Electron holography of functional materials

Rafal E. Dunin-Borkowsi and Takeshi Kasama

Center for Electron Nanoscopy, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark

Off-axis electron holography in the transmission electron microscope (TEM) is a powerful technique for studying magnetic and electric fields in functional materials and working devices with sub-10-nm spatial resolution. Here, we present results obtained from three distinct specimen geometries:

1. Magnetic remanent states in two-dimensional and linear arrangements of lithographically patterned nanostructures are studied. Regular arrays of spin-valve elements are prepared for TEM examination in plan-view geometry using focused ion-beam milling. The switching fields of the magnetic layers in individual elements are measured, and comparisons with micromagnetic simulations are used to infer the true magnetic thicknesses and widths of these layers. Inhomogeneities resulting from grain structure are observed to perturb the recorded magnetic states.

2. The effect of crystallography, size, shape and spacing on the formation and switching of magnetic states in sub-50-nm nanocrystals is studied. Interactions between neighboring crystals are observed to increase the critical size at which the transition from superparamagnetic to single domain behavior occurs. The combined effects of shape, crystallography and inter-particle interactions are found to stabilize single domain states in crystals that would normally be expected to support multiple domains if they were isolated.

3. Electron holography and the Fresnel mode of Lorentz electron microscopy are used to study domain wall motion and transformations following the injection of current pulses along permalloy wires that are patterned lithographically on electron-transparent silicon nitride windows. Spin structure transformations due to Joule heating are observed following the injection of current pulses and a set of indicators is devised to separate spin torque effects from heating. By using additional metal layers, the structures are cooled sufficiently to demonstrate current-induced domain wall motion due to spin torque.