The prospect of 3-dimensional induction mapping inside magnetic nanostructures by combining electron holography with electron tomography

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There is an increasing need to combine analytical techniques in the transmission electron microscope with microscope control and image analysis to obtain unique information about nanostructured materials.

Here, we examine the prospect of characterizing magnetic vector fields inside nanocrystals in three dimensions by combining electron tomography with electron holography, a technique that allows the phase shift of an electron wave that has passed through a specimen to be measured.

When characterizing three-dimensional magnetic fringing fields in vacuum, the acquisition of two ultra-high-tilt series of electron holograms about orthogonal axes can be used to provide the three-dimensional distribution of two of the three components of the induction Bx and By within and around a sample, where x and y are directions perpendicular to the incident electron beam direction z.

If each phase image is differentiated in a direction perpendicular to the tilt axis, then standard tomographic reconstruction algorithms can be used to calculate the three-dimensional distribution of the component of B that lies parallel to the tilt axis.

After determining Bx and By in three dimensions this way, Bz can be evaluated by making use of the criterion that V.B = 0.

The application of this approach to the characterization of magnetic fields inside nanostructured magnetic materials is complicated by the fact that the (often dominant) mean inner potential contribution to the measured phase shift must be removed at each sample tilt angle.

This requirement can be achieved if each tilt series is recorded both before and after reversing the direction of magnetization in the specimen (e.g., using the microscope objective lens).

Subsequently, half of the difference between pairs of reversed images acquired at each tilt angle can be used to provide the desired magnetic contribution to the phase shift.

In practice, many additional difficulties must be overcome if this combined technique is to be applied successfully:

The region of interest must lie close enough to a large enough hole in the thin specimen support film to allow electron holograms to be acquired at high sample tilt angles about two tilt axes, without the region of interest (or the hole) being shadowed by other parts of the specimen. For a sample of magnetic nanocrystals on a carbon support film on a Cu grid, only regions that are both close to the centre of a grid square and near the center of the 3 mm sample are suitable for analysis.

In general, the distribution of nanocrystals imaged must be isolated and small, as the magnetic field from them should ideally decrease to close to zero at the edge of the field of view in each hologram. The difficulty of finding such a region is illustrated in the figures shown on the right and below. A chain of six magnetite nanocrystals is obscured by dirt on the specimen at high tilt angles even though it is located close to a 20 μm hole in a carbon support film.

The need to record images at tilt angles of up to ±80° to avoid reconstruction artifacts is also much more strict than for applications of tomography to the characterization of microstructure or chemistry. This difficulty results from the fact that the desired magnetic vector field may decay slowly towards (and indeed outside) the edges of the reconstructed volume, and each component of the vector field is likely to change within the field of view.

Few of these difficulties are insurmountable if sufficient resources are invested in the development, and ultimately automation, of this technique.

The figure on the right shows holograms taken from a tilt series of a chain of ferromagnetic FeNi particles acquired successfully about orthogonal tilt axes.

References:

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