Integrated Magnonic Reservoir Computing with Magnetic Metamaterials

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Reservoir computing (RC) is a machine learning paradigm where computation is performed using the intrinsic memory and nonlinearity of a dynamical system. Traditionally, the dynamic system is provided algorithmically by a recurrent neural network, but such a network can be replaced with a physical dynamic system to realise the paradigm in hardware [1]. Substituting the complex simulation of a neural network with measurements of the *intrinsic* physical dynamics of a device has the potential to greatly reduce the energy costs of both training and inference.

Magnetic metamaterials such as artificial spin ices and interconnected magnetic nanoring arrays (NRAs) [2] exhibit rich, emergent dynamics that stem from the local interactions between the constituent elements in an array. The complex, history dependent and highly non-linear magnetisation dynamics of these arrays, coupled with their enormous state spaces, make magnetic metamaterials compelling candidates for use as physical reservoirs.

Motivated by this, we have shown state-of-the-art performance of interconnected NRAs as reservoir computers when their global anisotropic magnetoresistance is used as a readout method [3]. However, this low dimensional readout of restricts the representation of the NRA's complex state space to a scalar value, this sacrificing computationally useful information.

In this presentation we first review our previous work on RC with NRAs before presenting new experimental results that explore the feasibility of using the characteristic spin wave spectra of NRAs to provide a richer, more detailed readout of the number, orientation and type of magnetic states in the array. We both demonstrate how this allows us to perform benchmark machine learning tasks, such as signal transformation, and use task agnostic computational metrics to evaluate the NRA's computational properties. Finally, we show the feasibility of creating device-compatible implementations of this approach by integrating a microscale-array onto a Pt waveguides. We experimentally demonstrate the reading out of magnonic spectra via the inverse spin Hall effect, and use micromagnetic simulations to demonstrate that the array's dynamics can be driven using the spin Hall effect, thus offering a clear route towards miniaturisation.

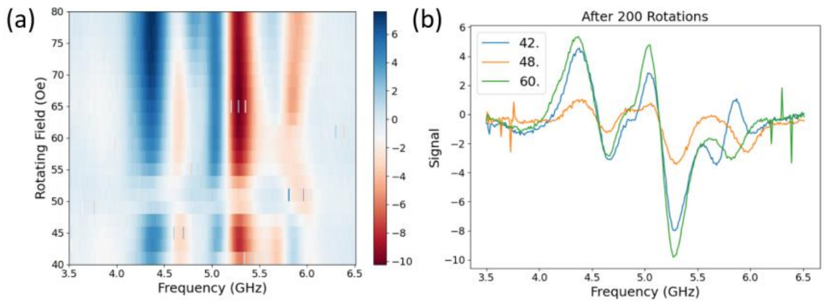

Figure 1: (a) Colourmap of the frequency response of an interconnected NRA with ring diameter = 4 μm and linewidth = 400 nm and 500 nm following 200 rotations of an applied field. (b) Example line scans from the plot in (a) taken close to the point where emergent behaviour occurs. Data is shown for rotating fields of amplitude = 42 Oe (blue), 48 Oe (orange) and 60 Oe (green).

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[2] R.W. Dawidek *et. al.* Adv. Funct. Mater **31**, 2008389 (2021).
[3] I.T. Vidamour *et. al.* Comms. Phys. **6**, 230 (2023).