Analysis of magnetic domains using small-angle electron diffraction

Mori, S.[1], Nakajima, H.[2], Kotani, A.[2] and Harada, K.[3]

[1] Osaka Prefecture University, Japan, [2] OsakaPrefecture University, Japan, [3] RIKEN & Osaka Prefecture University, Japan

Small-angle electron diffraction (SmAED), which uses a long camera length of several tens or hundreds of meters, is a useful technique in electron diffraction. In ferromagnetic materials, the angles of magnetic deflection or diffraction from long wavelength periodic domains are smaller than those of crystallographic Bragg diffraction by two or three orders of magnitude. When the accelerating voltage of the electrons is 200 kV, magnetic deflection angles are 10^{-4} ~ 10^{-6} rad. Therefore, SmAED is required to disclose magnetic domain structures and to measure the magnitude of the magnetization.

Here we constructed an electron optical system for Foucault imaging and SmAED using a conventional TEM. This system utilizes an objective-mini lens to make a crossover on the plane where a selected area aperture is located [1]. The aperture works as an angular selective aperture of the Foucault mode. An objective lens is switched off and can be used to apply external magnetic fields. The first Intermediate lens is adjusted to switch from SmAED to Foucault modes. Furthermore, Bragg diffractions (~10^{-3} rad) can be observed under the magnetic fields, in addition to the magnetic deflection (~ 10^{-5} rad). This optical system was constructed with JEM-2010 and the camera length can be controlled in a range from 0.8 to 1350 m.

We applied this optical system to analyze magnetic skyrmions in FeGe [2]. The magnetic skyrmion lattices gave rise to diffraction spots (Figure 1) in a similar manner in which a crystal lattice causes diffraction spots corresponding to the lattice plane in the reciprocal space. The diffraction spots of 4.0×10^{-5} rad equal (65 nm)$^{-1}$ in Fig. 1(b). This value coincides with the skyrmion lattice distance $d = (\sqrt{3}/2)a_{sk}$ ~ 65 nm, where a_{sk} ~ 75 nm is the distance between two skyrmions. Furthermore, the SmAED pattern from the skyrmion lattice at 140 K showed high-order diffraction spots, thus indicating that the skyrmion lattice is ordered when the temperature decreases.

[1] H. Nakajima et al. Microscopy **65**, 473 (2016). [2] H. Nakajima et al. APL **111**, 192401 (2017).

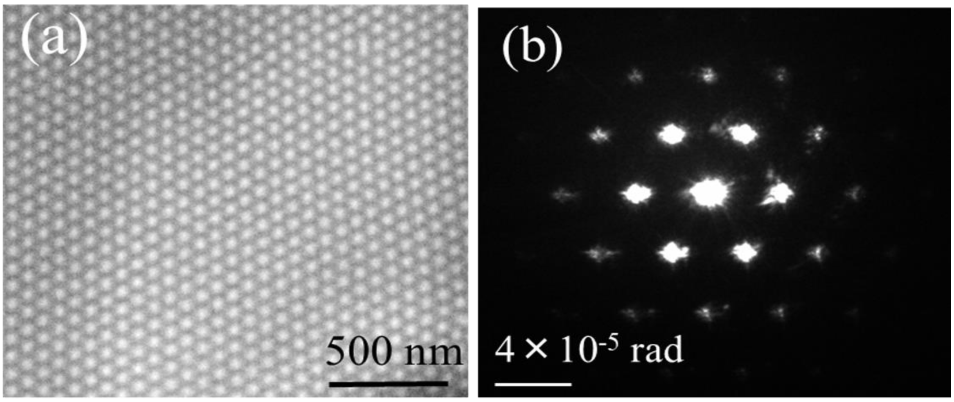

Figure 1. (a)Fresnel image and (b) SmAED pattern of the skyrmion lattice at 140 K under 88 mT.