Lens-less imaging with coherent soft X-rays has been successfully performed in various studies in the fields of nanotechnology, biology, and condensed matter physics [1]. The method is extremely useful for the structural examination of non-crystalline specimens, and can be used to determine the exact positions of individual scattering objects and to map defects in periodically ordered structures. One of the promising applications of coherent soft X-rays is the imaging of the local magnetization of magnetic specimens. In the soft X-ray regime, by exciting electrons from the 2p state to the 3d state of transition-metal atoms, it is possible to study the magnetic ordering in wide-angle diffraction [2] or small-angle scattering geometry [3-4]. Dichroic resonant soft X-ray scattering can be successfully combined with coherent scattering approaches such as iterative phase retrieval [5] and Fourier transform holography-based methods [6].

In this study, we employed a phase retrieval algorithm to reconstruct lens-less images of the magnetic textures from the coherent small-angle resonant soft X-ray scattering (RSXS) patterns measured from the magnetically ordered compound FeGe [7]. Helical magnetic ordering appears in FeGe at zero field near room temperature (Tc = 280 K) due to the interplay between the exchange interaction, Dzyaloshinskii-Moriya interaction, and anisotropy. By applying a moderate magnetic field in a range between B = 50 and 100 mT, the helical structure can be transformed to the ordered lattice of topologically protected vortex-like spin configurations, a magnetic skyrmion crystal (SkX) [8]. The characteristic length-scale of the skyrmion in B20 compounds ranges from a few tens to hundreds of nanometers, which corresponds to the small-angle scattering region for soft X-rays with energies matching the L absorption edges of transition metals [3].

A resonant soft X-ray scattering (RSXS) experiment was carried out at BL-16A. The setup was equipped with a high-vacuum chamber. The scattered intensity was collected by an in-vacuum charge coupled device (CCD) detector protected from the transmitted direct beam by a tungsten beamstop with a size of 0.2–0.3 mm situated at a fixed distance in front of the CCD matrix. A magnetic field produced by a Helmholtz coil up to 400 mT was applied parallel to the incident X-rays and perpendicular to the sample plane. A He-flow-type refrigerator was used to control the sample temperature.

The experiment was performed with a single-crystalline thin plate of FeGe using soft X-rays at the resonant energy E = 707 eV corresponding to the Lα absorption edge of Fe ion. Since the X-ray attenuation length for FeGe at this edge is a few hundreds of nanometers, a plate with a thickness of l = 200 nm was prepared by focused ion beam (FIB) milling and fixed to a Si3N4 membrane by a tungsten contact. The back side of the membrane was coated with a 4-μm Au absorbing layer to protect the detector from the transmitted X-ray beam. A binary image and an SEM image of the sample aperture produced in the gold mask by FIB. Coherent resonant soft X-ray diffraction pattern from (a) helical magnetic structure and (d) magnetic skyrmion crystal.

REFERENCES