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Observation of a geometrically constrained domain wall in epitaxial FCC Co small disks

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Abstract

The magnetic nanostructure of epitaxial FCC Co/Cu(0 0 1) circular elements ($\sim 1.7\ \mu m$ in diameter) has been imaged with scanning electron microscopy with polarisation analysis. A closed flux configuration (quadrant configuration) is observed for most of the disks, characteristic of systems with cubic anisotropy. However, the measured width of the 90° domain wall varies with the distance from the vortex core, from 70 ± 25 nm up to a value determined by the disk radius. Such a wide domain wall is a consequence of the geometrical constraints imposed by the element, thus defining a geometrically constrained domain wall, as confirmed by micromagnetic simulations.

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The equilibrium magnetic states and magnetisation reversal mechanisms in small elements are strongly determined by the interplay of the different anisotropy terms with the physical shape of the element. Whereas the effect of the physical shape of the element has been well studied [1–3] the role of the magnetic anisotropy has not been so extensively investigated [3–5]. In general, the effect of the magnetic anisotropy is to restrict the states with flux closure to those compatible with local domains pointing along the easy direction axis. Less clear, however, is how the magnetocrystalline anisotropy and the dipolar interactions (i.e., shape of the element) together determine the form and extent of the effective transition at a magnetic domain boundary in small elements. More generally, there is strong current interest in the concept of a geometrically constrained domain wall [6].

The elements studied here were fabricated by deposition of a Cu(100 nm)/Co(34 nm)/Cu(2 nm)/Au(4 nm) 4-layer structure onto a prepatterned Si(0 0 1) substrate (sample preparation details can be found in Ref. [7]). The disk diameter was fixed at $\sim 1.7\ \mu m$ and the separation between the elements was set to 6 μm. This assures that the disks do not interact with each other. The height of the Si structures (700 nm) ensures that the continuous background film and that of the circular structures are not physically connected.

The magnetic domain structure of the elements was imaged at remanence with scanning electron microscopy with polarisation analysis (SEMPA) [8] which measures the magnitude and direction of the in-plane magnetisation. The SEMPA results show that the prevalent state observed is that of a nearly closed flux, four quadrant configuration typical of a system with cubic anisotropy, although other more complicated magnetic configurations are also observed. From a higher magnification image of one of the disks [7] we determined the width of

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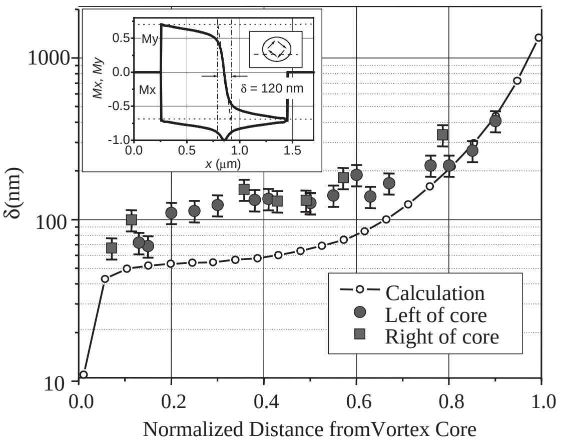

Fig. 1. Domain wall width as a function of the normalised distance from the vortex core. Inset shows the domain wall profile as obtained from the micromagnetic simulation.

the 90° domain wall (DW) from the slope of the magnetisation line scan ($\delta = \pi/2(\partial\theta/\partial x)_0^{-1}$). We find that away from the vortex core the domain wall width is much wider than the value expected in bulk or continuous film systems (Fig. 1).

In order to understand both the remanent magnetic states observed and the width of the domain wall, we performed micromagnetic simulations to calculate the equilibrium state at remanence, using the OOMMF micromagnetic package [9]. The Co parameters used were $M_s = 1.424 \times 10^6$ A/m for the saturation magnetisation, $A = 3.3 \times 10^{-11}$ J/m for the exchange constant and $K_1 = 6.5 \times 10^4$ J/m^3 for the anisotropy constant of FCC Co/Cu(0 0 1). The simulations show that, after saturation in an in-plane magnetic field, the remanent equilibrium state is the quadrant state, as observed experimentally.

The width of the domain wall is the result of the energetic compromise between the exchange, anisotropy and dipolar interaction terms: while close to the perimeter of the disk the magnetisation minimises the free magnetic poles by remaining parallel to the perimeter, in the centre of the disk the spins try to orient along the magnetocrystalline easy axes. This results in a rather wide, geometrically constrained domain wall, whose width decreases from the outside towards the centre of the disk. The DW width δ as a function of the normalised distance from the centre of the disk is shown in Fig. 1. For small distances from the vortex core the DW width assumes a value close to $\pi/2(A/K)^{1/2}$ while at the periphery of the disk it assumes a value close to the geometrical parameter $r_0\pi/2$ corresponding to a circular magnetisation configuration. The experimental values show the same trend as the calculations, a plateau followed by an upturn in the domain width with increasing distance from the vortex core, although the value of the DW at the plateau is a factor of two larger than that predicted by the simulations. This discrepancy may be due either to a smaller magnetocrystalline anisotropy constant than that measured in continuous films or to a larger exchange constant than that assumed in the calculations (or a combination of these two factors).

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