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IT-11-P-1514 Observation of the magnetic flux and three-dimensional structure of skyrmion lattices by electron holography

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Topological spin textures have been attracting increasing interest for use in studying quantum magneto-transport and for possible application to spintronics. Skyrmions are particularly attractive for use as information carriers in memory and logic devices because of the emergence of spin transfer torque at extremely low current densities (~106 A/m2) [1]. Several challenges must be addressed before the skyrmion can be applied to actual devices. They include realization of skyrmions at room temperature, clarification of their three-dimensional (3D) structures, and fabrication of thin films containing skyrmions. Despite recent theoretical studies, the 3D structures of skyrmions remain elusive. Observing the 3D structures of skyrmions at the microscopic level is a prerequisite for applications of skyrmions to spin-electronic devices.

Electron holography, using the wave nature of electrons, provides opportunities for directly detecting and visualizing, in real space, the phase shifts of the electron waves due to the electromagnetic fields [2]. However, precise phase measurement of weak phase objects such as skyrmions is very challenging because procedures are needed for averaging the phase images and separating the electric and magnetic vector potentials. Nevertheless, the advantage of electron holography compared to Lorentz electron microscopy and magnetic force microscopy, under just-focused condition, makes it possible to visualize a quantized magnetic flux with nanometer resolution, in addition to determining its density in the vicinity of skyrmions. Here we investigated the 2D magnetic flux distributions (Fig. 2) of skyrmion lattices in helimagnet Fe0.5Co0.5Si thin samples with a stepped thickness as shown in Fig. 1 and estimated the 3D structures of the helical and skyrmion phases by using high-voltage holography electron microscopes [3].

References:

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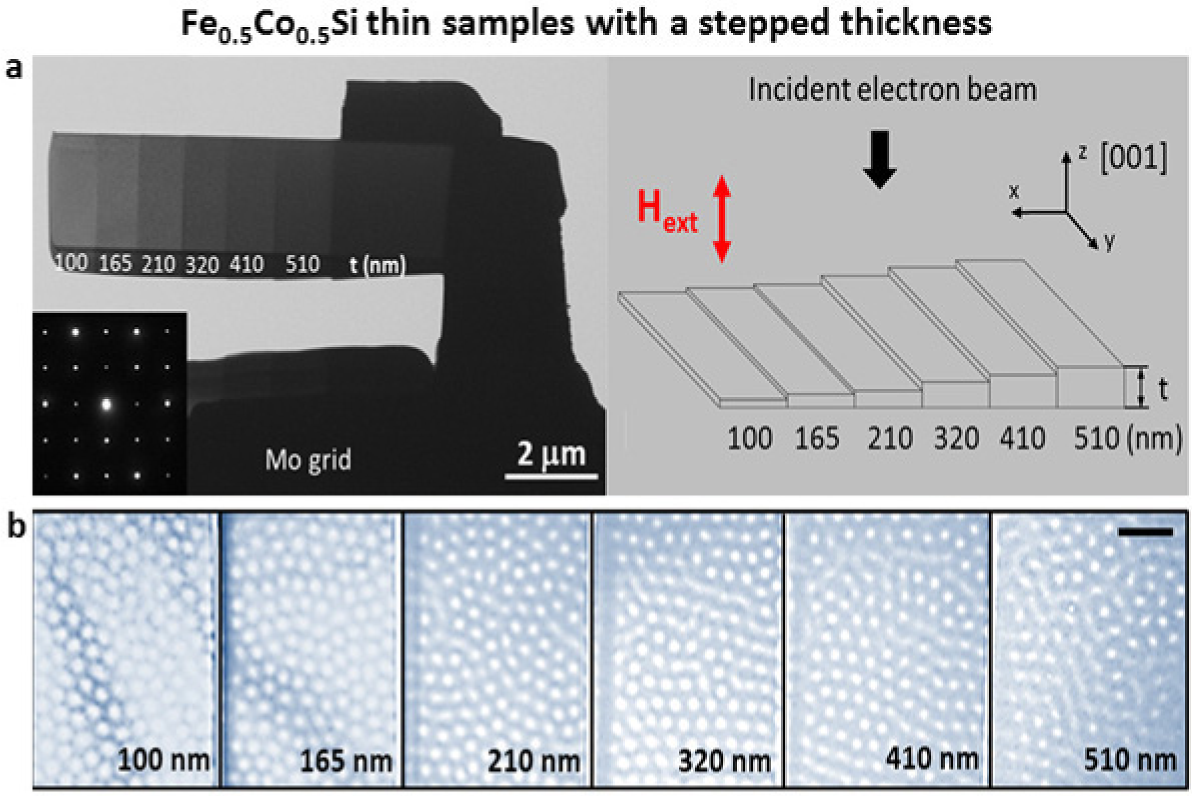

Fig. 1: Fig. 1. Lorentz micrographs. (a) A thin sample produced by FIB technique and its illustration. Thickness differences are represented by different levels of contrast. (b) Thickness dependence of skyrmion lattices along sample with field cooling at 25 mT and 12 K. The scale bar is 300 nm.

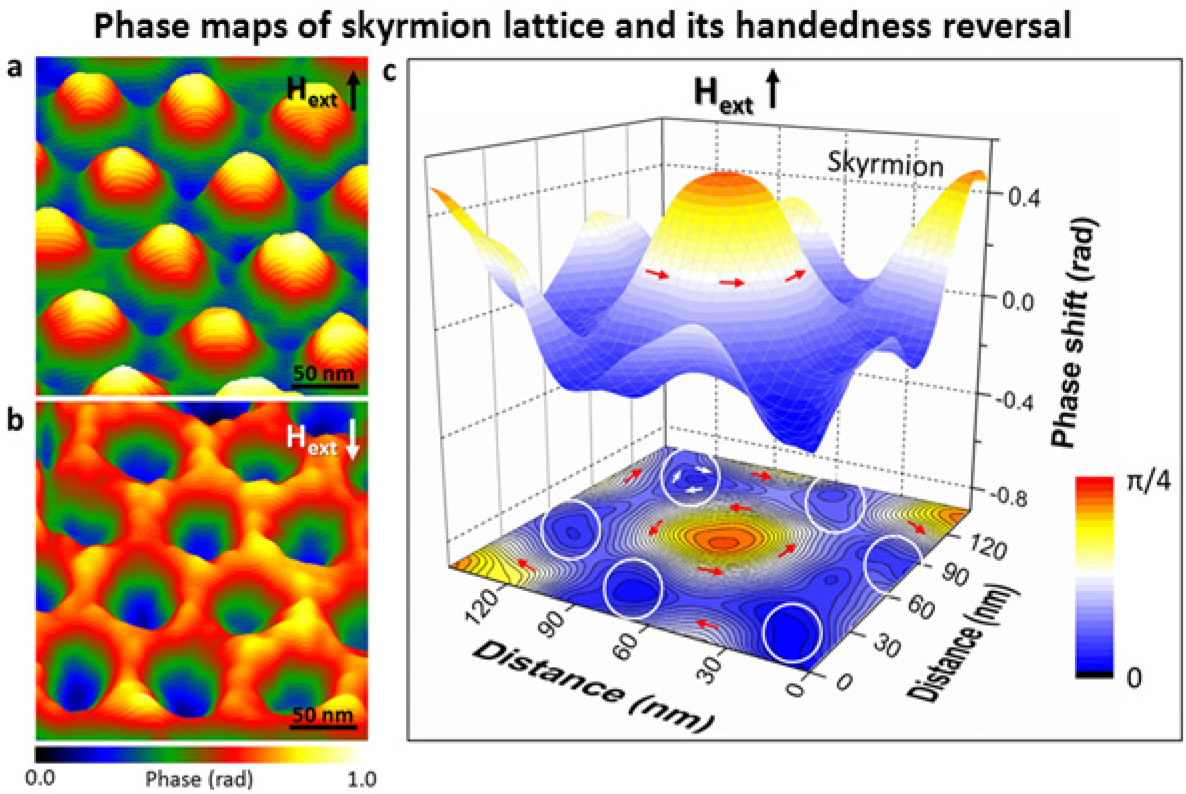

Fig. 2: Fig. 2. Handedness reversal of magnetic flux flow with change in direction of applied field. (a,b) Surface plots of phase image. Sign reversal of phase shift with change in applied field direction is clearly visible. (c) Enlarged surface plot in vicinity of skyrmion. Red and white arrows represent direction of lines of magnetic flux.