Spin excitations in the magnetic skyrmion-lattice phase

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MnSi attracts renewed interest because of the recent discovery of the magnetic skyrmion-lattice structure under finite magnetic field [1]. The magnetic skyrmion is a topological spin texture made of swirling magnetic moments. The magnetic skyrmion carries integer topological number, called skyrmion number. In the real magnets, such as MnSi, the skyrmion forms a triangular lattice. The elementary excitation of ordered magnet is "magnon", which is a propagating quantized wave of spin fluctuations. The magnon would exists in the skyrmion-lattice phase, forming magnon bands with the Brillouin zone set by the periodicity of the triangular lattice. In addition, the topological nature of the scatterers (i.e. skyrmions) will give rise to non-trivial characters to the magnon bands, forming the topological magnon band [2]. Such a topological magnon is of current interest and are under active scrutiny, recently.

In search for the topological magnons, it was necessary to use Ge-doped MnSi, as Ge-doping increases the magnetic modulation vector k, relaxing Q-resolution requirement for the experiment. A single crystal sample $MnSi_{0.98}Ge_{0.02}$ of 15.5 grams was grown using Bridgman method. We performed elastic and inelastic neutron scattering using the cold-neutron triple-axis spectrometer SIKA, ANSTO. The collimations were Open-20'-20'-60' with vertically focusing monochromator. The final neutron energy was fixed to 2.75 meV. Pyrolytic graphite 002 reflections were used for monochromator and analyzer. The sample was mounted on the aluminum plate, aligned with 110 and 001 in the scattering plane. The vertical superconducting magnet was used in the experiment, applying external magnetic field along the $\bar{1}10$ direction.

From elastic neutron measurement, we obtained the modulation vector and the helical ordering temperature as $k = 0.0462$ Å^{-1} and $T_c = 32$ K, respectively. The obtained modulation vector and the helical ordering temperature are larger compared to MnSi ($k = 0.036$ Å^{-1} and $T_c = 29.5$ K). In the inelastic neutron measurement, the magnetic excitation in the skyrmion-lattice phase was measured at Γ, M, and their midpoint at $T = 30.5$ K and $H = 0.2$ T. Shown in the figure is the representative magnetic excitation spectrum observed at the midpoint. Broad inelastic peak can be seen around $\hbar\omega \sim 0.13$ meV. We confirmed that this excitation is intrinsic in the skyrmion-lattice phase, by comparing it to the excitation spectra both in the fully-polarized and helical phases. Detailed analysis, including theoretical estimation of the magnon scattering intensity in the skyrmion-lattice phase, is in progress.

[1] S. Mühlbauer *et al*. Science 323, 915-919 (2009); [2] K. A. van Hoogdalem *et al*., Phys. Rev. B 87, 024402 (2013).

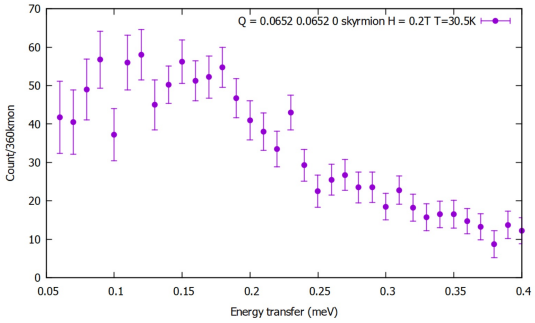

Fig. 1. Neutron inelastic spectrum at the mid point of the Γ and M points observed in the magnetic skyrmion-lattice phase