CO1-1 Development of the CCD-based UCN Detector with Fine Spatial Resolution

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INTRODUCTION: Quantum states of matter in gravitational field are expected as well as those in electromagnetic and strong force. However, there are only a few experiments that demonstrate such a quantum effect of the gravity. One of the experiments was done using the Ultra Cold Neutron (UCN), which can be bound by the gravitational potential and a bottom reflecting mirror, by measuring a height-wise modulated distribution of quantized UCNs. [1,2] The measured distribution was not clear statistically. Spatial resolution of the detector was not enough to see the modulation of several micron scales. To confirm the existence of the quantum states, we are planning to conduct verification experiment with independent setups. The key components are a position sensitive detector and a fine slit of 100-micron space with neutron absorber, which select neutrons of lower level eigenstates. In this paper, development status of those components is reported.

POSITION SENSITIVE DETECTOR: We have developed a CCD-based, position sensitive detector with a thin neutron converter directly deposited onto the sensor surface. Two nuclear reactions, ^{10}B(n, alpha)^{7}Li and ^{6}Li(n, alpha)^{3}H, are considered for converter design. Charged particles, emitted via those interactions, deposit those energies in the CCD sensor and make signals. A back-thinned type sensor (S7170-0909, Hamamatsu Photonics K. K.) is used to avoid an energy loss caused when the charged particle pass through the insensitive region. The active area is 12.3 x 12.3 mm^2 (512 x 512 pixels of 24 x 24 microns). The converter was made using the Neutron Mirror Fabrication System at the KURRI. The thicknesses for the boron-based and lithium-based converters are both decided to be 200 nm in consideration of conversion efficiency and production easiness. The deposition rate is set to 0.1 nm/sec. They are sandwiched between titanium layers of 20 nm thicknesses to prevent oxidizing and crumbling. The detectors ware tested using cold neutron beams supplied at JRR-3/MINE2 beam line. Detection efficiency was measured to 1.7%(0.3%) with boron (lithium)-based converter by comparing with the ^{3}He reference detector. Uniformities were evaluated to less than 3% over the sensitive area. Spatial resolution was estimated to 3 microns for the boron-based detector. [3]

NEUTRON ABSORBER FOR THE SELECTION SLIT: Absorbers were fabricated also by evaporating absorber material onto glass (SiO2) substrates. We used natural Gd or Ti(54%)-Gd(35%)-Zr(11%) compound metal. Fermi potentials of those are 51.1 - 108i neV and -13.8 - 26.5i neV, respectively. Two substrates with different surface roughness, Ra ~ 0.4 microns and ~ 0.03 microns are prepared. Fig.1 shows a surface image of the absorber with compound metal on the substrate with roughness of 0.4 microns, taken by a laser microscope (VK-9700, KEYENCE).

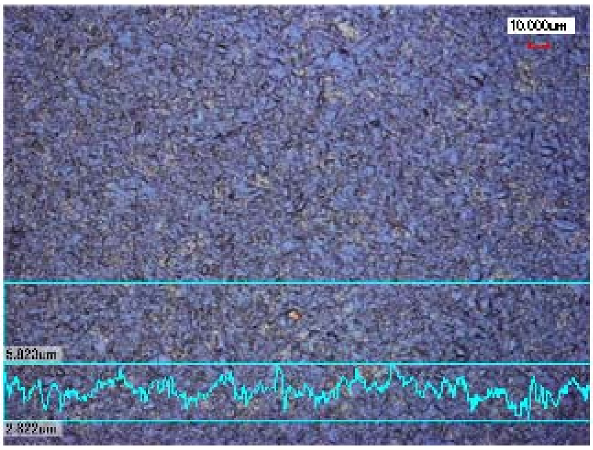

Fig. 1. Surface image of the absorber with the compound metal, where the roughness of substrate is 0.4 microns. Lower kinked line shows a cross-section view on the upper straight line.

CONCLUSION: Using the Neutron Mirror Fabrication System at the KURRI, we succeeded to make the CCD-based position sensitive detector and UCN absorber for the selection slit. The detector was tested using cold neutron beams and the special resolution is estimated to 3 microns. We are going to evaluate the absorber performance by measure the selection efficiency of the slit for each with the UCN beams.

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採択課題番号 20016　　CCD を用いた高位置分解能超冷中性子検出器の開発　　共同通常

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CO1-2

Thickness of Adsorbed Layer on Metal Surfaces Measured by X-Ray and Neutron Reflectometry

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INTRODUCTION: Under a lubricated condition, "compatibility" between a sliding surface and a lubricant largely affects the friction coefficient of surface. The compatibility is dependent on many properties such as wettability of the surface, adsorptive performance of the lubricant to surfaces. To get better tribological performances, many studies have been conducted focusing on the compatibility between target surfaces and lubricants under boundary lubricated conditions. Even under full lubricated conditions, some reports say that the compatibility affects the friction properties on Stribeck curve. However, there have been no reports on the nano structures of interfaces between surfaces and lubricants through a direct observation or analysis of the interface. In this paper, thickness of adsorbed layer of additive in lubricant on metal surfaces is measured by X-ray and neutron reflectometry.

EXPERIMENT: The metal surfaces were obtained by PVD on an ultra-flat silicon block. Two kinds of metal surfaces, iron and cupper, were prepared for the study. The metal surfaces were soaked in lubricant (poli-alpha-olefin: PAO) in a specially-designed sample holder, and the neutron beam was directly entered to the metal/lubricant interface from the side of silicon block. Then, the instrument we used was a X-ray reflectometer in KURRI and a neutron reflectometer 'MINE' in Japan Atomic Energy Agency (JAEA), and the X-ray reflectivity profiles from the metal surface and the neutron reflectivity ones from the interface between metal surfaces and lubricant were obtained by the instruments.

RESULTS – STRUCTURES: The obtained neutron reflectivity profiles for the interface between iron surface and lubricant are shown in Fig. 1. Through an analytical fitting approach with Parratt's theory to the obtained profiles, we can see that the additive forms 3 nm-thick adsorbed layer on the iron surface. On the other hand, the adsorbed layer formed by additive was not observed on the cupper surface.

RESULTS – COEFFICIENTS OF FRICTION: The coefficients of friction of each metal surface under boundary lubricated condition were measured using a ball-on-disk friction tester. The ball material and size are SUJ2 and Sϕ 3/16 inch. The applied load to the ball was 0.2 N. In the case of iron surface, the coefficient of friction considerably decreased when the additive was added in the PAO. However, on the other hand, the coefficient of friction of cupper surface was almost constant even after adding the additive in PAO. We conclude that the nano structure of interface between surface and lubricant are very influential to the friction property under lubrication.

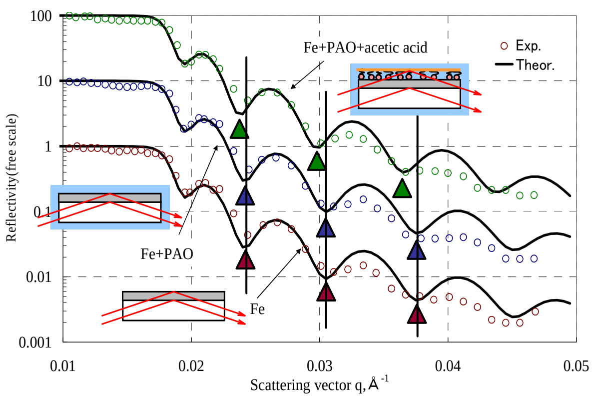

Fig. 1. Neutron reflectivity profiles for the interface between iron surface and lubricant.
(Red: profile plots in air, blue: profile plots in poli-alpha-olefin (PAO) and green: profile plots in PAO with additive (acetic acid)).

採択課題番号　20017表面エネルギーの異なる DLC 膜表面における吸着層厚み測定　共同通常
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CO1-3 Development of Cold Neutron Interferometer for Pulsed Source

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INTRODUCTION: Neutron interferometry is a powerful technique for studying fundamental physics. A large dimensional interferometer for long wavelength neutrons has the advantage to increase the sensitivity to small interactions. Such a kind of interferometer was realized by using multilayer mirrors. Multilayer mirror is suitable for Bragg reflection of cold neutrons. We demonstrated Jamin-type interferometer for cold neutrons using beam splitting etalons (BSEs), which enables us to align the four independent mirrors within required precision [1]. A neutron supermirror is one of the multilayer with continuous latice constants, which reflects the wide range of the wavelength of neutrons. The interferometer can be applied to pulsed neutrons by using the BSEs with supermirrors. Such interferometer increase the neutron counts for high precision measurements, for example, Aharonov-Casher effect [2]. Wevelength dependence of the interaction in the interferometer also can be measured by the time of flight detection for pulsed neutrons.

EXPERIMENTS: As the first test we made polychromatic mirrors by using ion beam spattering in KURRI. The polychromatic mirror contained of two multilayers with the different lattice constants. The lattice constants were 15.8nm and 21.0nm respectively. We fabricated two polychromatic mirrors with intermediate gap layer of 500nm on the top of Si substrate. The distortion by the fabrication of the complex multilayer was compensated by making the thick monolayer of Si on the opposite side of the substrate. The flatness of the center of the mirror was better than 100nm of PV-value. This device enabled us to provide two separated paths of the Jamin-type interferometer for two wavelengths of neutrons. The experiment has been performed using the cold neutron beam line MINE2 at the JRR-3 reactor in JAEA. The beam has a wavelength of 0.88nm and a bandwidth of 2.7% in FWHM. In the case of monochromatic beam of MINE2, the polychromatic mirrors functions at two Bragg angles. The interferometer can be constructed at the two incident angles. We observed clear interference fringes at the incident angle of 1.14 degree and 1.62 degree, which were corresponding to the two multilayers in the polychromatic mirror (Fig. 1).

RESULTS: We demonstrated the feasibility of cold neutron interferometer for pulsed source. Now we are planning to apply the supermirror for BSEs and to construct the interferometer for pulsed neutrons.

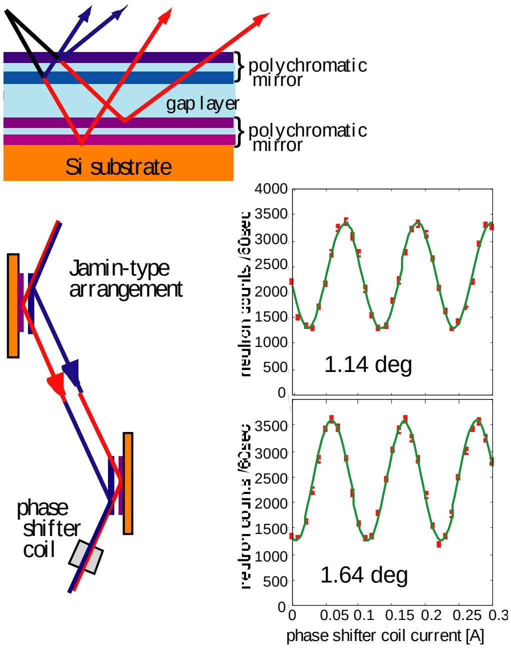

Fig. 1. Polychromatic multilayer mirrors with gap (top) and the interferometer using the mirrors (bottom). Clear interference fringes were observed at two incident angles.

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採択課題番号 20024 冷中性子干渉計のための多層膜中性子ミラーの開発研究 III 共同通常
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CO1-4

Preparation of Hydrogen Storage Alloy Membrane and Analysis of the Surface Structure by X-ray Reflectivity

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INTRODUCTION: Ti-V based bcc solid solution alloys are good candidates as an excellent hydrogen storage material, because the atomic ratio of hydrogen-to-metal (H/M) is around 2.0 [1,2]. The hydrogen storage alloy can be decomposed a hydrogen molecule into two metallic hydrogen's ($H_2 \rightarrow H + H$) on its surface, and then stores up a lot of H's. Therefore, this bcc alloy has attracted much attention as a promising catalyst material alternative to platinum (Pt) for proton ionic conductors.

The aim of this study is to develop a functional catalyst membrane for the proton ionic conductors. Especially, in this work, we focused on the Ti-Cr-V bcc solid solution alloys, and attended to make its membrane. The obtained Ti-Cr-V alloy membrane was evaluated by X-ray reflectivity (XR).

EXPERIMENTS: $Ti_{25}Cr_{35}V_{40}$ alloy was prepared by arc melting of the constituent elements in Ar atmosphere. The H/M is around 1.6, according to the pressure-composition (P-C) isotherms. The $Ti_{25}Cr_{35}V_{40}$ ingot was evaporated in a vacuum, and then the $Ti_{25}Cr_{35}V_{40}$ alloy membrane grown on a silicon basis was obtained, as shown in Fig. 1. The thickness and the surface-roughness were evaluated by the XR.

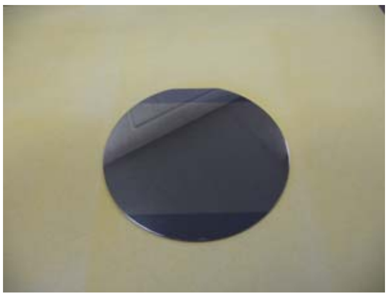

Fig. 1. $Ti_{25}Cr_{35}V_{40}$ alloy membrane.

RESULTS: Figure 2 shows XR profile as a function of *Q*, scattering vector, for the $Ti_{25}Cr_{35}V_{40}$ alloy membrane. Some fringes are clearly observed in the XR profile; this means that there is a $Ti_{25}Cr_{35}V_{40}$ alloy membrane with a fixed thickness. The solid curve in Fig. 2 is the result of model fit, taking into account the X-ray form factor and density of membrane. As a result, the thickness was 18.2 nm, and the density of membrane was 5.90 g/cc, respectively.

The $Ti_{25}Cr_{35}V_{40}$ alloy membrane has been also investigated by neutron reflectivity (NR) on the NR spectrometer, MINE-2, of Research Reactor Institute, Kyoto University (KURRI), installed at JRR-3 of Japan Atomic Energy Agency (JAEA). In the NR profile, there are some fringes obviously. The results of the NR experiments will be reported elsewhere. In addition, we are planning to charge H's into the $Ti_{25}Cr_{35}V_{40}$ alloy membrane, carrying out the NR and the NR experiments. This work is now in progress.

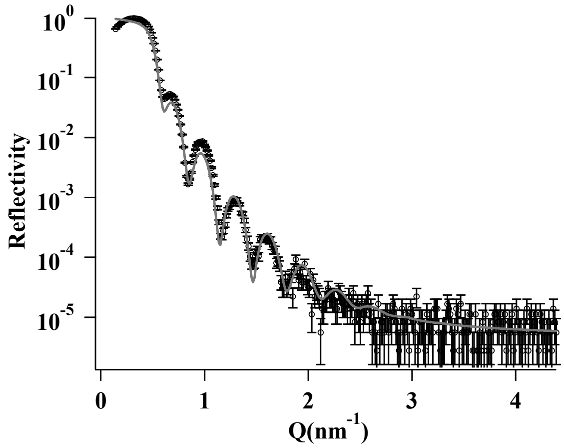

Fig. 2. XR profile of $Ti_{25}Cr_{35}V_{40}$ alloy membrane.

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採択課題番号 20030　水素吸蔵合金薄膜を媒体とした新規プロトン移動型固体電解質の作製　共同通常
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CO1-5

Development of Spin Flip Chopper System with High S/N Ratio for Pulsed Neutron Beam

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INTRODUCTION: Neutron spin flip chopper (SFC) consists of magnetic mirrors and pulsed spin flippers. SFC can provide a very short pulse for a wide beam. It is easy to optimize the pulse characteristics such as pulse width, duty ratio and precise timing of the pulse operation. Nevertheless, so far SFC is not popular as chopper machine owing to the poor S/N ratio, which is about 25 [1].

This problem can be overcome by using multiple SFCs. A high S/N ratio of about 160,000 was achieved using a triple SFC system [2]. The experiment was performed using magnetic monochromatic mirror and continuous neutron beam, although the SFC system is suitable for pulsed neutron sources. To obtain more neutron intensity in performing fundamental particle physics or neutron scattering experiments at pulsed neutron sources, we need SFC with large-*m* polarizing supermirror that can be fabricated at KURRI.

To demonstrate the advantage of multiple SFC system at pulsed neutron beam, we have performed a test experiment using the polarzing magnetic supermirror and pulsed neutron beam of BL5(NOP) beam line at J-PARC.

EXPERIMENTS: The magnetic supermirror was fabricated using the ion beam sputter (IBS) machine at KURRI [3]. The critical angle of total reflection was four times larger than that of natural nickel. We deposited Fe and $SiGe_3$ as magnetic and non-magnetic material, respectively. In order to improve the magnetic property of supermirror, we inserted thin Si layer in which thickness 0.5 nm between Fe and $SiGe_3$ layer [4]. The size of the substrate was 145 mm in length and 70 mm in height.

We used RF spin flipper. The radius and the length of the flipper were 30 mm and 100 mm, respectively. The static magnetic field for the flipper was 7.5 G.

The incident neutron wavelength ranges from 0.2 nm to 1.0 nm.

As shown in Fig.1, we have succeeded to demonstrate that the SFC can be applicable for pulsed neutron beam. The S/N ratio is about 10 and it is not so high since it used single SFC system only. To improve the S/N ratio, we are preparing multiple SFC system by using the IBS machine at KURRI.

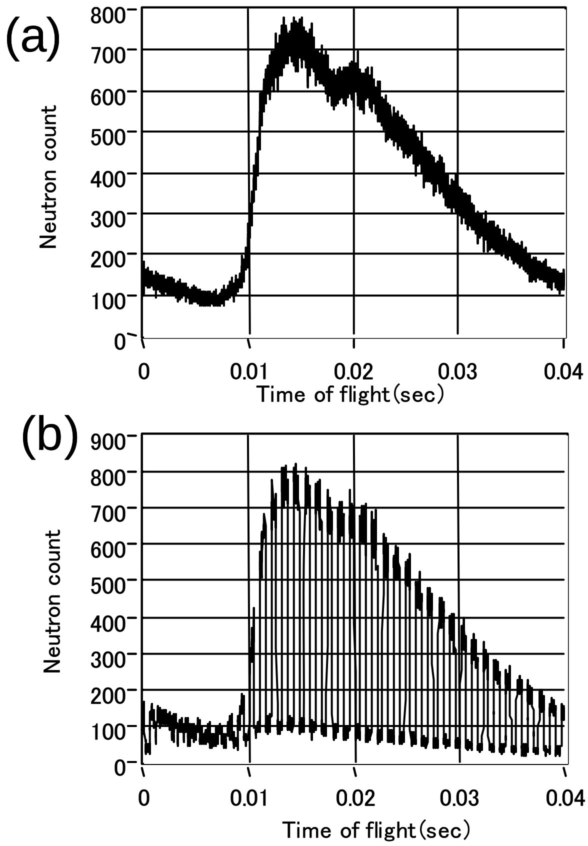

Fig. 1 Measured time of flight spectrum without (a) and with (b) the SFC.

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採択課題番号 20034　　中性子基礎物理測定用磁気反射光学系の開発研究　　共同即時
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