Experimental report

17/05/2022

Proposal: **5-54-352** **Council:** 10/2020

Title: Domain wall dynamics in arrays of Permalloy rings

Research area: Materials

This proposal is a new proposal

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Samples: Ni80Fe20 nanostructures grown on Silicon substrates

Instrument	Requested days	Allocated days	From	To
D33	4	0		
D17	4	2	15/06/2021	17/06/2021

Abstract:

Stochastic behaviour has traditionally been a limiting factor in the development of nanomagnetic technology. However, it can also give rise to emergent behaviour that can help us to understand phenomena in frustrated systems. In particular, this emergent behaviour is useful for a novel form of neuromorphic computing called 'reservoir computing' which is highly efficient for time domain processing of signals.

In this experiment, we plan to study the in-plane magnetic emergent behaviour in Ni80Fe20 ring arrays using grazing incidence small angle neutron scattering and off specular scattering. We will study different diameter (2 and 4 microns), widths (100, 200 and 300 nms) and lattice arrangements (hexagonal and Kagome) of rings which will significantly affect the emergent behaviour and thus give us the option of tailoring system emergent response for computing purposes. The experiment will form part of a wider effort to understand emergent behaviour in nanomagnetic arrays for reservoir computing applications (supported by the SpinENGINE HORIZON 2020 grant 861618). The results will allow us to gain unique insights into the population behaviour of interacting magnetic ring arrays.

The aim of these measurements was to study the emergent behaviour of magnetic domain walls in nanoring arrays for their utility in novel computing architectures such as reservoir computing (RC). We have previously simulated RC and tasks such as spoken digit recognition using such arrays [1] and showed the possibility of low power computing. Using this proposed study, we wanted to explore additional behaviour by exploring the parameter space of the ring arrays which can lead to possible advantages in computation.

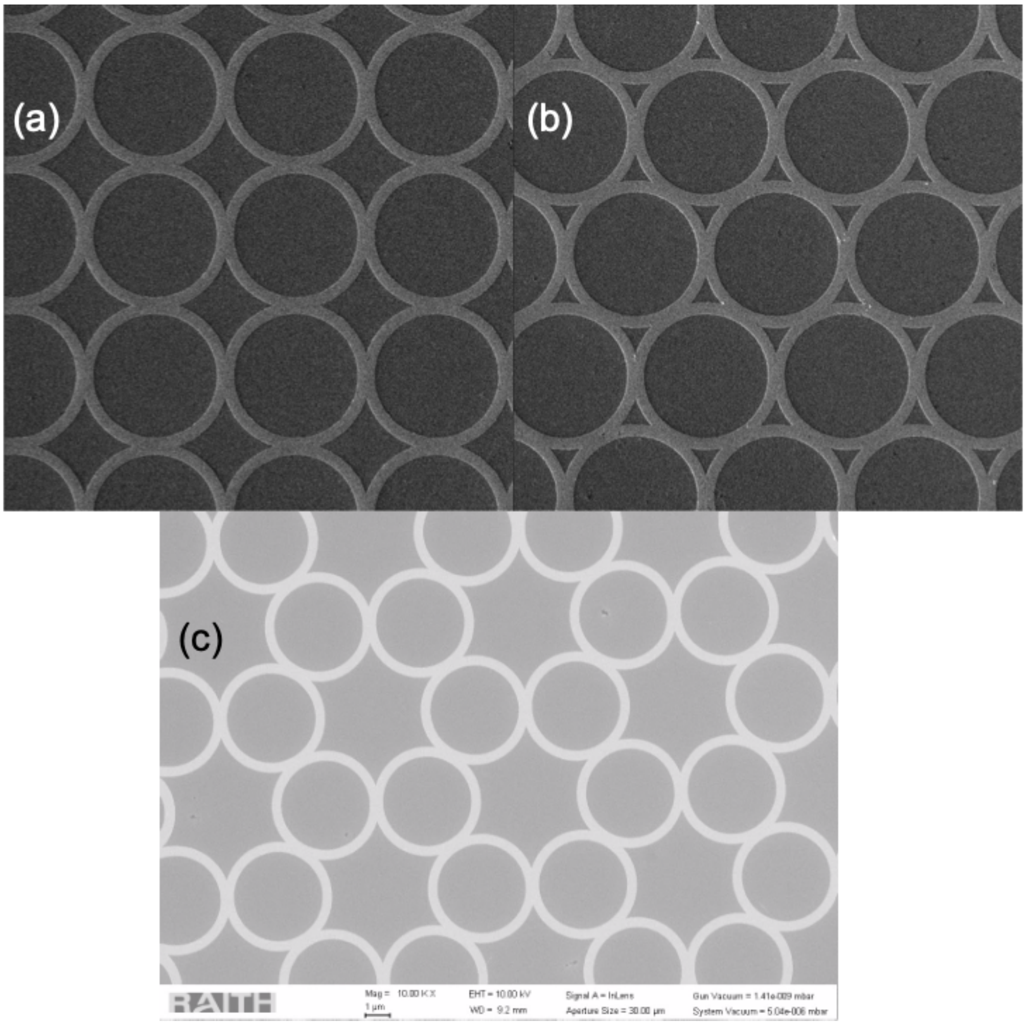

Figure 1: Scanning electron microscopy micrographs of (a) square, (b) trigonal and (c) Kagome arrangements of rings in arrays.

We decided to vary the lattice arrangements of the ring arrays as (a) square, (b) trigonal and (c) Kagome arrangements (as shown in Fig. 1). The rings were made on p-doped Si by spin coating, electron beam lithography, thermally evaporating 10 nm of $Ni_{80}Fe_{20}$ followed by subsequent liftoff. The rings were 4 μm in diameter, 300 nm in width and had an overlap of 50% of the width (or 150 nm). Each array covered a 15x15 mm2 area of sample so as to get appreciable scattered signal in PNR measurements. Note that compared to the PNR measurements reported in [1], rings in these arrays did not have any gaps between them and so resulting measurements were devoid of artefacts due to that.

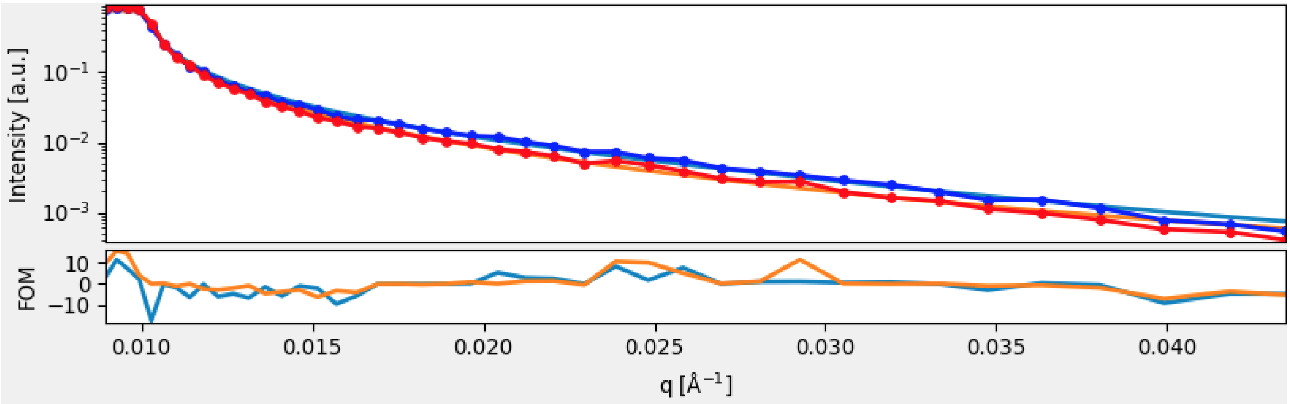

Figure 2: The scattered PNR spectra from the Kagome sample with fits obtained using GenX [2].

The measurements were performed as follows: An extended spectrum (with decent statistics) was collected from each sample with a saturation field and this was fit (using GenX) to obtain parameters such as thickness, density and roughness (as shown in Figure 2). The fitting procedure also used a subroutine to find parameters such as the ‘fill ratio’ of rings in the array (which is expected to be different for each lattice arrangement). Now for each subsequent measurement, after saturation, a rotating magnetic field was applied (using a custom motor driven rotating sample holder constructed by the beamline scientist) and the PNR spectra collected. This was repeated for different rotating field amplitudes and each such spectra was now fit to find only the magnetisation for that rotating field (using other parameters obtained from the saturation fit). The variation of the magnetisation (**M**) of the array with rotating field amplitude for the different lattice arrangements is shown in Figure 3.

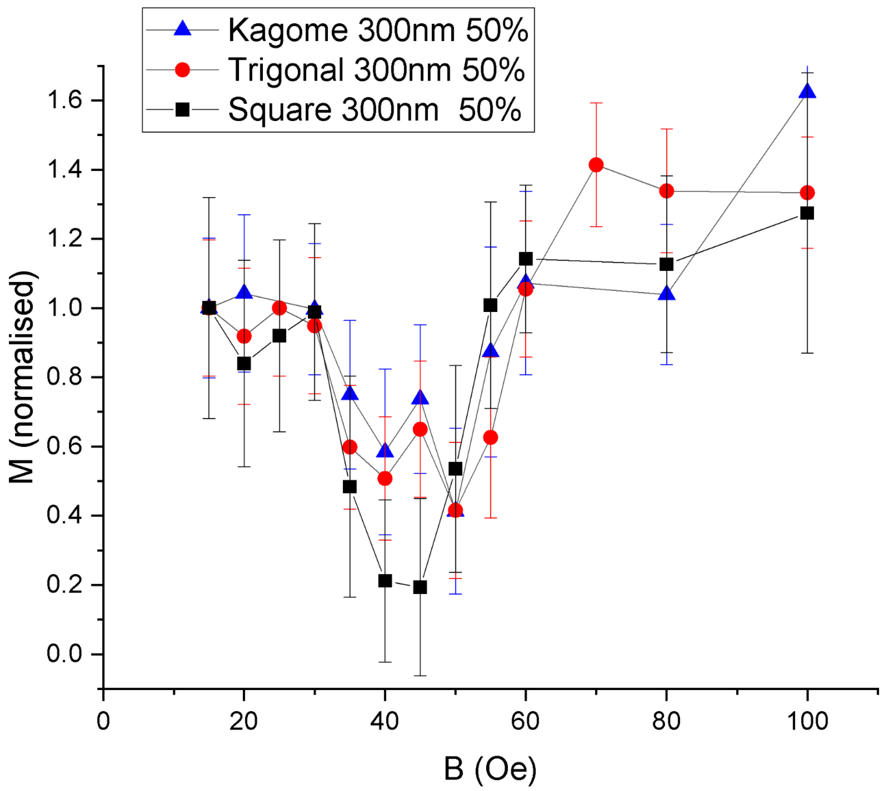

Figure 3: The variation of the array magnetisation with rotating field amplitude for the different lattice arrangements. Each plot has been normalised to the value of ***M*** *at the lowest field for ease of comparison.*

We expected to see differences in the variation of **M** for the different lattice arrangements due to the variation in the number of nearest neighbours of each ring. We can see that all the three arrays start off with a constant level of **M** which then decreases and reaches a minimum followed by a subsequent increase and a final saturation. This final saturated level is not the same as the initial level (for low fields) for the trigonal state while it is approximately the same for the other arrangements. Also, the width of the intermediate dip in **M** might be slightly larger for the trigonal and Kagome arrangements compared to the square arrangement. The extinction ratio of the dip for the square arrangement is the maximum indicating the largest change in the magnetic microstates in that arrangement of rings.

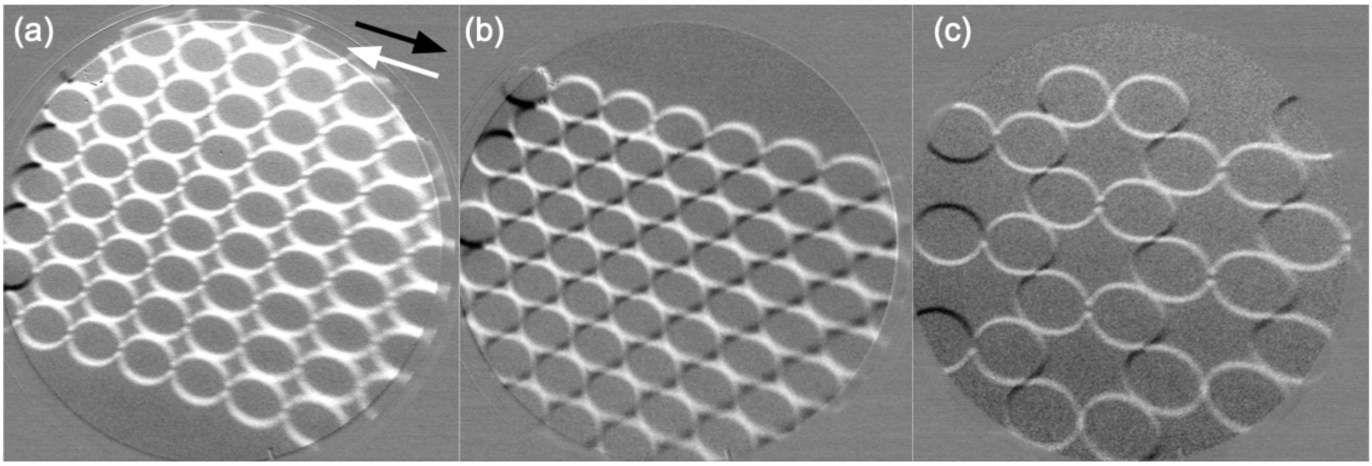

Figure 4: PEEM images showing the saturated states of each lattice arrangement. The arrows show the directions of sensitivity of the PEEM measurement.

We have now also imaged the microstates in each of these lattice arrangements using Photo-emission electron microscopy (PEEM) at the ALBA synchrotron in Spain and some images for each arrangement is shown in Figure 4. We can see that the ground (saturated) state of each array is significantly different which starts to explain the different dynamics shown by them. We are now in the process of analysing all the PEEM images we have collected to correlate with the PNR measurements. We expect that this work will lead to a novel publication exploring the different behaviours shown by these arrays and also the possible added functionality offered by them for reservoir computing.

REFERENCES:

1) R. W. Dawidek *et al.* "Dynamically driven emergence in a nanomagnetic system." *Advanced Functional Materials* 31.15, 2008389 (2021).
2) M. Björck and G. Andersson, "GenX: an extensible X-ray reflectivity refinement program utilizing differential evolution." *Journal of Applied Crystallography* 40.6, 1174 (2007).