Development of a Spin Analyzer for Ultra-Cold Neutrons

T. Higuchi[A], H. Akatsuka[B], K. Hatanaka[A], M. Hino[C], G. Ichikawa[D], S. Imajo[A], S. Kawasaki[E], M. Kitaguchi[B], K. Mishima[D]

[A]RCNP, Osaka Univ., [B]Nagoya Univ., [C]KURNS, Kyoto Univ., [D]IMSS, KEK, [E]IPNS, KEK,

Ultracold neutrons (UCNs), neutrons with kinetic energies of $\lesssim 300\,\mathrm{neV}$, have played important roles in fundamental physics experiments, notably in searches for the neutron electric dipole moment (nEDM). A finite nEDM, if found, would violate time-reversal symmetry, thus being an important observable in understanding Charge Parity violation in the universe. The state-of-the-art nEDM measurements utilize stored UCNs [1]. The spin precession frequency of UCNs under a weak (~1 uT) magnetic field and a strong (~10kV/cm) electric field is measured by the Ramsey's technique of separately oscillating fields. A constraint on the nEDM is derived from the difference of the spin precession frequencies between parallel and antiparallel configurations of the electric and magnetic fields. This experiment at JRR-3 is concerned with the development of a thin-iron film used for UCN polarization analysis, which constitutes the last step of the Ramsey sequence. When a UCN traverses a magnetized iron film, it experiences an effective spin-dependent potential $V_{\pm} = V_{\mathrm{Fe}} \pm \mu_n \cdot B = 209\,\mathrm{neV} \pm 90\,\mathrm{neV/T} \cdot B$. An iron film magnetized to B~2 T creates a potential that blocks UCNs with the spin + state, while transmitting those in the other state. Used with a spin flipper, such film allows counting both spin states of UCNs, and determining the UCN polarization.

For a thin iron film to be used as an effective spin analyzer, the reflectivity of the spin + UCNs is critical. For an iron film made on a mirror surface, its specular reflection properties can in principle be evaluated by cold neutron reflectometry with a small momentum transfer q without the use of UCNs [2]. With this motivation, we conducted polarized cold-neutron reflectometry experiment on the JRR-3 C3-1-2 (MINE-2) beamline.

The experimental setup mainly consists of a polarizing mirror (M1), a π spin flipper (SF), a Helmholtz coil, an analyzing mirror (M2), and an ^{3}He neutron detector. A magnetic multilayer mirror (Fe/SiGe, d~14nm) is used as a polarizing/analyzing mirror at its Bragg angle of 1.7°. The sample is a 90 nm thick single-layer iron film sputtered on a 1 mm thick silicon wafer [3]. To measure the beam polarization, M1 and M2 are placed. From the neutron counts with SF on and off, beam polarization of 97(1)% is obtained. To measure the reflectivity of the sample, M2 is removed from the mirror holder, and the sample is placed either in the Helmholtz coil (to apply magnetic field up to 55 Oe) or in the mirror holder for M2 (300 Oe). We observed a significant increase in the reflectivity of spin + neutrons at 300 Oe compared to ≤55 Oe (Fig. 1).

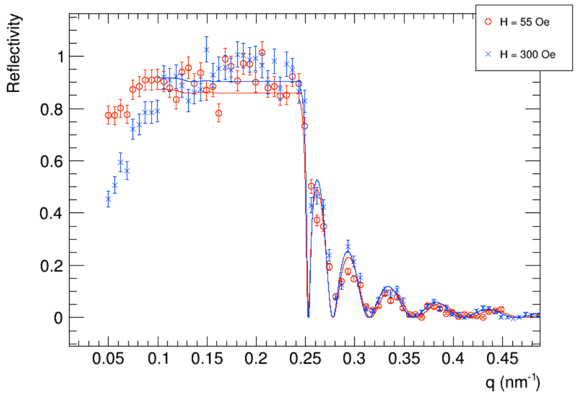

Fig. 1. Comparison of the reflectivity profiles between applied magnetic field of 55 Oe and 300 Oe. A significant rise of the reflectivity is observed.

As the next step, we plan to take measurements with intermediate strength of the magnetic fields to determine at which magnetic field the sample reflectivity rises.

[1] C. Abel *et al.*, Phys. Rev. Lett. **124**, 081803 (2020).
[2] H. Akatsuka *et al.*, JPS Conf. Proc. **37**, 020801 (2022).
[3] M. Hino *et al.,* Nucl. Inst. Meth. A **797**, 265 (2015).