Artificial Spin Ice Studied by In-plane Bragg XRMS

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Artificial spin ice is a patterned 2d array of single domain magnetic nano-ellipses which collectively exhibit geometrical frustration and distinctly "icey" behaviour (1, 2), directly analogous to real spin ice materials (3). Exploiting shape anisotropy, thermally stable moments are confined to well-defined axes, enforcing conflicting dipolar interactions. In calculation moments are often defined as Ising dipoles. Such model frustrated systems allow for the physics of frustration to be explored with unique control in real and reciprocal space, using magnetic microscopy and scattering techniques.

Currently being studied is the square ice system, figure 1(a), where frustration occurs between the four elements on each cross-like vertex. The FeNi elements are spaced by 500 nm, ~ 100 nm by 300 nm in lateral size, and 25 nm thick. The geometry enforces a two-fold degenerate antiferromagnetic groundstate, however, the system possesses a complex energy landscape of local minima into which it can become frozen.

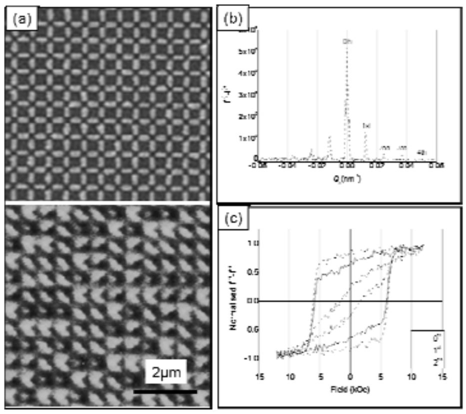

Figure 1. (a) Atomic and magnetic force microscopy of a 500 nm artificial square ice. (b) In-plane (01) rocking curve from magnetically polarized state. (c) In-plane magnetic hysteresis loops measured at 0^{th}, 1^{st} and 2^{nd} order Bragg positions.

Questions remain open regarding short and long range magnetic reversal mechanisms, as well single element accommodation of field. We have used x-ray resonant magnetic scattering, tuned to the FeL_3 absorption edge, to study magnetic hysteretic behaviour at (01) in-plane Bragg positions, figure 1(b). Distinctly different hysteresis loops are found to occur at different diffraction orders, ranging from easy axis-like at 0^{th} and 1^{st} order, to hard axis-like loops at 2^{nd}, 3^{rd} and 4^{th} order, figure 1(c) reflecting the average magnetic behaviour of the two perpendicular sub-lattices of the system.

Such axis specific information shows that, under applied fields, moments are non-Ising. Also, non-zero magnetic remanence indicates that the moments may act to locally compensate for the vertex interactions, which itself may lift degeneracy as well as reduce frustration.

References

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