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Seeing with Phase: Interferometric Electron Microscopy for Magnetic Materials and Biological Specimens

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Advances in imaging solid state materials at the nanoscale can lead to advances in imaging biological materials, and vice versa. For example, methods used to study biological materials in cryoEM are quite similar to methods developed for the study of magnetic materials. In both materials, features of interest are often only stable at low temperatures, and both are also essentially transparent to electrons. Materials composed of light elements such as biological specimens do not efficiently scatter electrons, and predominantly only impart subtle phase shifts to directly transmitted electrons. Likewise, nanoscale magnetic field textures inside samples do not scatter electrons, but introduce phase gradients onto the electrons. Thus, researchers in both cryoEM and nanomagnetic microscopy communities apply similar methods to provide phase contrast: defocus the instrument to a degree that subtle phase variations interfere to form observable intensity contrast. Perhaps new methods designed to image electric and magnetic fields more efficiently at higher resolutions can be applied to biological specimens.

At the University of Oregon, we apply aberration-corrected Lorentz TEM at cryogenic temperatures to image magnetic features in thin specimens [1,2]. By analysing these images with the transport of intensity equation (TIE), we can reconstruct the phase quantitatively, and from that extract the magnetic vector field (Fig. 1). These studies have revealed magnetic pseudoparticles with unusual topological features. Lorentz TEM, like cryoEM, is sensitive to gradients in the phase imparted to electrons by the sample, and both techniques must trade spatial resolution for contrast.

Electron interferometry [3–7] may provide a way to image both magnetic fields and biological specimens with improved phase sensitivity and spatial resolution. For example, the advent of fast direct electron detectors and nanofabricated diffractive electron optics have enabled recent demonstrations of atomic resolution phase imaging using a scanning electron interferometer [6]. For this work, a single modified condenser aperture equipped with a diffraction grating is used to coherently divide the electrons into two probes, one of which passes through the sample. Spherical aberration can even be removed holographically by incorporating design elements into the grating [8]. Combining such interferometric techniques with advanced cryoEM imaging and reconstruction methods might improve imaging of dose-sensitive specimens, and so collaborations between microscopists from different communities could be fruitful [9].

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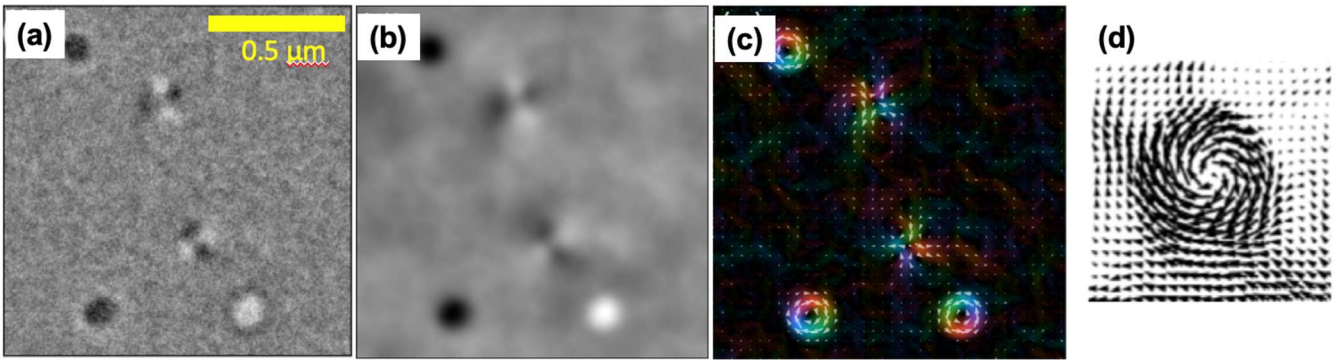

Figure 1. Phase contrast imaging of magnetic fields in an FeGd multilayer thin film using cryo Lorentz TEM. As described in [2], a single defocused image (a) can be used to reconstruct the phase (b) of the specimen, which can in turn be used to calculate the magnetic vector field (c).