Current driven motion of skyrmions in MnSi

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Emergent electromagnetic field out of a topological spin texture is a novel concept in condensed matter, and has been intensively studied recently [1]. The skyrmion, a nontrivial swirling spin structure carrying a topological quantum number, is an intriguing example of such spin texture[2]. Its finite scalar spin chirality $S_i \cdot (S_j \times S_k)$ generates fictitious magnetic field acting on the conduction elections, giving rise to the nontrivial topological Hall effect in electron transport phenomena [3]. Inversely, it can be expected that the skyrmion motion is driven by the current flow, resulting in deformation, rotation, and translation of the skyrmion lattice. Recently, indeed, this current-driven rotation of the skyrmion lattice is experimentally observed at very low current density of 1 MA/m^2 [4]. Although this first experiment is tricky, realized only under temperature gradient, such low current density threshold for the skyrmion motion attracts special attention, as it opens a new way to manipulate spin structures by ultra-low electric current, a key technology to realize spintronics.

To investigate the deformation of the magnetic skyrmion lattice under the electric current flow, we performed SANS experiment with suppressing the thermal gradient as much as experimentally achievable. SANS experiments were carried out at NG7 (National Institute of Standards and Technology). The single crystal MnSi samples were grown by the Czochralski method, and were cut in the rectangular shape. The incident neutron wave- length was selected using the velocity selector as λ_i = 6 Å. To further reduce the temperature inhomogeneity in the measured region only a small part of the sample was illuminated by using narrow beam. An electric current was applied along the [0 0 1] direction. For such a large electric current, due to the self heating the sample temperature slightly deviates from the sensor temperature. However, the maximum difference between the sensor and sample temperatures was 0.16 K at j = 2.7 MA/m^2. The temperature gradient along the current-flow direction was also estimated, and was confirmed to be less than 0.035 K/mm at the sample region investigated in the present study under the maximum current density 2.7 MA/m^2. This is at least one order of magnitude smaller than the earlier work [3]. The sample mount was attached to the sample stick, and was installed in the horizontal-field magnet with the magnetic field applied along [1 -1 0] parallel to the incident neutron beam.

The magnetic skyrmion reflections were observed at the two temperatures, T = 28.3 K and 28.6 K, respectively, under B = 0.2 T and j = 0 MA/m^2. The six-fold magnetic reflections characteristic to the skyrmion lattice were observed in a temperature range of approximately 28 K $< T <$ 29.2 K at B = 0.2 T. This observation is identical to those in the earlier works, and confirms the reproducibility of the present measurement. The integrated intensity shows its maximum at T = 28.6 K, and then decreases at lower temperatures. The SANS patterns were also obtained under the finite electric current flow j = 2.7 MA/m^2 at B = 0.2 T. By comparing to SANS data at j = 0, one can clearly see considerable broadening of the skyrmion-lattice peaks in the azimuthal direction. The peak broadening is apparently temperature dependent; the width is considerably larger at T = 28.3 K compared to that at T = 28.6 K. This result clearly indicates significant deformation of the skyrmion lattice under large electric current.

In summary, we clearly observed that the skyrmion peaks in the SANS pattern significantly broaden for $j > j_t$ (threshold current density), indicating that the skyrmion lattice considerably deforms when the lattice starts to flow.

Reference:

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