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EFFECT OF APPLICATION OF FIELDS ON THE DOMAIN STRUCTURE IN SMALL REGULARLY SHAPED MAGNETIC PARTICLES


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Abstract. – The dynamical magnetic behaviour of small regularly shaped permalloy particles has been investigated using an in situ magnetising stage in a transmission electron microscope.

Introduction

Previously we have studied the domain structure in the as-deposited state of small square and rectangular particles of permalloy (Ni$_{82.5}$Fe$_{17.5}$) [1]. The particles, whose in-plane dimensions were in the range 0.25-4.00 $\mu$m, were produced using a combination of electron beam lithographic and evaporation techniques. The extreme regularity and high edge acuity of the particles resulted in their supporting very regular domain structures as was revealed using the Fresnel mode of Lorentz microscopy in a JEOL 1200EX transmission electron microscope. In the final section of this paper we describe further investigations of these particles involving their in situ magnetisation. For this work a special magnetising stage was constructed for use with the microscope and this is described in the following section.

The magnetising stage

Magnetising coils have been incorporated into a special side entry rod which can be inserted through the standard specimen airlock of JEOL 100, 1200 and 2000 electron microscopes. The coils comprise four layers of copper wire wound on soft iron formers situated either side of the specimen. Currents up to 1.5 A can be passed through the coils and under these conditions the field at the specimen is approximately 10 kA.m$^{-1}$. As no compensation coils are included in the stage, deflection of the electron beam occurs when the magnetising coils are energised. This deflection is corrected through use of the ALIGNMENT TILT coils incorporated in the microscope. Similarly, any astigmatism introduced can also be corrected by varying the excitation of the INTERMEDIATE STIGMATOR. To allow fields to be applied in any direction with respect to the axes of a particle, the stage was designed to include a manually controlled rotation mechanism. This allows specimen rotation through a maximum angle of 270°.

Experimental results and discussion

Figure 1a shows a Fresnel image of a 60 nm thick square particle (side 4 $\mu$m) in the as-grown state. The domain structure achieves flux closure with the magnetisation in each domain lying parallel to an edge of the particle. Thus, the domains are separated by 90° walls which intersect at the particle centre in a Bloch line. In particles of the thickness under investigation here the walls are expected to be of the one dimensional symmetric Néel type [2].

Figure 1b shows the result of applying a horizontal field of 5.25 kA.m$^{-1}$ parallel to the magnetisation direction in the bottom domain in the particle. As a result of the field the bottom domain grows as the expense of the top domain and the Bloch line moves vertically upwards. In addition, the magnetisation in the left and right hand domains is expected to rotate towards the field direction, leading to the formation of free poles at the surfaces where the normal component of magnetisation is non-zero. Although the Fresnel micrographs give no direct information on the direction of the magnetisation within each domain, it is evident from the wall contrast that a change in the orientation of magnetisation within these domains has taken place. In particular, the walls marked AA' in figure 1b are of higher contrast than those marked BB' indicating that the magnetisation rotates through a greater angle at A than at B. This is in accord with expectation.

A further point of note is that, for the normal component of magnetisation to be continuous across the domain walls, the angle between walls A and B (or A' and B') should be 90°. This is not geometrically possible for straight domain walls, so as walls BB' approach the Bloch line they curve and their contrast decreases indicating that the change in magnetisation direction across the walls is further reduced. Thus, the angle through which the magnetisation rotates varies along the wall so that the magnetisation distribution cannot be divergence free.

An increase in the external field causes further movement of the domain walls until splitting occurs at the
Decreasing the external field resulted in the domain configuration returning to the flux closure state of figure 1a via the states shown in figures 1c and b.

Some results from a magnetising experiment on a rectangular particle of the same thickness but with in-plane dimensions of 4 μm by 3 μm are shown in figure 2. Figure 2a shows the domain structure in the as-grown state. As before the magnetisation lies parallel to the edges of the particle but in this case a section of 180° cross-tie wall is present, along with the 90° walls, from the outset. On application of the magnetic field the bottom domain again increased in area at the expense of the rest and, because no cross-tie wall had to be created, the observed structures closely resembled those shown in figures 1c and d. Again it was noteworthy that the closer the cross-tie wall approached the particle edge the greater the density of cross-ties became. However, in this instance a field lower than the maximum available was sufficient to drive the cross-tie wall into contact with the edge of the particle and the configuration which resulted is shown in figure 2b. This particular structure is not.

Fig. 1. - Fresnel micrographs of a 4 μm square particle, thickness 60 nm, with the following values of applied field in the horizontal direction (a) 0 A.m⁻¹, (b) 5.2 kA.m⁻¹, (c) 6.4 kA.m⁻¹ and (d) 8.9 kA.m⁻¹.

Fig. 2. - As figure 1 for a 4 μm by 3 μm particle with applied field (a) 0 A.m⁻¹ and (b) 8.9 kA.m⁻¹.

Bloch line with the introduction of a section of cross-tie wall. This is shown in figure 1c where the applied field was 6.4 kA.m⁻¹. All walls are now much straighter and the angle between AB and A'B' reverts to 90°. In figure 1d, where the field has been increased to 8.9 kA.m⁻¹, this angular relation is preserved through the length of the cross-tie wall increasing. It should also be noted that the density of cross-ties increases as the wall is forced closer to the edge of the particle.