CO1-1

Development of absorption grating devices with CN-3 beamline at KURNS

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INTRODUCTION: Neutron imaging techniques are very powerful as a versatile nondestructive analyzing tools in many research fields. Neutron Talbot-Lau interferometry (nTLI) has attracted considerable attention since it was proposed in 2006[1]. The nTLI consists of three gratings, a source grating G0, a beam splitter grating G1 and an analyzer grating G2. G0 and G2 are absorption gratings and G1 is a phase grating. The absorption gratings are very important key devices, and Gadolinium (Gd) is used in the fabrication of absorption gratings due to its high absorption cross section. This study presents a novel fabrication method for absorption gratings using a Gd-based multilayer optimized for ultra-high precision cutting.

EXPERIMENTS: The Gd-based multilayer consists of Gd and Ti (titanium), and the G0 and G2 gratings were created by micro-cutting the Gd/Ti multilayer on a substrate. The gratings were subjected to an evaluation at an actual nTLI installed to CN-3 port of the Kyoto University Reactor (KUR) [2], with the visibility of moiré fringes being assessed. In the case of nTLI at CN-3, the required effective thickness of Gd is larger than 20 μm. The coating of Gd film in this development was performed by an ion beam sputtering instrument (KUR-IBS) at KURNS [3].The number of Gd/Ti bilayers for G0 fabrication was 2000 and the deposition time of each Gd and Ti layers were 5 minutes and 30 seconds, respectively, which was same as that of the above cutting test. The total thickness of the films was estimated to be 46μm. After sputtering, the Gd/Ti multilayer was shaped using the ultra-high precision cutting machine NPIC-M200 (Nagase Integrex Co.,Ltd.) at RIKEN and a V-shape binder-less nanodiamond cutting tool, the apex angle of which is 62 degrees within a range of 50 mm square. The total number of grooves was 400 with a pitch of 125 μm in 50 mm square.

RESULTS: Fig.1 shows the groove depth of different parts of the micro cut G0 grating measured by confocal laser microscope VK-X1000 (KEYENCE Co.,Ltd.) at RIKEN. It shows that the Gd/Ti multilayer of the newly fabricated G0 was totally penetrated to surface of Al substrate. The small peaks in bottoms of grooves were caused by Al residues from cutting. The G0 grating has also been used with another joint-use research in the nTLI at the CN-3 port.

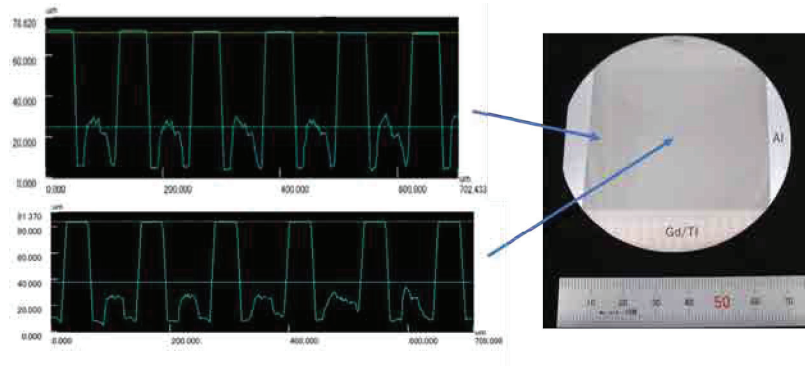

Fig.1 Groove depth of different parts of the micro-cut G0 grating.

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CO1-2

Trial of mass production of *m*=6 neutron focusing supermirrors II

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INTRODUCTION: A new research reactor construction project is underway at the "Monju" site in Tsuruga City, Fukui Prefecture. One of main purposes of the research reactor is to make more extensive use of neutron beams, to produce results including those for industrial use, and to contribute to various fields, especially the local community. The actual use of the focusing mirror is one of the very important things to be at par with the top-level institute for neutron science and technology. We have established a fabrication method for aspherical focusing supermirrors with metal substrate [1]. The metal substrate is robust and ductile, which can produce a steeply curved surface with high shape accuracy. It is also applicable to use under high radiation irradiation and high temperature field, even at a place close to the neutron target and moderator. We have realized smooth surface for high-m supermirror coating. Here, m is the maximum critical angle of the mirror in units of the critical angle of natural nickel. In this study, we report on the status of mass production for high-m neutron focusing supermirrors.

EXPERIMENTS: We fabricated ellipsoidal metallic substrates with electroless nickel-phosphorus plating, based on the technology using ultrahigh precision cutting with correction processing, followed by mechanical precision polishing. The first precise manufacturing was conducted at a CNC machine for development of neutron optical devices at workshop of the KURNS. The ultra-precise manufacturing, polishing and cleaning of the metallic sub-strate were conducted at RIKEN. The supermirror coating was conducted with ion beam sputtering machine at the KURNS (KUR-IBS)[2]. Fig.1 shows photograph of ellipsoidal supermirror deposited on one LOT (three pieces) and two Si substrates. The semi-major and semi-minor axes of the ellipsoidal supermirror were 1250 mm and 65.4 mm, respectively. Eventually, we have fabricated m=6 NiC/Ti(C) supermirrors in which maximum effective number of layers was 12180, where the half of the layers were very thin carbon interlayers. The performance of supermirrors deposited on the Si substrates were evaluated by neutron reflectivity at CN-3 port of KURNS and C3-1-2(MINE) port of JRR-3.

Fig.1 Photograph of three parts of ellipsoidal neutron supermirrors coated by the ion beam sputtering instru-ment (KUR-IBS) at KURNS.

RESULTS: Although the measured reflectivity was not expected due to some problems such as grid problems, we succeeded in producing m=6 supermirrors from LOT-34 to LOT-38. Including the m=6 supermirrors, in which the number of layers was 9750 , fabricated last year, we now completed 18 LOTs (54 pieces) required for the full-circumference ellipsoidal supermirror with a length of 0.9m.

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R6056

CO1-3

Measurement and improvement with neutron interferometer

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INTRODUCTION: Neutron interferometry is a powerful technique for studying fundamental physics. Numerous interesting experiments [1] have been performed since the first successful test of a single-crystal neutron interferometer [2]. However, the single-crystal interferometer is inherently not able to deal with a neutron that has a wavelength longer than twice its lattice constant. In order to investigate problems of fundamental physics, including tests of quantum measurement theories and searches for non-Newtonian effects of gravitation, the interferometry of cold neutrons is extremely important, since the sensitivity of interferometer for small interaction increases with the neutron wavelength. A large scale of interferometer also has the advantage to increase the sensitivity to small interactions. One of the solutions is an interferometer using neutron multilayer mirrors [3,4]. We can easily control parameters such as Bragg angle, reflectivity, and Bragg peak width by selecting the deposited material and tuning the bilayer thickness and the number of layers. We have demonstrated a multilayer interferometer for pulsed cold neutrons at the beamline 05 NOP in J-PARC MLF [5]. In the case of pulsed neutrons, the phase of interference fringes depends on neutron wavelength which is resolved by time-of-flight.

EXPERIMENTS AND RESULTS: We tried to measure the neutron scattering lengths of ^{3}He and ^{4}He gas with the interferometer. The gas cell which can be installed into the narrow gap of the interferometer was developed. Although the accuracy was not yet good, a clear phase shift was observed. We consider that the gas cell is the cause of the contrast reduction and are currently working on improving it.
In order to enlarge the number of neutrons, neutron supermirrors which can reflect wide bandwidth of wavelength were developed for interferometer by using Ion Beam Sputtering facility in KURNS. The number of layers of the multilayer mirrors was reduced compared to the conventional supermirrors to suppress deformation of the mirror, that causes contrast loss of the interferogram. Figure 1 shows the reflectivity of the half mirrors with wide bandwidth. We will apply the mirrors to the interferometer.

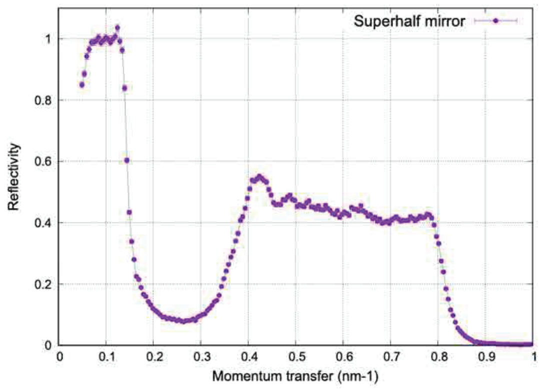

Fig. 1. Reflectivity of the half mirror with wide band of neutron wavelength measured at MINE2 in JRR3.

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CO1-4

Iron films on an aluminum substrate for polarization analysis of ultra-cold neutrons

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INTRODUCTION: A finite electric dipole moment (EDM) of the neutron implies violation of time-reversal symmetry, and has been searched since the 1950s. Searches for a non-zero neutron EDM in high sensitivity constitute stringent tests of theories beyond the Standard Model of particle physics and shed light in the mystery of baryon asymmetry of the universe. In the state-of-the-art neutron EDM experiment, spin-precession frequencies of ultracold neutrons (UCNs), neutrons with kinetic energies on the order of 300 neV or less, are compared under different electromagnetic configurations. One of the key components required for neutron EDM experiments is spin analyzer of UCNs, whose efficiency directly impacts the precision of the spin-precession frequency measurement, thus the sensitivity of the neutron EDM search. Because of extremely low energies of UCNs, magnetized Fe thin films with small coercivities can be used as effective UCN spin analyzers, functioning as filters that selectively transmit the high-field seeking state of UCNs. In this project at the Institute for Integrated Radiation and Nuclear Science, Kyoto University, we have developed sputtered thin Fe films produced with KUR-IBS [1,2,3]. In FY2024 we succeeded in developing Fe films on 0.1-mm thick Al foils as substrate, which have minimum neutron absorption and suited for application to UCNs.

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EXPERIMENTS: Polarized neutron reflectometry measurement was performed using a monochromatic cold neutron beam at 0.88 nm wavelength from the JRR-3/MINE2 beamline. A dedicated θ-2θ stage with an electromagnet was constructed for measurement with variable magnetic fields.

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RESULTS: The results of the reflectometry at an applied filed of 288 Oe are presented in Fig. 1 for Fe films on Al foils and Fe films on glass. It can be observed that the reflectivity on the plateau for spin slipper off are comparable between the Fe films on Al and glass substrates. The systematic measurements sweeping the magnetic field on the sample were taken for each sample.

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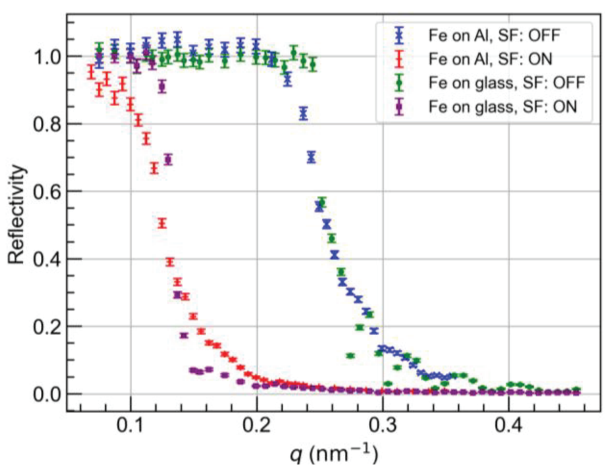

Fig. 1. Polarized neutron reflectometry with a monochromatic 0.88-nm neutrons from the MINE2 beamline. The beam was polarized with a magnetic Fe/SiGe multilayer mirror. The applied magnetic field was 288 Oe for all the measurements shown.

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