CO1-1 Development of Multilayer Neutron Mirror for Doppler Shifter

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INTRODUCTION: An ultra-cold neutron (UCN), whose kinetic energy is less than 300neV, can be used for the measurement of the neutron electric dipole moment (nEDM). While the Standard Model predicts its value around 10^{-32} e・cm, it may be as large as 10^{-22}-10^{-30} e・cm according to supersymmetric models. At present, the upper limit of 2.9×10^{-26} [e・cm] (90% C.L.) was obtained [1]. A new experiment to improve the sensitivity down to 6×10^{-28} e・cm, by constructing a UCN source with the pulsed proton beam at J-PARC, is proposed [2].

A Doppler shifter [3], which decelerates very cold neutrons by use of a rotating mirror, is a one of the candidates of UCN sources strong enough to start R&D of new devices such as a UCN rebuncher. It can be installed downstream of the High Intensity Branch of the MLF BL05 beamline at J-PARC. The velocity of the mirror has been adjusted to 68m/s, so as to synchronize the pulsed proton beam from the accelerator. Thereby, twice faster (136m/s) neutrons will be almost stopped after reflection by the mirror.

In order to inject such neutrons into the Doppler shifter, a monochrometer, which consists of four multilayer neutron mirrors in parallel, was installed as shown in Fig. 1.

FABRICATION: By using an ion beam sputtering instrument, nickel and titanium multilayers were deposited on a silicon wafer. Both sides of each wafer were equally coated to avoid deflection of the mirror. The multilayer configuration was chosen so as to reflect neutrons with wavelength 17.2nm vertically (i.e. m=3.4).

The result of a measurement of the reflectivity of every side of four mirrors at JRR-3 is shown in Fig. 2. As expected, the reflectivity is large enough at wavelength of 17.2nm.

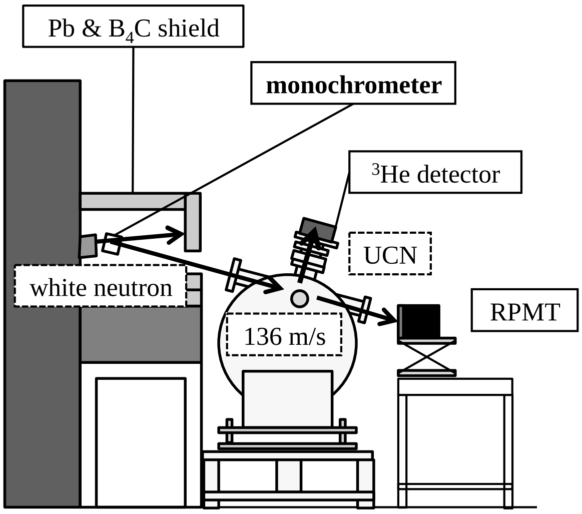

Fig. 1. Side view of the Doppler shifter apparatus.

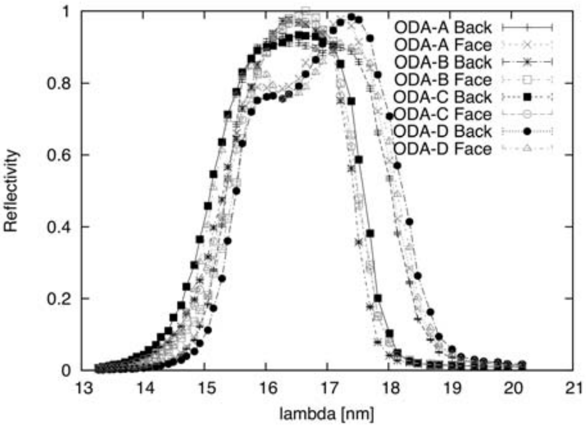

Fig. 2. Reflectivity of neutrons as a function of wavelength.

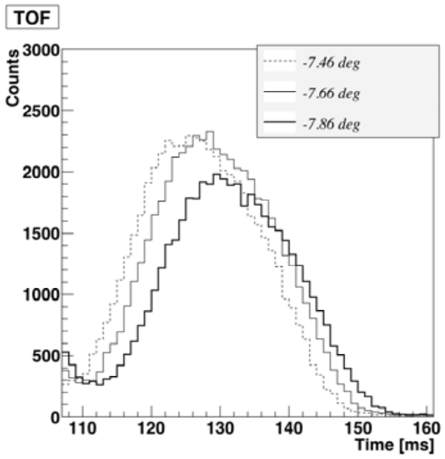

Fig. 3. Time-of-flight dependence on the rotation angle of the monochrometer.

EXPERIMENT: Before installing a Doppler shifter, the neutron beam reflected by the monochrometer was detected by a RPMT. By adjusting the rotation angle of the monochrometer to -7.66 degrees, the time-of-flight distribution was peaked at ~130ms, which corresponds to ~138m/s as the flight distance is 17.9m.

CONCLUSION: The monochrometer for injection of 136m/s neutrons into the Doppler shifter was developed. The velocity of the reflected neutrons was measured by the time-of-flight technique, and it was found to be centered around 136 m/s as expected.

REFERENCES:

[1] C. A. Baker *et al*., Phys. Rev. Lett. **97** (2006) 131801.
[2] H. M. Shimizu *et al*., J-PARC P33 proposal.
[3] S. Imajo, Master’s Thesis, Kyoto University (2011)

採択課題番号 22041 UCN生成ドップラーシフターのための多層膜中性子反射ミラーの開発 共同通常
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CO1-2

Fosucing SANS Development for KURRI

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INTRODUCTION: Recent development of neutron optics makes it possible to construct a high efficiency small-angle neutron scattering (SANS) instrument not only for large neutron facilities but also for small-power reactors and small accelerator based neutron sources. Generally speaking, conventional SANS instruments are very large, of the order of a few tens of meters long altogether and need a vacuum tank of 2m diameter or more. By using a neutron-focusing device, there is a possibility of reducing the size of such SANS instruments. We are now making a conceptual design of SANS instrument for Kyoto University Research Reactor (KUR). Monochromator is also a very important component for such instruments. Usually, a mosaic crystal monochromator, such as a graphite one is used for such purposes, but it has a relatively poor wavelength-band and therefore the integrated intensity from such monochromator is low. We are considering using either a bent-perfect silicone crystal (BPSC) monochromator or construct a focusing supermirror as a wide-band monochromator.

Conceptual Design of a Focusing SANS Instrument for KUR: Target of our design is to realize an instrument that has a Q_{min} of below 0.1 nm^{-1} without using a cold source, with the sample size of more than 10 mm square, possibly larger by a factor of 2 to 4. Total length should be less than 4700 mm, the constraint from the size of the experimental hall of KUR. By using an ellipsoidal mirror with 4 Q_c supermirror coating on it, we can design an instrument as shown in Fig. 1, using a monochromatized neutron beam with 0.28 nm wavelength. In this design, the sample size can be as large as 10mm×20mm and the flight path is 1.45 m. With 4 mm diameter upstream aperture, we can measure Q_{min} of less than 0.1 nm^{-1}. We need to design the supermirror so that it should have a wavelength bandwidth $\Delta\lambda/\lambda$ of more than 10%.

Monochromator Development: To optimize a monochromator, we need to match the incident beam divergence and the mosaic spread of the monochromator crystal. When we need a very large wavelength bandwidth, the monochromator has to have a very large mosaic spread, and therefore, we need a very large beam divergence. If we only have a low beam divergence beamline, such as the beam from a nickel guide, we need to enlarge the incident beam divergence. For such situation, we have developed a neutron beam spreader using many pieces of supermirror to enhance beam divergence. We coupled the device with a bent-perfect silicone crystal monochromator and obtained almost 1 order of magnitude higher monochromatic neutron intensity. Unfortunately, the BPSC monochromator that had a bent radius of 2 m performed rather poorly; therefore the overall performance of the monochromator system was also not as good as expected. We developed a BPSC with an extreme bent radius R of 700 mm, and the performance of the monochromator component itself became excellent; it was comparable to that of a pyrolytic-graphite one. We will try again to couple the BPSC monochromator with the beam spreader to have extremely high performance cold neutron monochromator.

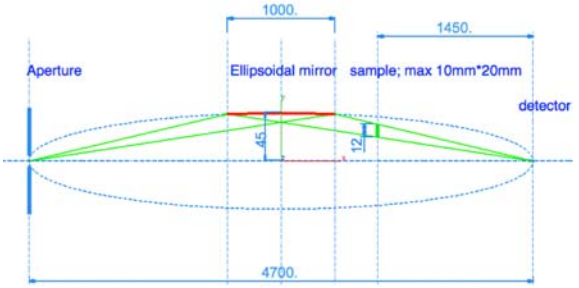

Fig. 1. A conceptual design of the focusing SANS for the KUR reactor using 0.28 nm wavelength neutrons.

採択課題番号 22046　　大強度中性子モノクロメータの開発　　プロジェクト
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CO1-3 Novel Analyzing Method of Amount of Hydrogen in Metal Alloy Utilizing Small-Angle Neutron Scattering

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INTRODUCTION: Hydrogen storage alloy is expected to be one of next portable hydrogen storage tanks due to its high hydrogen density in unit volume and also in unit weight. Therefore, in these years, many researchers have being improving hydrogen storage performance of alloy, such as hydrogen density in unit volume, in unit weight, plateau temperature and so on. One of difficult problems for improving the performance of hydrogen storage alloy is `*residual hydrogen*', which remains in the alloy under the external hydrogen pressure less than that of plateau. In other words, it is considerably effective to reduce an amount of the residual hydrogen to improve an amount of available hydrogen in an alloy. Therefore, we have started to research characteristic feature of hydrogen in alloy to reduce the amount of the residual hydrogen in alloy as a final goal.

As a first step of the research, we have to analyze the amount of the hydrogen in alloy. It is usually measured with the classical subtraction method: the amount of the hydrogen in the metal is calculated by measuring the pressure change of a buffer tank connecting to a container of an alloy before and after the hydrogen charge or discharge. This method is easy but not accurate very much and difficult to measure an environment out of the hydrogen charge and/or discharge system. Therefore, we developed the novel technique to measure the amount of hydrogen in an alloy just under the atmosphere and/or various circumstances utilizing small-angle neutron scattering (SANS). In this report, we show our recent result.

METHOD: Small-angle scattering (SAS) is utilized as one of very powerful tools to analyze nano-scale structure. However, we focused on the incoherent scattering intensity which is observed in relatively higher *q*-range. The incoherent scattering in the material including hydrogen originates from the hydrogen due to its high cross section 80.26 barn. Therefore, by measuring the intensity of the incoherent scattering, we can estimate the amount of hydrogen in the material.

RESULTS: Figure 1 shows SANS profiles of the hydrogen storage alloy, $Ti_{0.31}Cr_{0.49}V_{0.20}$, with various amount of hydrogen. The incoherent scattering intensity increases with increase of the amount of hydrogen in the alloy: Broken, dash-dot and solid straight lines show the incoherent scattering intensity of charged, discharged and non-charged (virgin) samples, respectively. Open circles denote the scattering intensity after discharge of the hydrogen, which profile is coincident with that of non-charged one. On the other hands, the profile shows deviation in the higher *q*-region. As described before, the deviation corresponds to the amount of residual hydrogen. From this result, we found the amount of residual hydrogen was 0.2 in H/M unit.

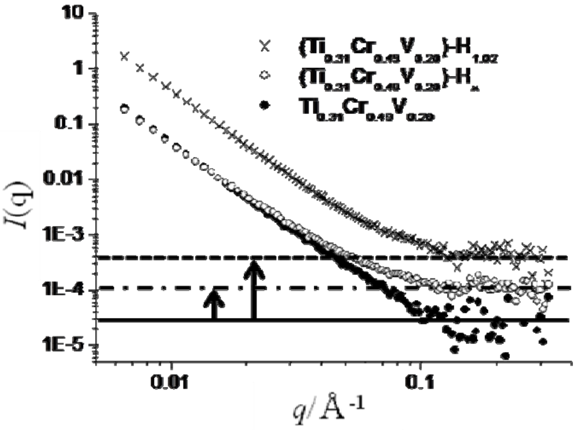

Fig. 1. SANS profiles of $Ti_{0.31}Cr_{0.49}V_{0.20}$ with various amount of hydrogen. Cross, open circle and closed circle denote charged, discharged and non-charged (virgin) samples, respectively.

採択課題番号 22057　水素貯蔵金属内の繰り返し水素脱着による水素分布揺らぎの研究　共同通常
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