Lorentz TEM observation of deformed skyrmions in supercooled state

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Magnetic skyrmions are spin vortices with topological nature characterized by an integer so-called skyrmion number. Due to favorable features such as a topological stability and a mobility with ultralow current flow, the magnetic skyrmions are promising for the application to new memory and storage devices. In some chiral magnets, the competition of ferromagnetic exchange and chirality-induced antisymmetric exchange interaction induces helical magnetic structure as a ground state. Thermally equilibrium skyrmions are stabilized with applying an external magnetic field at just below the magnetic transition temperature. From the point of view for applications, to find the skyrmion phase for enough wide temperature range is desired.

β-Mn type Co-Zn-Mn alloys show a variety of magnetic transition temperature with different compositions. The transition temperature covers well over the room temperature, however the thermally equilibrium skyrmion phase is still limited. Recently by using supercooled state, metastable skyrmion state has been reported by using neutron small angle scattering and Ac magnetic susceptibility [1]. The purpose of this study is a real space observation of the metastable skyrmions in supercooled state using Lorentz transmission electron microscopy (TEM). The Supercooled state was created by a magnetic-field cooling process passing through the thermally equilibrium phase. The observed metastable skyrmions at the lowest temperature (6 K) shows strongly distorted structure [2]. We also observed the temperature dependence of the length of magnetic modulation and the conservation of the number of skyrmions. The strong distortion comes from these two factors.

[1] K. Karube *et al., Nat. Mater.* **15**, 1237 (2016).
[2] D. Morikawa *et al., Nano Lett.* **17**, 1637 (2017).