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HoMMage

Hysteresis Design of Magnetic Materials for Efficient Energy Conversion

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Three-dimensional nanomagnetism: from textures in the bulk to patterned magnetic nanostructures

Abstract:

Three dimensional magnetic systems promise significant opportunities for applications, for example providing higher density devices and new functionalities associated with complex topology and greater degrees of freedom [1,2]. With recent advances in both characterization and nanofabrication techniques, the experimental investigation of these complex systems is now possible, opening the door to the elucidation of new properties and rich physics.

For the characterization of 3D nanomagnetic systems, we have developed techniques to map both the three-dimensional magnetic structure, and its response to external excitations. In a first demonstration of X-ray magnetic nanotomography [3,4], we determined the complex magnetic structure within the bulk of a µm-sized soft magnetic pillar. The magnetic configuration contained vortices and antivortices, as well as Bloch point singularities [3]. With these new datasets comes a new challenge concerning the identification of such nanoscale topological objects within complex reconstructed magnetic configurations. To address this, we have recently implemented calculations of the magnetic vorticity [5,6], that make possible the location and identification of 3D magnetic solitons, leading to the first observation of nanoscale magnetic vortex rings [6].

In addition to the static magnetic structure, the dynamic response of the 3D magnetic configuration to excitations is key to our understanding of both fundamental physics, and applications. With our recent development of X-ray magnetic laminography [7,8], it is now possible to determine the magnetisation dynamics of a three-dimensional magnetic system [7].

Finally, recent advances in nanofabrication make possible the fabrication of complex 3D magnetic nanostructures [9], leading to the realisation of artificial chiral structures [10] and 3D spintronic devices [11]. These new experimental capabilities for 3D magnetic systems open the door to complex three-dimensional magnetic structures, and their dynamic behaviour.

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[3] Donnelly et al., “Three-dimensional magnetization structures revealed with X-ray vector nanotomography” Nature 547, 328 (2017).
[4] Donnelly et al., “Tomographic reconstruction of a three-dimensional magnetization vector field” New Journal of Physics 20, 083009 (2018).
[5] Cooper, “Propagating magnetic vortex rings in ferromagnets.” PRL. 82, 1554 (1999).
[6] Donnelly et al., “Experimental observation of vortex rings in a bulk magnet” Nat. Phys. 17, 316 (2020)
[7] Donnelly et al., “Time-resolved imaging of three-dimensional nanoscale magnetization dynamics”, Nature Nanotechnology 15, 356 (2020).
[8] Witte, et al., “From 2D STXM to 3D Imaging: Soft X-ray Laminography of Thin Specimens”, Nano Lett. 20, 1305 (2020).
[9] Skoric et al., “Layer-by-Layer Growth of Complex-Shaped Three-Dimensional Nanostructures with Focused Electron Beams” Nano Lett. 20, 184 (2020).
[10] Sanz-Hernández et al., “Artificial Double-Helix for Geometrical Control of Magnetic Chirality” ACS Nano 14, 8084 (2020).
[11] Meng et al., “Non-planar geometrical effects on the magnetoelectrical signal in a three-dimensional nanomagnetic circuit” ACS Nano 15, 6765 (2021).

About the speaker:

Claire Donnelly is currently a Leverhulme Early Career Research Fellow in the Cavendish Laboratory, University of Cambridge. She was awarded her PhD in 2017 from the ETH Zurich for her work on hard X-ray tomography of three-dimensional magnetic structures based at the Paul Scherrer Institute. Following a postdoc at the ETH Zurich, she moved to the University of Cambridge and the Cavendish in January 2019, where she is focusing on the dynamics of three-dimensional magnetic nanostructures. She will be starting her own research group in the autumn at the Max Planck Institute for Chemical Physics of Solids, continuing this study of 3D magnetic systems. Her work has been recognised with a number of prizes, most recently with the European Magnetism Association Young Scientist Award.