Study of magnetic skyrmion in MnSi under an electric current flow by triple-axis spectrometer

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A magnetic skyrmion on chiral magnets has been extensively studied [1]. In metallic skyrmion compounds, there is important characteristic, a large coupling with the electric current. The electric current density required to realize the skyrmion lattice motion in MnSi is small as $j_t \sim 1$ MA/m^2 [2]. Hence, the magnetic skyrmion attracts growing attention, and is under intense scrutiny for elucidating its dynamical behavior under electric current.

Our group has conducted small-angle neutron scattering experiments on MnSi under an electric current flow at NIST, USA [3, 4]. We measured the magnetic skyrmion reflections and their response at low electric current density ($j > j_t$). A rotation and broadening of the magnetic skyrmion reflections were found only at low alternative current (AC) frequencies [4], whereas above the threshold AC frequency the rotation was not observed, and the spot width becomes sharper. The moving states of the magnetic skyrmion drastically change with the AC-frequency below and above the threshold value. In stark contrast, the moving state at high electric current density is unknown. Thus, we tried to measure the response of the magnetic skyrmion lattice at the high electric current.

We prepared the hand-made experimental probe to apply the electric current on the MnSi sample in the cryomagnet. The maximum electric current was 1 A ($j \sim 2.5$ MA/m^2), because above 1 A the resistivity of the sample was gradually increased. The sample was mounted on the sample holder to measure the nuclear and magnetic scattering on the (1 1 0)-(0 0 1) plane. The electric current and magnetic field were applied to the (0 0 1) and (1 -1 0) directions, respectively. Three thermometers were put on the sample, near the heater on the sample stick, and the sample well. These thermometers displayed same temperature values under zero electric current. At the experiment, the displayed temperature and magnetic field were $T = 28.6$ K and $B = 0.2$ Tesla, the center of the magnetic skyrmion phase [3]. The incident neutron energy was tuned at 3 meV.

In the experiment, we observed (1 1 0) and (1 1 1) nuclear reflections. However, (h h h) magnetic reflections in the helical magnetic ordered phase at $B = 0$ and the magnetic skyrmion reflection in the magnetic skyrmion phase at $B = 0.2$ T could not be observed. Here, we considered the reason why we did not observe the magnetic reflections. (1) The remanent magnetic field in the cryomagnet. In the cryomagnet, there is a problem of remanent magnetic field, and there is a possibility that the displayed and actual magnetic fields are different. The pockets of helical ($-0.1 < B < 0.1$ T) and magnetic skyrmion ($-0.225 < B < -0.175$, $0.175 < B < 0.225$ T at 28.6 K) phases are narrow. Thus, we need to carefully check the actual magnetic field value. (2) The position of the blade of the third collimator. To measure the diffraction from the small sample, we need to consider the possibility that the scattered neutron hits the blade of the third collimator. Thus, we should carefully determine the sample position or the position of the blade of the collimator, when we measure the small sample. At next time, we will improve those points.

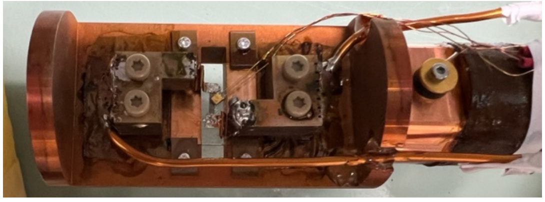

Figure 1. The sample holder used in this time.

[1] S. Muhlbauer, et. al., Science 323, 915 (2009). [2] F. Jonietz, et. al., Science 330, 1648 (2010). [3] D. Okuyama, et. al., Commun. Phys. 2, 79 (2019). [4] D. Okuyama, et. al., Phys. Rev. B 110, 014431 (2024).