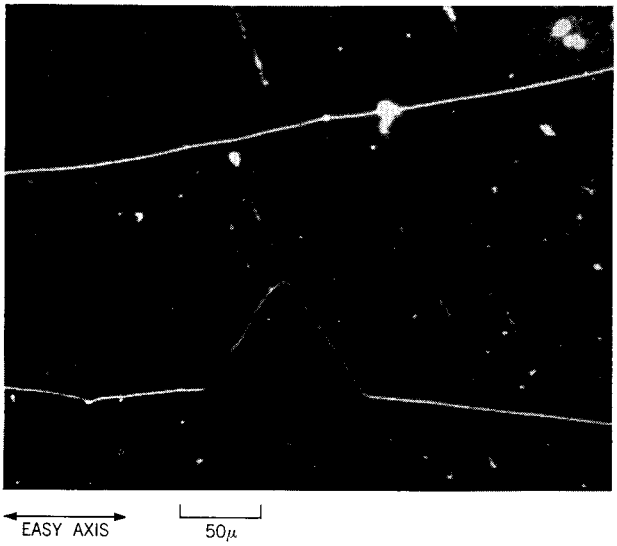


Figure 6 Bitter picture of the upper layer of a double film (250 Å Ni-Fe, 300 Å SiO, 350 Å Ni-Fe), showing a missing triangular domain.

Figure 6 is a Bitter photograph of a wall in a double film (250 Å Ni-Fe, 300 Å SiO, 350 Å Ni-Fe) where an obstacle blocked the straight wall. The inclined walls are reasonably visible, probably due to the fact that the thicknesses of both layers in this case were rather unequal.

From these observations it appears that the peculiar domain behavior in double films can be attributed to the occurrence of two kinds of domain interactions.

References

1. S. Middelhoek, *Appl. Phys. Letters* **5**, 70 (1964).
2. S. Middelhoek, *IBM Journal* **6**, 394 (1962).
3. S. Middelhoek, Thesis, University of Amsterdam, Holland, 1961.

Received February 1, 1965.