

Observation of magnetic nanostructures by phase plate microscopy with hole-free phase plate

Kotani, A.¹, Malac, M.², Harada, K.³ and Mori, S.¹

¹ Osaka Prefecture University, Japan, ² Nanotechnology Research Centre, Canada, ³ RIKEN, Japan

Magnetic nanostructures such as magnetic bubbles and magnetic skyrmions have been attracted much attention for practical application to magnetic devices. Lorentz microscopy (LM), small-angle electron diffraction (SmaED) and electron holography (EH) in a transmission electron microscope (TEM) are powerful tools to reveal the spin configuration of the magnetic nanostructures. It is, however, difficult to detect the spatial variations in magnetic moments in real space images. In this study we applied phase microscopy with a hole-free phase plate (HFPP) to investigate the spin configuration of magnetic nanostructures such as magnetic bubbles and magnetic skyrmions. Phase microscopy with a HFPP does not suffer from the edge effect produced by the phase plate edge. A potential advantage of HFPP, as compared to LM, is that the phase images are obtained in focus. In focus phase images with a HFPP do not exhibit Fresnel fringes, and make it possible to extract the local magnetization from the HFPP images, according to Aharonov-Bohm effect that the electron phase is shifted by the magnetic flux due to sample magnetization. We observed skyrmions in FeGe using phase microscopy with a HFPP and succeeded in obtaining phase contrast images and extracting the magnetization distribution of the skyrmions. An in-focus HFPP image and an in-focus image without a HFPP are shown in Fig. 1. In addition, we will report the spin configuration inside magnetic bubbles in multiferroic hexagonal ferrites. [1] M. Malac, et al., *Ultramicroscopy* 118, 77 (2012).

