Dynamics of Artificial Spin Ice in Real and Reciprocal Space

S. A. Morley[1], A. Stein[2], M. C. Rosamond[3], D. Alba Venero[4], A. Hrabec[1], S. Riley[3], J. M. A. Porro[5], P.M. Shepley[1], P. Steadman[6], M.-Y. Im[7], P. J. Fischer[7], S. Langridge[5], C. H. Marrows[1]

[1]*School of Physics and Astronomy, University of Leeds, United Kingdom.*
[2]*Center for Functional Nanomaterials, Brookhaven National Laboratory, United States.*
[3]*School of Electronic and Electrical Engineering, University of Leeds, United Kingdom.*
[4]*Deprtment of Earth Sciences and Condensed Matter Physics, University of Cantabria, Spain.*
[5]*ISIS, STFC Rutherford Appleton Laboratory, United Kingdom.*
[6]*Science Division, Diamond Light Source, United Kingdom.*
[7]*Center for X-ray Optics, Lawrence Berkeley National Laboratory, United States.*

Artificial spin ices (ASI) are nanomagnetic islands confined in a two-dimensional plane. Their shape anisotropy and size means they can be considered as single domain Ising-like spins and as such provide an interesting, and more importantly, tuneable statistical toy model [1]. However, the first systems studied were athermal and only effective thermodynamics were realised. In the systems studied here we have shrunk the island volume, and therefore the energy barrier associated with flipping the magnetic moment of the island, in order to realise a true statistical mechanical model. It has been shown that when the barrier is of the order of $k_B T$, thermal fluctuations take place, as the macrospin system is able to fluctuate and equilibrate [2,3]. In real space we have observed dynamics in ASI using Transmission X-ray Microscopy, a synchrotron-based imaging technique. In these experiments we have injected ‘monopole-antimonopole’ pairs into our arrays and studied their propagation as a function of applied magnetic field, temperature and interaction strength.
In-plane magnetic elements with lateral dimensions < 50 nm are challenging for current magnetic microscopy techniques and in the case of studying dynamics in much smaller-element ASI ($\approx 30 \times 70$ nm) we have developed a reciprocal space technique here at Diamond Light Source. This is a technique that uses resonant magnetic soft x-ray photon correlation spectroscopy (XPCS) to observe the time-time correlations of the thermally induced magnetic fluctuations in our ASI systems [4,5]. In XPCS, a small part of the sample is illuminated coherently. The resulting Bragg spots have speckle that can be imaged on a CCD camera. As the sample’s magnetic configuration varies with time, so do the details of the speckle pattern. We have determined the form of these correlations as a function of temperature, observing faster dynamics with increased temperature.

References

1. R. F. Wang, C. Nisoli, R. S. Freitas, J. Li, W. McConville, B. J. Cooley, M. S. Lund, N. Samarth, C. Leighton, V. H. Crespi, and P. Schiffer. Artificial ’spin ice’ in a geometrically frustrated lattice of nanoscale ferromagnetic islands. *Nature*, **439**, 303, (2006).
2. Farhan A., Derlet P. M., Kleibert A., Balan A., Chopdekar R. V., Wyss M., Anghinolfi L., Nolting F., Heyderman L. J., Nature Phys. **9**, 375, (2013)
3. Kapaklis V., Arnalds U. B., Farhan A., Chopdekar R. V., Balan A., Scholl A., Heyderman L. J., Hjörvarsson B., Nature Nano. **9**, 514 (2014)
4. Konings S., Schüßler-Langeheine C., Ott H., Weschke E., Schierle E., Zabel H., and Goedkoop J. B, *Phys. Rev. Lett.* **106**, 077402, (2011)
5. Chen S.-W., Guo H. , Seu K. A., Dumesnil K., Roy S, and Sinha S. K., *Phys. Rev. Lett.* **110**, 217201, (2013)

Email corresponding author: py07s2m@leeds.ac.uk