Small-angle neutron scattering study of ferromagnetic submicron particles

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Iron oxide ferromagnetic particles have attracted a great deal of attention in the biomedical field due to their useful applications such as drug delivery, magnetic hyperthermia, magnetomechanical stimulation. In particular, hollow particles are potentially used for high-performance targeted drug carriers due to their higher surface-to-volume ratio and large pore volume. Since magnetic response to applied field determines their performance, understanding of their magnetization process is critically important. In this study, we performed polarized small-angle neutron scattering (SANS) experiments for 420 nm-sized hollow magnetite (Fe_3O_4) submicron spherical particles to evaluate magnetization distribution parallel and perpendicular to magnetic field. SANS experiments were performed at T = 10 K and 300 K using the small and wide-angle neutron scattering instrument (TAIKAN) installed in MLF of J-PARC. We measured two neutron scattering intensities for polarized spin-up and spin-down neutrons and calculated square of spatial Fourier transforms of magnetic scattering length density, $|\tilde{\boldsymbol{M}}|^2$, as a function of scattering vector Q. We found that $|\tilde{M}z|^2$, which is the square of parallel magnetization component, decreases with lowing magnetic field and minimizes at $H \sim$ -300 Oe at T = 10 K (Fig.1), whereas the perpendicular component maximizes around zero applied field. Similar field dependence was observed at T = 300 K above the Verwey transition temperature of ~ 120 K. On the basis of recent micromagnetic simulations and electron holography[1)], the result was interpreted by the deviation of the vortex axis from the magnetic field direction at low fields where Zeeman energy becomes not important for core spins. Such behavior was confirmed also for 265-nm cubic submicron particles, where a vortex formation is expected at low applied fields.

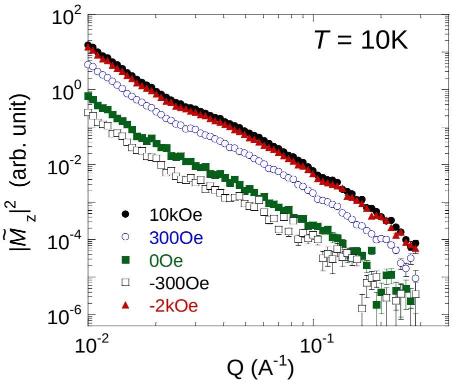

Fig.1. Magnetic-field dependence of $|\tilde{M}z|^2$ at T = 10 K

References

1) N. Hirano, S. Kobayashi et al., Appl. Phys. Lett. 119, 132401 (2021).