Recent Progress in Electromagnetic Field Mapping at the Nanoscale

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Recent studies of electromagnetic fields using off-axis electron holography in the transmission electron microscope (TEM) have involved the use of specimen holders with multiple electrical contacts to examine working devices, the application of holographic tomography to record three-dimensional potentials and the use of ultra-stable TEMs and phase-shifting holography to improve phase sensitivity. Here, we highlight a selection of the latest examples of our use of off-axis electron holography to quantify electromagnetic fields within and around novel device structures.

We have succeeded in measuring the magnetic field of a nanoscale current-carrying wire. As a current flowing parallel to the plane of an untilted TEM specimen produces no net magnetic phase shift, we examined a free-standing wire that contained a short nano-fabricated segment oriented parallel to the electron beam direction. The azimuthal magnetic field around this short section of wire resulted in a tuneable phase distribution that could be varied by changing the current in the wire. Different regions of such a wire could in principle be used to apply in-plane or out-of-plane magnetic fields to closely-adjacent nanomagnets in the TEM.

We have measured the electrostatic potentials of two collinear electrically-biased metallic needles. Phase images were analysed both through comparisons with simulations and by using a model-independent approach involving contour integration of the phase gradient [1]. Interestingly, spectacular caustic phenomena containing fold, butterfly and elliptic umbilic catastrophes were observed in defocused bright-field TEM images of the same electrically-biased metallic needles. The main features in the caustics were found to depend sensitively on defocus, on the applied voltage between the needles and on their separation.

We are currently working on the reconstruction of three-dimensional magnetization distributions inside materials directly from tilt series of phase images recorded using electron holography. Forward simulations are used in an iterative algorithm to solve the inverse problems from tomographic tilt series of phase images. The use of such model-based approaches avoids many of the artefacts that result from using classical tomographic techniques, while allowing additional constraints to be incorporated [2].

References

[1] M. Beleggia, T. Kasama and R.E. Dunin-Borkowski: Ultramicroscopy Vol. 110 (2010), p. 425

[2] G. Pozzi, V. Migunov, A.H. Tavabi, C. Dwyer, A. Kovács, J. Caron, P Diehle, A. Savenko, M. Beleggia, T. Kasama, A. London, T.F. Kelly, D.J. Larson and M. Farle are thanked for valuable contributions to this work.