

Soft X-ray phase nano-microscopy of micrometre-thick magnets

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The development and optimisation of magnetic materials in various applications, including clean energy generation and spintronics, depend on an understanding of their nanoscale magnetisation configurations. However, until recently, nanoscale magnetic imaging was limited to thin film or surface investigations, with thicker magnetic systems greater than a few hundred nanometres limited to rare-earth materials [1]. As a result, investigations of extended non-rare earth magnets were not possible.

Here, we overcome this limitation by using pre-edge phase magnetic imaging with soft X-ray ptychography, providing nanoscale imaging of extended magnetic systems of arbitrary composition. Using X-ray ptychography, we gain access to the prominent pre-absorption edge phase X-ray Magnetic Circular Dichroism (XMCD) signal, which we use to demonstrate imaging of the magnetic configuration of samples upto 1.7 μm in thickness, an order of magnitude larger than typically measured with conventional soft X-ray absorption based techniques.

The prospect of combining pre-edge phase XMCD with 3D magnetic vector imaging [2,3] is particularly exciting, as it enables the direct mapping of the magnetisation vector field of buried magnetisation textures in a variety of extended samples. These advances enable nanoscale imaging of a broad range of samples, including thick chiral helimagnets with novel topological states and naturally-occurring magnetite micro-magnets that until now, have not been possible to measure.

[1] Donnelly, C. et al., (2016) Phys. Rev. B, 94 (064421).

[2] Donnelly, C. et al., (2017) Nature, 547 (328-331).

[3] Di Pietro Martínez, M. et al., (2023) Phys. Rev. B, 107 (094425).

[4] Neethirajan, J. et al., (2024) Phys. Rev. X, 14 (031028).

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