Towards nano-scale magnetic biosensors: demonstration of nanoparticle detection with a magnonic crystal

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Magnetic biosensors function by detecting chemically functionalised magnetic nanoparticles that are used to label disease markers in biological samples [1]. Such schemes are compatible with magnetic separation methods and a range of biological media, providing routes for highly sensitive and versatile diagnostic tests. Nanoparticles have traditionally been detected electronically using magnetoresistive devices with lateral dimensions on the order of 10-100 μm. In these room temperature devices, the quasi-static magnetic configuration of the ferromagnetic sensing element, and thus the device's resistance, is modified by stray magnetic fields generated by nearby nanoparticles, enabling voltage-based nanoparticle detection.

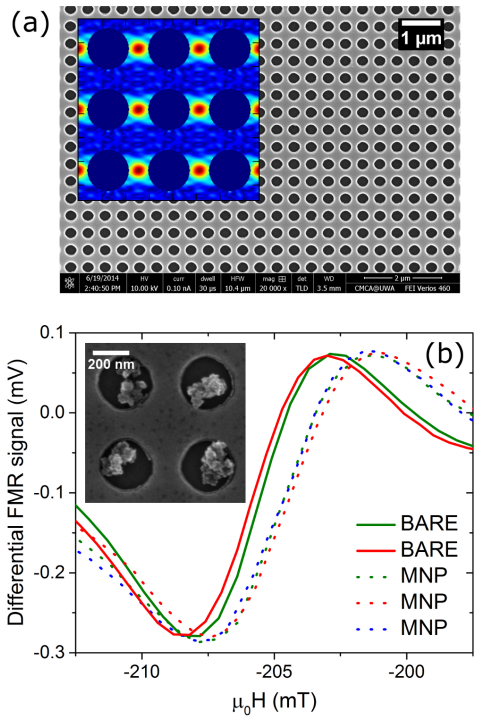

Figure 1: (a) Wide field of view scanning electron micrograph of a magnonic crystal consisting of a ferromagnetic NiFe film with a periodic array of holes. Inset shows an example visualisation of a resonant mode localised between neighbouring holes, simulated in a region containing a 3×3 array of holes with periodic boundary conditions. (b) Experimentally obtained derivative of the ferromagnetic resonance peak at 11.5GHz for a magnonic crystal consisting of 300 nm wide holes before ('Bare') and after ('MNP') the application of magnetic nanoparticles. Multiple traces are shown for different physical replacements of the sample, indicating the error associated with removing and replacing the sample (a requirement to apply nanoparticles). Inset shows a scanning electron micrograph of 4 holes containing cluster-shaped magnetic nanoparticles.

In this work, we demonstrate the use of resonant magnetisation *dynamics* for magnetic nanoparticle detection wherein magnetic nanoparticles modify localised GHz frequency oscillations of a nanostructured material's magnetic moment. This is directly relevant for recently developed magnetic field sensing devices known as spin torque nano-oscillators (STNOs) which are hoped to pave the way for frequency-based (rather than voltage-based) electronic magnetic biosensing [2]. As compared to conventional magnetoresistive devices, STNOs are expected to remain operational with reduced physical dimensions ($\sim$ 100 nm) and have faster response times.

After introducing magnetic biosensing techniques, we will discuss measurements carried out on large area (4×4 mm^2) magnonic crystals (periodically nanopatterned ferromagnetic films [3, 4], Fig. 1(a)). These systems enable macroscopic probing of spatially localised ferromagnetic resonance modes [Fig. 1(a), inset] which are analogous to those that arise in isolated nanostructures. Using field modulated ferromagnetic resonance (FMR) spectroscopy, we show that magnetic nanoparticles measurably modify these modes [Fig. 1(b) and its inset]. Resonance peak shifts, $H_{\rm shift}$, are shown to depend upon the mode's spatial localisation and the nanoparticle coverage. The mode shifts are comparable to the peak-to-peak resonance linewidths, ΔH_{p-p}, which is highly encouraging for practical applications (eg. $\mu_0 H_{\rm shift} = 2$ mT and $\mu_0 \Delta H_{\rm p-p} = 6$ mT in Fig. 1(b)). Additionally, there is good agreement between experiment and micromagnetic simulations [5, 6], both in terms of the sign and the magnitude of the resonance peak shifts.

Finally, we will briefly discuss ongoing work on nanoparticle detection with isolated magnetic nanostructures being carried out with collaborators in France.

This work was supported by the Australian Research Council's Discovery Early Career Researcher Award (DE120100155) and Discovery Projects (DP110103980) schemes, the National Research Foundation Singapore (NRF-CRP 10-2012-03), the EPSRC (DTC grant EP/G03690X/1), the University of Western Australia's (UWA) ECRFS, RCA and RDA schemes, iVEC@UWA and CMCA@UWA.

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