Dynamics of the magnetic skyrmion under an alternative current in MnSi

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A magnetic skyrmion is swirling spin texture characterized by a discrete topological number, called the skyrmion number. In experiment, magnetic skyrmions quite often condensate in the triangular-lattice form, giving rise to six-fold magnetic Bragg reflections in small angle neutron scattering (SANS) patterns, as first discovered by Muhlbauer et al. in the prototypical chiral magnet MnSi [1]. To date, the skyrmion lattice structures are widely confirmed in various magnets ranging from metallic to insulating compounds. There are several prominent characteristics in magnetic skyrmions that make them quite intriguing. One of such characteristics is its topological protection; once created, the skyrmion can hardly be annihilated. In metallic skyrmion compounds, there is another important characteristic, i.e., its surprisingly large coupling with the electric current flow. The electric current density required to realize the skyrmion lattice motion is considerably small as j ˜ 1 MA/m2 [2]. Hence, the magnetic skyrmion attracts growing attention recently, and is under intense scrutiny for elucidating its dynamical behavior under electric current.

To investigate the dynamics 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 incident neutron wave- length was selected using the velocity selector as λ i = 6 . An direct or alternative electric current with square wave was applied along the [0 0 1] direction. 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.

We observed the six-hold magnetic skyrmion reflections at 28.6 K, respectively, under B = 0.2 T and j = 0 MA/m2. 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. To investigate the origin of the broadening of the skyrmion reflections, we performed SANS measurements on the left-edge (+) or right-edge (-) of the sample. The size of the neutron illumination area is approximately 0.2 mm (width) $\times$ 1.0 mm (height). The observed patterns are identical for the two edges. In marked contrast to the zero-current condition, under j = 2.7 MA/m2 the reflection patterns taken from the left- and right-edge parts exhibit counterclockwise and clockwise rotations, respectively. The effect of inverting the current and magnetic-field directions was also investigated. The rotation direction does not change by inverting the magnetic field direction. On the other hand, the inversion of the current direction (from j = +2.7 to -2.7 MA/m2) results in a sign change of the rotation angle. This indicates that the skyrmion-lattice rotation observed in the thermally homogeneous condition depends not on the magnetization direction, but only on the current direction [3]. To observe the time dependence of the magnetic skyrmion rotation, we also performed the SANS experiment with applying the alternative electric current. The observed relaxation time of the skyrmion rotation is several seconds order, which is the very slow dynamics as a magnetic material.

In summary, we have used SANS to study skyrmion-lattice motion in bulk MnSi under electric current flow. The azimuthal width of the skyrmion-lattice peaks shows significant broadening above a threshold current density jt ˜ 1 MA/m2. We show this peak broadening originates from a spatially inhomogeneous rotation of the skyrmion lattice, that shows opposite senses of rotation at the sample edges.

Reference:
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