ELECTRON HOLOGRAPHIC TOMOGRAPHY OF THREE-DIMENSIONAL MAGNETIZATION DISTRIBUTIONS IN FERROMAGNETIC NANOTUBES

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Abstract

Off-axis electron holography is a powerful technique that can be used be used to record the phase shift of a high-energy electron wave that has passed through a thin specimen in the transmission electron microscope (TEM). The phase shift is, in turn, sensitive to the electrostatic potential and the in-plane components of the magnetic induction within and around the specimen, projected in the electron beam direction. Here, we combine electron holography with electron tomography to reconstruct the three-dimensional magnetization distribution in a ferromagnetic CoFeB nanotube deposited around a GaAs nanowire core.

Experiments were performed using a C_S-corrected FEI Titan TEM operated at 300 kV with the specimen in magnetic-field-free conditions. Our approach involves (i) the acquisition of two orthogonal tilt series of electron holograms, (ii) separation of the magnetic from the mean inner potential contribution to the phase shift at each specimen tilt angle and (iii) the use of an iterative model-based reconstruction algorithm to infer the three-dimensional magnetization distribution in the specimen from the recorded phase images. In order to turn the sample over inside the microscope for separation of the magnetic from the mean inner potential contribution to the phase, an on-axis tomography holder was modified to accommodate 3-mm-diameter specimens and equipped with an inclinometer to allow to the specimen tilt angle to be measured to a precision of 0.1°. A new iterative model-based tomographic reconstruction algorithm was then used to recover the magnetization distribution in the specimen. The algorithm involves the repeated application of a forward model to calculate phase images based on simulated magnetization distributions and the use of an iterative solver to compare the resulting calculated phase images with experimental measurements.

Our results suggest that the magnetisation in the CoFeB shell tilts away from the axis of the nanotube, forming magnetic vortices of opposite chirality close to its ends. The influence of geometrical parameters on the magnetization configuration was investigated for nanotubes of different shape, both experimentally and using finite element micromagnetic simulations.

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