

MEASUREMENT OF DOMAIN WALL WIDTHS IN PERMALLOY USING DIFFERENTIAL PHASE CONTRAST IMAGING IN STEM

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Domain wall width measurements have been made on small regularly shaped thin film particles of Permalloy using the differential phase contrast (DPC) mode of Lorentz microscopy. The results obtained show that walls are well represented by a one dimensional symmetrical variation of the magnetisation across the wall consistent with the model of Néel.

1. Introduction

Studies of the domain structures accommodated by small regularly shaped particles have previously been reported both for the particles in their as-grown state [1] and while subjected to a magnetic field [2]. The particles, of Permalloy ($\text{Ni}_{82.5}\text{Fe}_{17.5}$), were fabricated by means of electron beam lithography and evaporation techniques and were made with in-plane dimensions in the range 0.25–4.00 μm . As the particles tend to support very regular domain structures with straight sections of domain wall they are ideal for the detailed investigation of domain wall structures. In this paper we describe how differential phase contrast (DPC) imaging, as practised in a VG HB5 scanning transmission electron microscope (STEM), was implemented to extract domain wall profiles from the particles.

2. Experimental techniques

DPC imaging provides a signal which, in the absence of contributions from other sources, is linearly proportional to an in-plane component of magnetic induction integrated along the electron trajectory [3]. In practice the VG HB5 STEM is normally used with the objective lens switched off for imaging magnetic structures and under these conditions the probe diameter, which de-

termines image resolution, is ≈ 10 nm. Such a probe diameter is sufficient for looking at domain walls in soft magnetic materials as the magnetisation variation takes place over a much larger distance than this. A quadrant detector is used to intercept the bright field cone and, by combining signals from opposite segments of this, images corresponding to components of the total deflection suffered by the electron beam along its trajectory are obtained. These signals can be digitised and stored in a frame store so that subsequent analysis and processing can be performed. A line scan perpendicular to a domain wall and showing the signal variation across it provides a measure of the induction profile across the wall from which its width can be determined.

In the experiments detailed below the analysis is not as simple because signal contributions do arise from non-magnetic sources. The Permalloy is evaporated onto the supporting substrate at normal incidence and indi-



Fig. 1. DPC image of a 4 by 2 μm^2 20 nm thick particle with induction mapped in the horizontal direction.

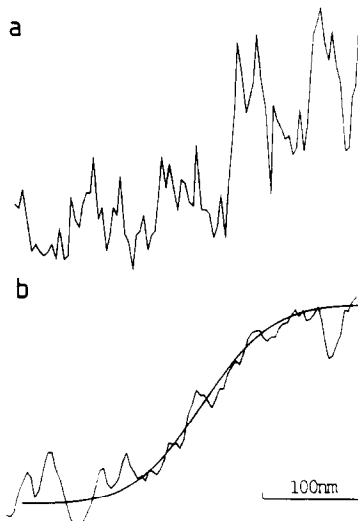


Fig. 2. (a) Single line trace across a DPC image of a 20 nm thick particle containing a 90° wall; (b) the sum of 30 such line traces. Also shown superimposed on the profile is a tanh curve with the parameter $A = 70$ nm.

vidual particles are composed of small randomly oriented grains of diameter $\approx 5\text{--}10$ nm. The amount of scattering of the electron beam due to differently oriented crystallites thus varies considerably and this gives rise to strong crystalline contrast in the DPC images as can be seen in fig. 1. The magnitude of this contrast in relation to the magnetic signal variation is shown clearly in fig. 2a which is a single line trace across a 90° wall in a 20 nm thick particle. It is obvious that the crystallite contrast almost completely swamps the underlying magnetic contrast and any measurements performed on such data would be highly inaccurate. To reduce this effect many line traces are summed as the random orientation of the crystallites effectively leads to a cancellation of crystallite contrast whereas the magnetic contrast is enhanced. As the domain walls are not always perpendicular to the electron beam scan direction across the specimen, successive line scans must be brought into registration prior to summing.

3. Results and discussion

From the previous studies [1,2] it was noted that many of the regular domain structures accommodated by the particles contained straight sections of 90° and 180° walls. The results given here are from an analysis of both types of wall in particles of thickness 20 and 60 nm. An example of the type of profile obtained from the procedures outlined in the previous section is shown in fig. 2b for a 90° wall in a 20 nm thick particle. It is obvious that the crystallite contrast compared to fig. 2a is considerably reduced and the magnetic signal variation is clearly visible.

It is also evident from fig. 2b that, although it is not possible to comment on the detailed wall structure from such a profile, it is still perfectly adequate to allow a measurement of the domain wall width to be made. In order to make this measurement as simple as possible the profile was modelled by a hyperbolic tangent function and such a curve is superimposed on the profile in fig. 2b. Domain walls in films of the thickness studied here are expected from theory [4] to be one dimensional symmetric Néel walls and a tanh function is a convenient and reasonable approximation, as can be seen from fig. 2b. If we denote x as the coordinate normal to the wall and y as the coordinate parallel to the wall, the induction profile of the wall is given by $B_y(x) = \tanh(x/A)$ where the parameter A is chosen to give the

Table 1

Experimental and theoretical domain wall widths. All lengths quoted are in nm

Particle thickness	Wall angle	A	W (exp.)	W (theory)
20	90°	70 ± 10	123 ± 18	137
20	180°	28 ± 4	49 ± 7	47
60	90°	32 ± 4	56 ± 7	62
60	180°	16 ± 2	28 ± 4	20

best fit to the experimental profile. Fits using a range of A values were made to each type of wall studied and the best values, together with their associated errors, are given in table 1. It should be noted that the value for the 180° wall in the 60 nm thick particle was taken from the main wall section of a cross-tie wall.

A number of definitions of domain wall width W exists in the literature. One frequently used in connection with electron microscopy is defined as the half width of the derivative of the direction cosine of magnetisation across the domain wall. In the case of a tanh profile this yields a value for the wall width of $W = 1.76 \times A$. This definition of wall width is also useful as it has been used for the theoretical wall model [4] with which comparisons are to be made. Table 1 lists experimental and theoretical values of W for each of the walls. Clearly there is good agreement between the two sets of values.

We conclude that DPC images can be used very effectively to determine domain wall widths from thin polycrystalline samples. Although the images recorded contain non-magnetic contributions to the signal variation, these effects can be minimised by simple signal processing. A comparison of the results with theory suggest that the domain walls in the small particles under investigation closely resemble one dimensional symmetric Néel walls.

References

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