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Domain and Domain Wall Structures in Magnetic Nanowires and Nanoelements

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Interest in domain and domain wall (DW) structures supported by magnetic nanowires and nanoelements continues to grow. The wide variety of magnetic structures found excites scientific curiosity whilst the manipulation of domains by magnetic field, spin-polarised currents, heat and various combinations thereof open up possibilities for novel storage, sensing and logic systems [1].

The electron microscope provides a powerful means of studying nanomagnetic systems. The high spatial resolution attainable using the various modes of Lorentz microscopy is invaluable when key structural dimensions are in the range a few 10's to few 100's of nanometres. Moreover the modern TEM is well suited to in situ experimentation whereby the magnetic state of the sample can be changed using one or more of the external stimuli listed above whilst directly observing a magnetic image. Inevitably the temporal resolution is limited by the inherent brightness of the electron gun so that ultra fast processes cannot be observed directly. Nonetheless, it is possible to image systems at standard video rates so that irreversible changes that have occurred following, for example, application of a current pulse of duration in the nanosecond to microsecond regime can readily be studied.

More information can be gleaned when Lorentz imaging is combined with micromagnetic modelling. Many codes are available [e.g. 2] and their sophistication is increasing allowing incorporation of, for example, the microstructure of the film and edge roughness, an inevitable consequence of the patterning technique used to fabricate the nanostructure. Here analytical TEM has a prominent role to play in determining the relevant physical parameters for input to the computer models.

Much attention has been paid to the alternative DW structures that form in straight nanowires fabricated from soft magnetic alloys such as permalloy [3]. Here we concentrate more on wires with more complex geometries such as those shown in fig. 1. The vector nature of the differential phase contrast (DPC) mode of Lorentz microscopy [4] makes it a preferred technique for studying castellated structures (fig. 1a). In the ground state, simple DW structures form at each corner. However, under the influence of an antiparallel horizontal field, reversal of part of the structure leads to the formation of more complex DWs. Here the exchange energy is lowered but the rise in magnetostatic energy more than compensates for this leading to a higher overall energy state. Increase in field leads to the formation of higher energy DWs at all corners after which a further increase in horizontal field leads to a reversal of magnetisation in the orthogonal direction to restore the system to the ground state once the field is removed. Experimental images and those calculated using micromagnetic modelling illustrate the main features, fig. 2a-c. The agreement is excellent but it should be noted that the fields at which the various transitions occur do not always agree closely. Figure 2d shows an unexpected outcome of application of an orthogonal field. Even though the wires are narrow (200 nm) DWs can run parallel to their length on occasion and, once again, there is agreement between modelling and experiment.

In the second structure (fig.1b) the interest centres on how DWs can be trapped or simply transmitted through the structure depending on the sense of magnetisation in the ‘t’ section (marked A). Figure 3 shows illustrative results, again obtained by DPC imaging. Further examples, including instances where micromagnetic modelling and experiment do not align so closely will be presented.

[1] S. S. P. Parkin, et al., Science 320 (2008) 190.
[2] http://math.nist.gov/oommf/.
[3] Y. Nakatani, et al, J. Magn. Magn. Mater. 290 (2005) 750.
[4] J.N. Chapman, J. Phys. D: Appl. Phys. 17 (1984) 623.

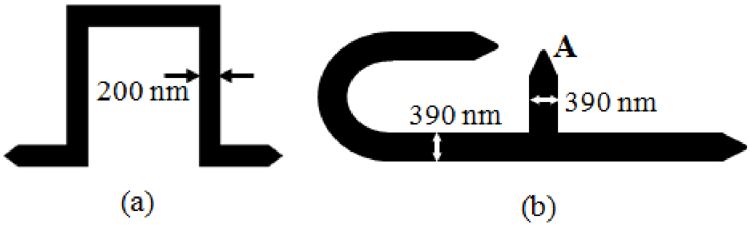

FIG. 1. Schematics of two different structures used for the manipulation of magnetic domain walls.

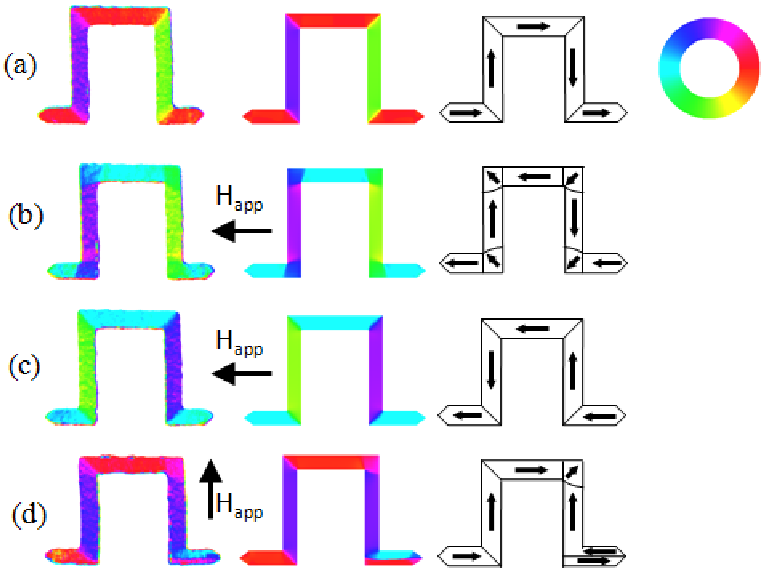

FIG. 2. (a) DPC image sequence of a castellated wire in the ground state, (b)-(d) under an applied field, along with corresponding calculated induction maps and a schematic of the magnetisation.

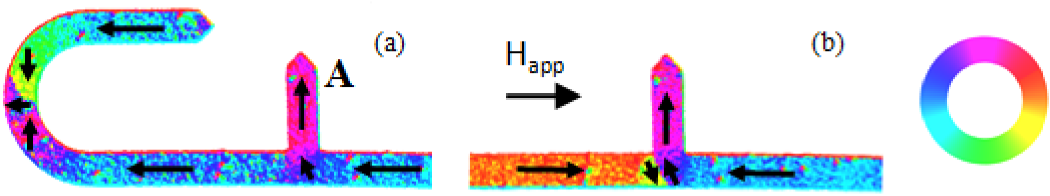

FIG. 3. DPC images of a domain wall (a) after nucleation and (b) pinned in front of the ‘t’ section.