PNN: Micromagnetic simulations and direct visualisation of artificial spin ice

Supervisor(s): Solveig Felton

Research Centre: CQMT

Suitable for: A student with knowledge of or interest in solid state magnetism and simulations

Type of Project: Simulations

Skills required: Basic knowledge of solid state magnetism; some programming ability

Skills gained: Development of experience in nanoscale physics and magnetic materials. Micromagnetic simulations and data interpretation

Background/Context/Introduction [Adjust as required]

Frustration, i.e. the inability to simultaneous satisfy all interactions, occurs in a wide range of systems such as glasses, neural networks and water ice making systems where the frustrated properties can be measured of fundamental scientific interest. One such type of model system is 'spin ice', where the atomic magnetic moments are frustrated due to geometrical constraints; this type of magnetic ordering was originally found in pyrochlore crystals at very low temperatures. In two-dimensional artificial spin ices the atomic moments are replaced with ferromagnetic islands with lengths of between 1 μm and 100 nm, which act as miniature bar magnets. This allows a number of the interesting properties of the canonical spin ices, such as emergent magnetic monopoles, to be reproduced.

Simulations are a key technique for understanding nanomagnetism, a subject that spans a wide range of topics from fundamental research on for example frustrated systems to applied technologies including data storage devices, spintronics and quantum computing. This project will therefore provide opportunities to develop useful transferable skills, as well as studying an interesting area of physics.

This Project

In this project, the Boris Computation Spintronics simulations package will be used to simulate the magnetic state of different types of artificial spin ice structures and their reversal mechanisms in magnetically connected and disconnected lattices. These results will also be used to simulate the anisotropic magnetoresistance of the network in different states, and compared to experimental data. We will employ magnetic force microscopy as well as Nitrogen vacancy (NV) based microscopy to image the magnetic frustration via direct imaging of the magnetic domains. The work will leverage high end scanning probe microscope and one-of-its-kind NV microscope in QUB.

Useful references

C. Nisoli, R. Moessner and P. Schiffer: Colloquium: Artificial Spin Ice, *Rev. Mod. Phys.* **85**, 1473 (2013)

M.J. Harris, S.T. Bramwell, D.F. McMorrow, T. Zeiske, and K.W. Godfrey, Geometrical Frustration in the Ferromagnetic Pyrochlore Ho2Ti2O7, *Phys. Rev. Lett.* **79**, 2554 (1997)

R.F. Wang et al., Artificial 'spin ice' in a geometrically frustrated lattice of nanoscale ferromagnetic islands, *Nature* **439**, 303 (2006)

S. Ladak, D.E. Read, G.K. Perkins, L.F. Cohen and W.R. Branford, Direct observation of magnetic monopole defects in an artificial spin-ice system, *Nature Phys.* **6**, 359 (2010)

Boris Computational Spintronics, http://www.boris-spintronics.uk/