Quantitative and new approaches for measuring magnetic fields in nanocrystals and devices

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Off-axis electron holography is a powerful technique for obtaining local magnetic information about nanoscale materials with a spatial resolution of better than 10 nm in the transmission electron microscope. The technique involves interfering a high-energy electron wave that has passed through the region of interest with a reference wave that has passed only through vacuum to record the phase shift of the specimen wave, which is sensitive to the electromagnetic field within and around the specimen.

Traditionally, studies of magnetic materials using off-axis electron holography have been semi-quantitative and have involved the examination of static magnetic fields in specimens that were synthesized outside the microscope. Recent advances in image interpretation and instrumentation now allow new quantitative information to be obtained and both dynamic experiments and chemical reactions to be studied.

We have recently developed an algorithm that can be used to measure the magnetic moment of an individual nanocrystal from electron-optical phase images recorded using electron holography. The approach involves evaluating either a contour integral of the phase around a circular path or the integral of the phase gradient bounded by the same loop. We illustrate its application to studies of magnetite and cobalt crystals examined as a function of the magnetic field applied to the specimen before hologram acquisition. Progress in the study of dipolar ferromagnetism and exsolved minerals using both this algorithm and a model-based method is discussed. We also describe the examination of working magnetic devices *in situ* in the transmission electron microscope and we discuss prospects for measuring weak magnetic fields at close to atomic resolution, measuring magnetic vector fields inside nanocrystals in three dimensions and combining electron holography with *in situ* reduction and oxidation studies in an environmental transmission electron microscope.