Direct Imaging of Domain Wall Interactions in Ni80Fe20 Planar Nanowires

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The properties of geometrically confined head-to-head and tail-to-tail [1] magnetic domain walls are currently a topic of great interest due to their potential applications in new data storage [2], magnetic sensing and logic [3] technologies. Depending on the orientation of the domains they separate, such domain walls carry either a net north or south monopole moment and are therefore inherently interacting objects. However, the details of these interactions have so far received remarkably little attention.

In this study we have used magnetic transmission x-ray microscopy (M-TXM) to image at high spatial resolution pairs of planar $Ni_{80}Fe_{20}$ nanowires with edge-to-edge spacings between 50 nm and 500 nm. By the nucleation and propagation of domain wall pairs into these wires, we have directly observed interactions between the walls as they are brought into close proximity (Figure 1).

As expected, we observe attraction between pairs of walls with opposite monopole moments and repulsion between pairs of walls with like monopole moments. However, when the spacing between the wires is < 200 nm we additionally observe coupling between the micromagnetic structures of the domain walls (Figure 2). Micromagnetic simulations are used to explain this in terms of a domain wall interaction energy which depends not only on the domain walls' relative displacement and monopole moment, but also upon their magnetisation structure (vortex or transverse) and chirality (clockwise or anti-clockwise). We show that these effects can be understood by examining the symmetry of the domain walls' magnetic pole distributions and by considering dipolar coupling in addition to simple monopolar coupling effects.

We also show that a static domain wall creates a pinning potential for domain walls propagating in neighbouring nanowires, and that this potential can take the form of either an energy barrier or an energy well depending on the relative monopole moments of the walls. This effect is likely to be important in future domain wall-based devices in which nanowire densities will be high and such interactions will manifest as cross-talk between channels.

We present experimental data which show that the applied fields required to overcome these pinning potentials can be as large as 100 Oe, and are therefore significant when compared to domain wall propagation fields. Finally, we present a simple model which uses a Coulomb-type interaction to approximate the pinning potentials for vortex walls, and explain why higher order multipole terms must be considered to make similar approximations for transverse walls.

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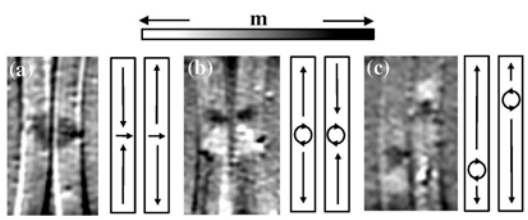
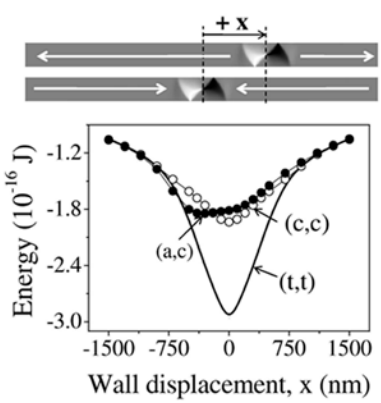
Figure 1:- M-TXM images of coupled domain walls in pairs of Ni-Fe nanowires. The nanowires are 33 nm thick, 440 nm wide and have edge-to-edge spacings of (a) 50 nm, (b) 100 nm and (c) 150 nm. (a) Domain walls have opposite monopole moments and have coupled transverse magnetisation structures. (b) Domain walls have opposite monopole moments and are coupled into vortex configurations with parallel chiralities. (c) Domain walls have like monopole moments and are repelled from each other. Coupling between the domain walls causes them to exhibit opposite vortex chiralities.

Figure 2:- Micromagnetically calculated domain wall interaction energy for a pair of nanowires with 100nm edge-to-edge spacing. The interaction energy is plotted as a function of x, the displacement of the upper wall. Data is shown for: (c,c) clockwise vortex walls in both wires, (a,c) anti-clockwise vortex wall in the top wire and clockwise vortex wall in the bottom wire and (t,t) transverse walls in both wires. The interaction energy can be seen to vary significantly with the domain walls' structure and chirality.

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