MONASH University
Centre for Electron Microscopy

SEMINAR

New directions in electromagnetic field mapping at the nanoscale in the transmission electron microscope

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Abstract

Off-axis electron holography is a powerful technique for recording the phase shift of a high-energy electron wave that passes through an electron-transparent specimen in the transmission electron microscope. The phase shift is, in turn, sensitive to the magnetic induction and electrostatic potential in the specimen. Recent developments in the technique have included the use of advanced specimen holders with multiple electrical contacts to study nanoscale working devices and the use of ultra-stable transmission electron microscopes to achieve sub-2π/1000-radian phase sensitivity.

We are currently working on a model-based approach that can be used to reconstruct the three-dimensional magnetization distribution in a specimen from a series of phase images recorded using electron holography. We generate simulated magnetic induction maps by projecting a best guess for the three-dimensional magnetization distribution onto a two-dimensional Cartesian grid. We simulate phase images of arbitrary three-dimensional objects from any projection direction by making use of known analytical solutions for the phase shifts of simple geometrical objects, with numerical discretisation performed in real space to avoid artifacts generated by discretization in Fourier space, without a significant increase in computation time. This forward simulation approach is then used in an iterative model-based algorithm to solve the inverse problem of reconstructing the three-dimensional magnetization distribution in the specimen from a tomographic tilt series of two-dimensional phase images. This approach avoids many of the artifacts that result from using classical tomographic techniques such as filtered backprojection, as well as allowing additional constraints and known physical laws to be incorporated.

We are also working on the application of off-axis electron holography to the measurement of electrostatic potentials and electric fields inside and surrounding nanoscale materials and devices. The first example that I will describe is related to the measurement of electric fields around electrically-biased atom probe tomography needles. The recorded phase shift can be analyzed either by fitting the phase distribution to a simulation or by using a model-independent approach that involves contour integration of the phase gradient to determine the charge enclosed within the integration contour. Both approaches require evaluation of the difference between phase images acquired for two applied voltages, in order to subtract the mean inner potential (and sometimes also the magnetic) contribution to the phase. The second example involves the study of individual two-dimensional flakes of transition metal dichalcogenides such as tungsten selenide, in which measurements of electrostatic potential can provide information about the redistribution of charge due to the presence of the specimen surface in a truly two-dimensional layered material.

When recording weak phase shifts in such materials using off-axis electron holography, it is important to remember that the sample must remain clean and undamaged for the time required to acquire images with a sufficient signal to noise ratio, that electron-beam-induced charging can affect the measured phase shift and that for crystalline specimens careful comparisons with dynamical simulations may be required even for a thickness of only a few atoms.

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