Electric Field and Strain-Induced Transformation of Magnetic Skyrmion in a Chiral Multiferroic Cu₂OSeO₃

We have investigated electric-field-induced magnetic phase transition between the skyrmion lattice and the helix, and the emergence of the chiral soliton lattice by uniaxial strain in the multiferroic chiral magnet Cu₂OSeO₃ by means of small-angle soft X-ray scattering at the Cu L₂ absorption edge. By application of an electric field, the skyrmion lattice transforms into helices with distinct modulation vectors depending on the sign of the electric field. On the other hand, the tensile strain stabilizes a helical spin structure with the modulation vector along the strain direction. When the field perpendicular to the modulation vector is increased, large shrinkage occurs and higher-order diffraction peaks are also observed, which is in accordance with a typical feature of the chiral soliton lattice.

Long after the first theoretical prediction of skyrmions in magnetic systems in the 1980s [1], skyrmions forming triangular lattices have been experimentally discovered in B20-type cubic chiral helimagnets [2–4]. Owing to their topological stability, nanometric size (2–200 nm), formation even above room temperature, and versatile electromagnetic responses, skyrmions are promising candidates for spintronic applications and have attracted extensive experimental and theoretical studies. In particular, the creation and annihilation of skyrmions is an indispensable function for device applications. Small-angle RXS measurement was performed at the soft X-ray beamline BL-16A. We used circularly polarized X-ray and the RXS was recorded using a direct-detection CCD camera. Since the attenuation length at the Cu L₂ edge (~931 eV) is less than 200 nm, to optimize transmission and diffraction intensity, a thin plate of Cu₂OSeO₃ with a thickness of about 200 nm was fabricated by using the focused ion beam (FIB) technique. The backside of the SiN membrane window was covered with gold film, and a pinhole of ~7 μm in diameter was drilled. The sample was mounted to cover the pinhole and affixed with tungsten contacts on gold electrodes in order to apply the electric field [Fig. 1(a)]. We applied a voltage of up to ±150 V between two tungsten electrodes a distance of ~100 μm apart and estimated the magnitude of the electric field by considering this distance. A magnetic field of up to 0.5 T was applied by using a Helmholtz coil along the normal of the plate.

In this study we investigated electric-field-induced phase transition and tensile strain effect in a thin plate of Cu₂OSeO₃ by means of small-angle resonant soft-X-ray scattering (RSXS) measurement. A single crystal of Cu₂OSeO₃ was grown by the chemical vapor transport method. Small-angle RXS measurement was performed at the soft X-ray beamline BL-16A. We used circularly polarized X-ray and the RXS was recorded using a direct-detection CCD camera. Since the attenuation length at the Cu L₂ edge (~931 eV) is less than 200 nm, to optimize transmission and diffraction intensity, a thin plate of Cu₂OSeO₃ with a thickness of about 200 nm was fabricated by using the focused ion beam (FIB) technique. The backside of the SiN membrane window was covered with gold film, and a pinhole of ~7 μm in diameter was drilled. The sample was mounted to cover the pinhole and affixed with tungsten contacts on gold electrodes in order to apply the electric field [Fig. 1(a)]. We applied a voltage of up to ±150 V between two tungsten electrodes a distance of ~100 μm apart and estimated the magnitude of the electric field by considering this distance. A magnetic field of up to 0.5 T was applied by using a Helmholtz coil along the normal of the plate.

Figure 1: (a) A picture of the thin plate of Cu₂OSeO₃ fabricated by a focused ion beam thinning technique. Diffraction patterns at 54 K and 30 mT under (b) E = 0 kV/mm, (c) +1.5 kV/mm, and (d) −1.5 kV/mm.

As shown in Fig. 2(b), the higher-order q diffraction peaks are clearly observed and |q| is reduced with increasing the magnetic field. The magnetic-field dependencies of the q vectors and the higher-order diffraction patterns in the strained sample. Diffraction spots existing on the right side are highlighted by white arrows.

In addition, when the sample is fixed at both edges by electrodes, the difference in thermal expansion between the sample and the SiN membrane produces tensile strain along the [001] axis which is of the order of hundreds of MPa. We revealed that the tensile strain would strongly stabilize the helical state up to higher fields at lower temperatures, and thus typical behaviors of the chiral soliton lattice (CSL) [Fig. 2(a)] appear [7].

REFERENCES