Development of efficient ultracold-neutron spin analyzers by the use of polarized cold-neutron reflectometry

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Measurement of the neutron electric dipole moment (nEDM) occupies an important place in today's particle physics. The state-of-the-art method for nEDM measurement is based on spin-precession frequency measurement of ultracold neutrons (UCNs) stored in a material vessel. One of the essential components for this experiment is UCN spin analyzers. Because of extremely low energies of UCNs ($\lesssim$ 300 neV), a magnetically saturated Fe film provides a sufficient spin-dependent potential to selectively transmit one spin state of UCNs. To test such films, a setup consisting of two films as a polarizer and an analyzer and two spin flippers is typically used to evaluate the film performance by the change of UCN transmission due to operations of spin flippers.

In this proposal at JRR-3/MINE continuing from FY2022, we investigate the use of polarized cold-neutron reflectometry as a method to test UCN analyzers. In FY2022, we used an existing infrastructure of the MINE2 beamline and conducted a polarized cold-neutron reflectometry measurement of a single-layer Fe film sputtered on a Si substrate with different magnetic fields applied on the film [1]. In FY2023, we built an improved setup where the following limitations of the previous experiment were addressed:

- An Helmholtz coil used to apply a magnetic field to a sample was replaced to a dipole magnet with yokes. This helped reduce stray magnetic and prevented settings of the sample magnetic field from influencing spin-flipper performance
- A dedicated θ-2θ stage for polarized reflectometry was built. This improved an accuracy of the incident angle in reference to the beam compared to a θ-x-stage setup that was used earlier.

With this setup, we performed detailed scans of magnetic field and obtained results that are consistent with an UCN transmission experiment conducted at J-PARC/MLF BL05 and functioned as a high-performance spin analyzer at a field of about 120 Oe, which is smaller by a factor of 6 compared to what was developed in previous work [2]. Based on this agreement, we can use polarized neutron reflectometry as a mean to test the Fe film performance in a complementary way to UCN transmission. In later beamtime, we succeeded in producing Fe films that magnetizes at an even smaller field. Furthermore, we developed a Fe film sputtered on a polished Al foil which can also be characterized by polarized reflectometry.

The Fe films thus developed are also useful in a sense that can be used as an efficient cold neutron polarizer/analyzer with a minimum stray magnetic field. A framework has been developed by theoretical collaborators to use the long-wavelength high-polarization beam of MINE2 for spin interferometry to test weak value amplification [3].

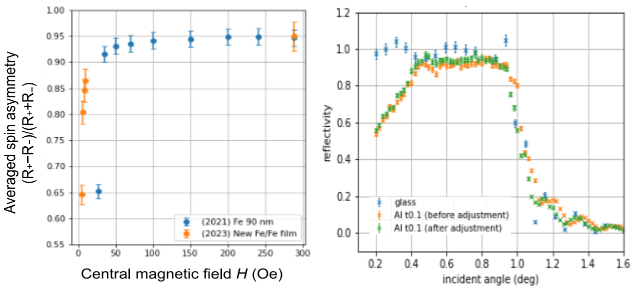

Fig. 1. (Left) Polarization performance as a function of the applied magnetic field for Si-substrate Fe films made in 2022 and 2023 (Right) Reflectometry profiles obtained for Fe film on a polished Al foil.

[1] T. Higuchi et al., JPSJ **93**, 091009 (2024).
[2] S. Afach et al., EPJ A **51** 143, (2015).
[3] D. Ueda and I. Tsutsui, arXiv: 2309.16281.