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Reconstruction of the magnetisation in a hard magnetic needle using model-based electron holographic tomography

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The development of an experimental technique that allows the three-dimensional (3D) magnetic state of a nanoscale object to be measured quantitatively is of great importance for fundamental and applied research in magnetism. Off-axis electron holography is a powerful technique that allows the phase shift of an electron wave that has passed through a specimen in the transmission electron microscope (TEM) to be recorded. The phase shift is, in turn sensitive to the in-plane component of the magnetic induction within and around the specimen projected in the electron beam direction. A combination of electron holography and conventional tomographic reconstruction has previously been applied to recover the 3D magnetic induction within and around materials (1, 2). Here, we use model-based iterative reconstruction (MBIR) to retrieve the 3D magnetization in a Nd-Fe-B needle from a tilt series of magnetic phase images recorded using electron holography (3).

A Nd-Fe-B needle was prepared using focused ion beam milling (Fig. 1a) and is examined in a dedicated 360° tomography holder. A 360° tilt series of off-axis electron holograms was recorded with a tilt increment of 5°. Linear geometric distortions originating from the projection system of the TEM were removed from each reconstructed phase image. In order to separate the magnetic and electrostatic (mean inner potential) contribution, each phase image was subtracted from a corresponding phase image recorded with the sample turned over to obtain a 180° tilt series of magnetic phase images and a corresponding 180° tilt series of mean inner potential phase images. The latter images were used to reconstruct the 3D morphology of the needle (Fig. 1b) using a conventional tomographic algorithm. This 3D shape was used as a mask to define the outer boundary of the magnetic moments that were recovered using the MBIR algorithm. A 3D magnetic buffer zone was also used to take account of contributions to the magnetic phase images from magnetic objects outside the field of view. The final reconstructed 3D magnetisation distribution (Fig. 2) comprises four magnetic domains, which are oriented in opposite directions orthogonal to the needle axis. These experimental findings are compared with micromagnetic simulations and a good agreement between experiment and theory is found.

References:

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Fig. 1: a) Bright-field TEM image and b) reconstructed 3D morphology of the Nd-Fe-B needle-shaped specimen.

Fig. 2: Reconstructed 3D magnetisation distribution in the Nd-Fe-B needle-shaped specimen obtained by applying the MBIR algorithm to a dataset recorded using off-axis electron holographic tomography.

Fig. 1

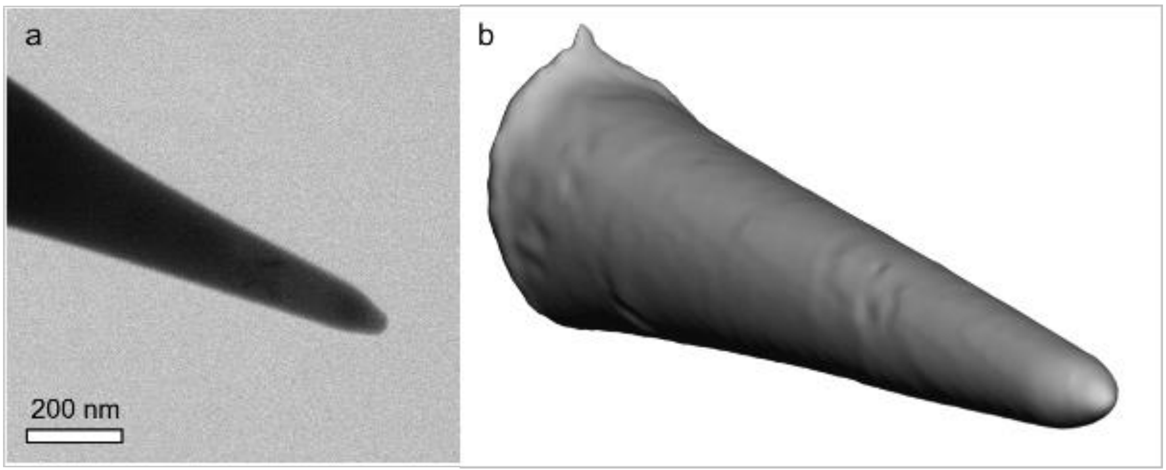

Fig. 2