Mapping local flux density distribution in nanomagnetic recording media

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At the heart of every hard disk drive are nanomagnetic thin-film recording media that are a *tour de force* of material science and technology. Information is stored in bits comprising approximately 200 ferromagnetic grains each around 10 nm in diameter, formed by compositional segregation during sputter deposition from a CoCrPt based alloy. We have used small-angle neutron scattering on D11 to probe the magnetic structure of these materials at the granular level, with some surprising results.

Recording media - that are metallically continuous but magnetically inhomogeneous - are of enormous technological commercial importance in high-density data storage devices. These media offer significant advantages over other current technologies, particularly in terms of reliability, access times and data density [1, 2]. There is a very large body of literature concerned with the characterisation and performance characteristics of these materials, yet very little of this work addresses the magnetic structures at length scales of the order of the magnetic grains.

Since the neutron possesses a magnetic moment, small-angle neutron scattering (SANS) is an ideal method to measure the magnetic structure of objects with lateral dimensions on the length scale of interest, about 10 nm. In thin film recording media, however, the magnetic data storage layer is typically only around 20 nm thick, whereas in most SANS experiments samples of macroscopic volume are measured. In addition, in order to have the desired properties, these thin films are grown on a series of seed layers and underlayers deposited onto substrates of glass or Al/NiP, so the total amount of material that scatters neutrons is typically 10 000 times greater than the magnetic layer in which we are interested. Given this, at first sight it would not seem feasible to perform these experiments, since one is looking for a magnetic needle in a haystack of nuclear scattering.

One crucial element in helping us to find the magnetic signal is the anisotropic form of the magnetic scattering. Due to the symmetry of the magnetic field produced by a magnetic dipole, no scattering will occur along a direction parallel to the axis of the dipole. Thus, if an external field is used to align all of the dipoles in a system along the same direction, the magnetic scattering goes to zero along that direction. In contrast, the non-magnetic contribution to the scattering, arising from the nuclei of all of the atoms in the material, will be isotropic. Hence, if a magnetic field induces some anisotropy in the scattering, then we can attribute this to the magnetism in the sample ***(see figure 1)***.

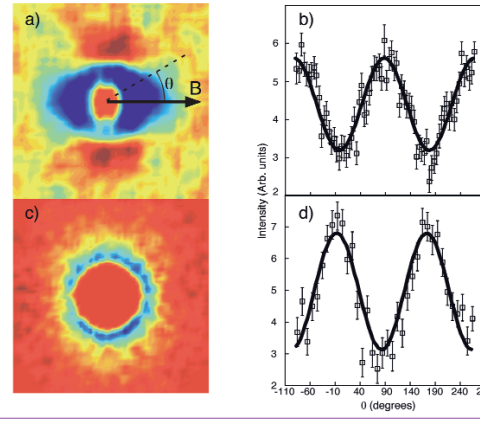

Figure 1: *Images of the small-angle neutron magnetic scattering from a CoCrPtB medium at* ***(a)*** *&* ***(b)*** *2.2 T and* ***(c)*** *&* ***(d)*** *0.45 T. Note that the anisotropy in the scattering changes its phase by 90° between the two fields, due to the growth of transverse components of the local magnetisation.*

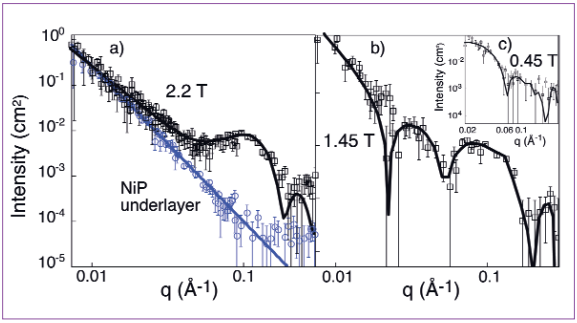

Figure 2: *q-dependence of the absolute value of the anisotropic component of the magnetic scattering intensity I_M (q) for the thin film CoCrPtB sample at different applied fields. Also shown in a) is I_M (q) due to a magnetic NiP underlayer in an identical thin film sample without the active CoCrPtB layer.*

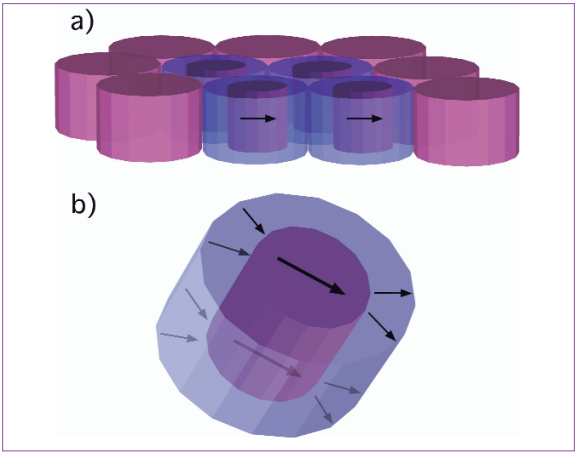

Figure 3: (a) *A schematic representation of the nanocrystalline grains within the active recording layer of the media; in some grains we illustrate the core-shell structure of the local magnetisation.*
(b) *A schematic representation of an individual grain magnetisation, showing a hard ferromagnetic core which can polarise the surrounding softer magnetic shell.*

The data reduction leads to curves such as those in ***figure 2***, which show the amplitude of the magnetic scattering as a function of the scattering vector *q*. Although the scattering pattern evolves with applied field, the parameters that describe the system are remarkably consistent. In this particular sample of CoCrPtB-based magnetic recording media, transmission electron microscopy measurements indicate an average physical grain size of around 11 nm. This dimension is also reflected in the magnetic scattering, but there is additional scattering corresponding to a significant change of local induction at a *smaller* length scale, around 6 nm. A simple analytic model fits the data extremely well ***(figure 2)***. Our model consists of a smaller core of magnetisation (around 6 nm) surrounded by a shell of weaker magnetisation (around 11 nm) ***(figure 3)***. As the field is varied, the directions of the inner and the outer magnetisation in our model are allowed to vary to reflect their response to the changing external magnetic field.

More information can be extracted by paying careful attention to the details of the two-dimensional scattering pattern, for example the 'phase' change illustrated in ***figure 1***. We used micromagnetic simulations to understand the evolving patterns, and found that the local magnetic induction may only be described by using a model that consists of a core of ferromagnet material with a surrounding shell that is composed of a magnetically polarisable material. The moments of the shell respond to both the applied external field and crucially to the local fields due to the ferromagnetic cores. By this mechanism the sample develops strong variations of the component of magnetisation perpendicular to the applied field, giving rise to scattering along the direction of the applied field [3].

One possibility to understand the magnetic data is in terms of the composition of the CoCrPtB alloy across the grain. The grain boundaries are Cr rich and Co poor, while the converse is true for the centre of the grains. The saturation magnetisation and coercivity are a function of the alloy composition, both of which decrease with increasing Cr concentration [4]. However, the extent of the magnetic variation across the grains is greater than had hitherto been generally believed, so these measurements provide invaluable input into the complex micromagnetic simulations that are often performed to aid the development of these extremely commercially important nanomagnetic materials.

References:

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