Fabrication and Measurement of Artificial Spin Ice

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Artificial spin ices (ASI) are arrays of nanomagnets fabricated by lithographic techniques such that the energy states of the system can be engineered through careful design and fabrication. These arrays can be used to study the physics of geometrical frustration, where it is impossible to satisfy all the pairwise interactions of the system. By controlling the size, geometry and material through the lithographic process, ASI's serve as model systems and the exact microsystem and its evolution in time can be observed directly for detailed comparison with theoretical prediction.

We have fabricated and tested artificial spin ices in permalloy, CoFeB alloy using electron beam lithography, metal deposition and ion milling. Square ice (fig. 1) has been fabricated with a sub-15nm CD in Py on silicon substrates for x-ray correlated photon spectroscopy (XPCS) experiments probing the thermodynamics of ASI over a wide range of temperatures and timescales. Initial experiments show a trend of faster decorrelation at increasing temperatures (fig 2). Similar ASI in CoFeB have been fabricated on silicon nitride membranes for x-ray magnetic circular dichroism (XMCD) microscopy studies which employ an on-chip thermometer to control the thermal state of the array. The flexibility of EBL also allows for more complicated geometries to study richer physics of ASI. Aperiodic Penrose-type arrays have been fabricated in Py on silicon and silicon nitride (fig 3). Fabrication techniques and experimental results will be presented.

J.P Morgan, A. Stein, S. Langridge, C. H. Marrows, "Thermal Ground State Ordering and Elementary Excitations in Artificial Magnetic Square Ice," Nature Physics, 7, 75-79 (2011).

Z. Budrikis, J.P. Morgan, J. Akerman, A. Stein, P. Politi, S. Langridge, C.H. Marrows, R.L. Stamps,"Disorder strength and field-driven ground state domain formation in artificial spin ice: experiment, simulation, theory," Physical Review Letters 109 (3), 37203, (2012).

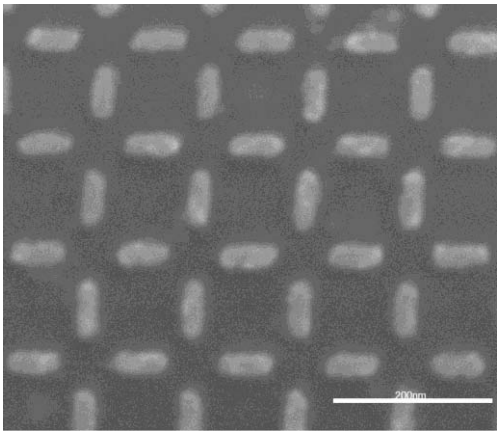

Fig. 1. Section of a square artificial spin ice fabricated in permalloy by electron beam lithography and lift-off. The dimensions of each island is 30nm x 74nm x 13nm thick.

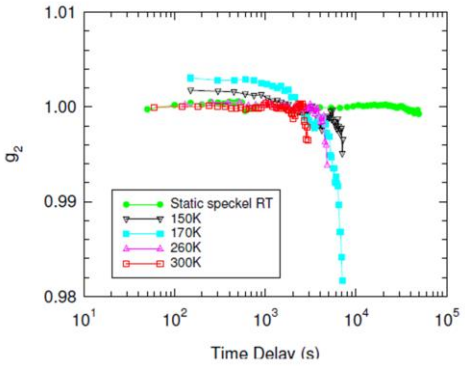

Fig. 2 XPCS data for 30x74x13 nm islands with an athermal sample (plotted in green) with 80x250x25 nm island volume for comparison. It is clear from this initial data set that with increasing temperature, the scattering intensity decreases suggesting a faster decorrelation time and an increase in fluctuations.

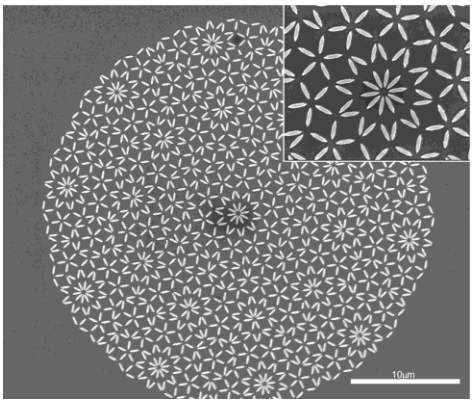

Fig. 3. Penrose-tile artificial spin ice fabricated by electron beam lithography and lift-off.