III-1

Accelerators and Instruments

Highlight

BL1U

Generation of Vector Beam with Tandem Helical Undulators at BL1U

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Some sorts of lights which have spatially structured in intensity, polarization, and/or phase, called "structured light", have stimulated significant interests for a range of applications. Optical vortices and vector beams which have a donuts-shaped intensity with spiral phase structure or spatially dependent polarization that direction rotates around its beam axis have long been interest in laser community [1, 2]. Figure 1 shows schematic illustration of vector beams.

In accelerator-based light sources, several ways to generate optical vortices has been proposed and demonstrated [3]. In addition, edge radiation and transition radiation belong a category of vector beam. In these situations, we devise a scheme to produce a vector beam based on synchrotron radiation technology, which enables the generation of vector beams in the VUV or x-ray range [4]. The scheme is similar to the idea of "cross undulator" [5] but we expanded it into two dimensions to superpose second harmonics from tandem helical undulators at their polarizations were opposite to each other. It was well known in the laser community that the vector beams can be generated by superposing optical vortices.

The experiment was carried out at the BL1U. The first harmonic of the undulators light was set to 496 nm, and the second harmonic to 248 nm. The intensity was monitored with a CCD camera 7.5 m downstream from the center of the downstream undulator after through the band-pass filter with a center wavelength of 248 ±1 nm and rotatable linear polarizer for analysis of polarization direction.

The experimental results and the numerical simulations results done by using the Synchrotron Radiation Workshop [6] are shown in the Fig. 2. In the vicinity of the center, distributions of polarization are well approximated as a vector beams of Fig.1. Obtained degree of linear polarization is distributing in the range of 60-80%. This scheme may form the basis of generating vector beam in diffraction-limited synchrotron light sources in future.

In the next machine time, Stokes parameters of undulator radiation including vector beams will be measured for obtaining all polarization parameters.

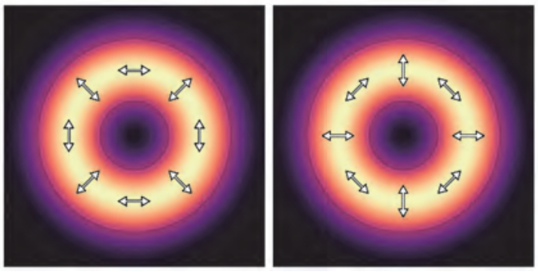

Fig. 1. Schematic illustration of intensity and polarization structure of vector beams.

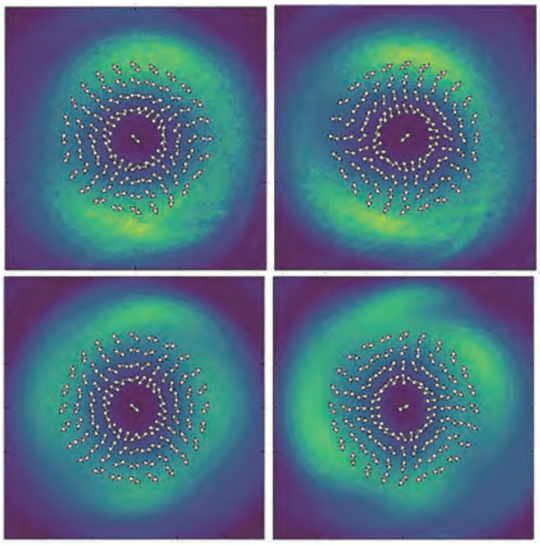

Fig. 2. Distribution of direction of linear polarization on the observed plane. The observed area is 6 mm × 6 mm square. Top and bottom rows show experimental and simulation results respectively. The experimental condition of results in right column have relative phase retardation of downstream undulator radiation from the condition of left column. The relative phase retardation is controlled approximately 180° by buncher magnets between undulators.

[1] H. Rubinsztein-Dunlop *et al.,* J. Opt. **19** (2017) 013001.
[2] Q. Zhan, Adv. Opt. Photon. **1** (2009) 1.
[3] M. Katoh *et al.,* Sci. Rep. **7** (2017) 6130.
[4] S. Matsuba *et al.*, Appl. Phys. Lett. **113** (2018) 021106.
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[6] O. Chubar *et al.,* Nucl. Instrum. Meth. Phys. Res. A **435** (1999) 495.

Accelerators

The Performance Evaluation of Nuclear Emulsion

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Nuclear emulsion is a kind of photographic film having sensitivity for ionization. The film is made by coating emulsion gel, consisting mainly of silver bromide crystals and gelatin, on plastic base (Fig. 1). When a charged particle passes through the film, its track is recorded by silver grains, for the particle runs in the film with silver bromides around it ionized. Our group uses the film to find neutrino interactions. It is not easy because the tracks we try to find are very fine. Nuclear emulsion resolves this difficulty. Because the silver bromide crystal's diameter is 200 nm, we can detect them. We produced the films by ourselves and checked their performance.

Grain density (GD) is a reference index of its sensitivity. This value is counts of silver grains per 100 µm. The larger the value is, the thicker the track is. Then, I use the films exposed electron beam at UVSOR which has equivalent energy with minimum ionizing particle. Figure 2 shows the deference of grain densities by product batches. These values are not extraordinary and it suggests that the films can be used safely.

The film has accumulated tracks since it is produced. It means the film keep on recording cosmic ray, natural radiation, and so on. These tracks recorded before an experiment become noise. We want to fade noise tracks because our targets contain fine tracks. Then, we make the films "refresh". Refresh is a process to fade tracks in the film. The film is filled with silver bromide crystals. If a charged particle flies near them, they are ionized and become silvers. The reaction that silver bromide turns to be silver is reversible. It suggests that the tracks may fade away. We call this phenomenon "fading", and try to inhibit it. Refresh uses the characteristics of fading. I checked that refresh is effective for our films to use in the neutrino experiment. Then, I use the films exposed electron beam at UVSOR. I make the film refresh and measure grain density. Figure 3 shows the result. It is recognized that electron tracks and cosmic ray tracks faded after refresh.

We check the film's performance by using electron beam at UVSOR. After figuring out it, we use the film in experiments.

Fig. 1. The structure of nuclear emulsion

Fig. 2. The diference of GD by product batches

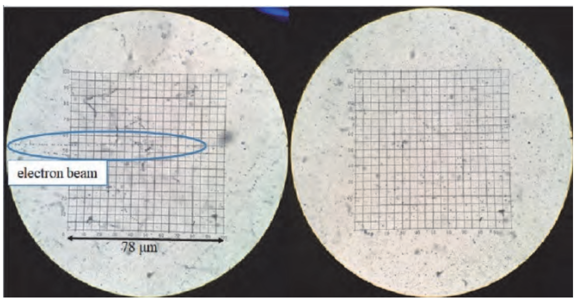

Fig. 3. microscope views of films (left: unrefreshed film, right: refreshed film)

BL1U

Laser Compton Scattering Gamma-ray Generation for Nonlinear Effect in QED

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Although QED is considered to be established yet, QED predicted unresolved nonlinear effects, such as photon-photon interactions. However, because their cross sections are extremely small, the interactions have not been well studied [1,2]. Recently, the scattering of virtual photon – virtual photon scattering has been measured for the first time [1]. One of the photon- photon interactions is Delbrück scattering. Delbrück scattering, in which a gamma-ray interacting with a Coulomb field creates an electron-position pair, which subsequently annihilates to generate a gamma-ray whose energy is almost identical with the incident gamma-ray, is one of important phenomena to study nonlinear effects by QED and vacuum polarization. However, there was a critical problem that one cannot derive only the amplitude of Delbrück scattering by the interference with other elastic scattering such as nuclear Tomson scattering and Giant Dipole Resonance.

Koga and Hayakawa [3] have presented that it is possible to measure selectively the amplitude of Delbrück scattering using linearly polarized gamma-ray beams. Furthermore, if one uses a linearly polarized beam with energies lower than 1.022 MeV, which is the threshold of the pair creation, it is possible to measure only the virtual process of Delbrück Scattering, namely vacuum polarization. For such a purpose, we have developed a laser Compton scattering (LCS) gamma-ray beam with a CO_2 laser having a wavelength of 10.6 μm at the UVSOR-III synchrotron radiation facility, in which the energy of the electron beam stored in top-up mode is approximately 750 MeV. We have demonstrated the 1-MeV LCS gamma-ray beam generation using a random polarization CO_2 laser [4].

We newly installed a linearly polarized CW CO_2 laser with power of up to 130 W in order to generate linearly polarized LCS gamma-ray beam (see Fig. 1). We measured the energy spectra of the generated LCS gamma-ray beam using 3.5” × 4” $LaBr_3$(Ce) scintillation detector. Figure 2 shows the measured energy spectra. The LCS gamma-ray intensity increases with increasing laser power.

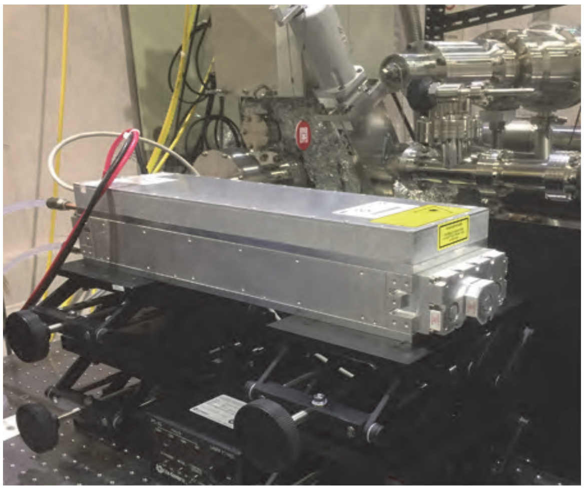

Fig. 1. Photo of the newly installed high power linearly polarized CO_2 laser.

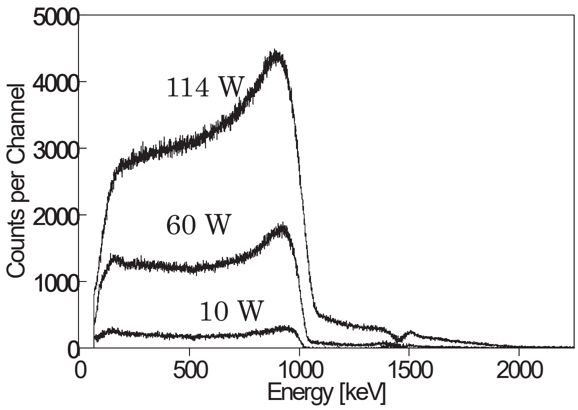

Fig. 2. Measured energy spectra of the generated LCS gamma-ray beam. The gamma-ray intensity increases with increasing laser power.

[1] ATLAS Collaboration, Nature Physcs **13** (2017) 852.
[2] T. Inada *et al.*, Phys. Lett. B **732** (2014) 356 .
[3] J. K. Koga and T. Hayakawa, Phys. Rev. Lett. **118** (2017) 204801.
[4] H. Zen *et al.*, J. Phys.: Conf. Ser. **1067** (2018) 092003.

BL1U

Study on Isotope 3D Imaging Using NRF Absorption Method in UVSOR-BL1U

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A Nuclear Resonance Fluorescence (NRF) method is a powerful tool for investigation not only of the nuclear physics, but also of isotope imaging inside the spent nuclear fuel canisters and nuclear wastes. We have been developing an isotope imaging technique by using NRF [1]. The absorption can be measured by sample material and “witness target”[2].

A demonstration experiment of the NRF-CT imaging by using LCS gamma-ray beam has been carried out at the LCS gamma-ray beamline, BL1U (Fig. 1), at UVSOR-III where 5.4 MeV LCS gamma-rays with a flux of 1×10^{7} photons/s can be available [3]. In 2018, we upgraded the energy of LCS gamma-rays up to 5.5 MeV and about 10 times higher flux by replacing the IR fiber laser.

By using NRF absorption method a NRF-CT image has been taken for a sample target consists of aluminum, stainless steel, and lead rods (shown in Fig. 2 (a)). The NRF signals from the witness target (natural lead) were measured by a Ge detector. At the same time, transmission gamma-rays have been measured by a $LaBr_3$(Ce) detector which gives a density distribution of the sample target. The segmented CT reconstruction method has been developed and we obtained clear ^{208}Pb distribution as shown in Fig. 2 (b) [4].

After the upgrade of the UVSOR-III BL1U beamline, we have been trying to take a real isotope image by using enriched targets, ^{206}Pb and ^{208}Pb. The experiment has been performed and the isotope CT image reconstruction is under processing. To obtain a high resolution image and 3D CT have also been planned.

[1] N. Kikuzawa *et al.*, Appl. Phys. Express **2** (2009) 036502.
[2] H. Ohgaki *et al.*, Proceedings of IPAC2016, Busan, Korea, 2007-2010 (2016).
[3] H. Zen *et al.*, Energy Procedia **89** (2016) 335-345.
[4] H. Zen *et al.*, AIP Advanced **9** (2019) 35101.

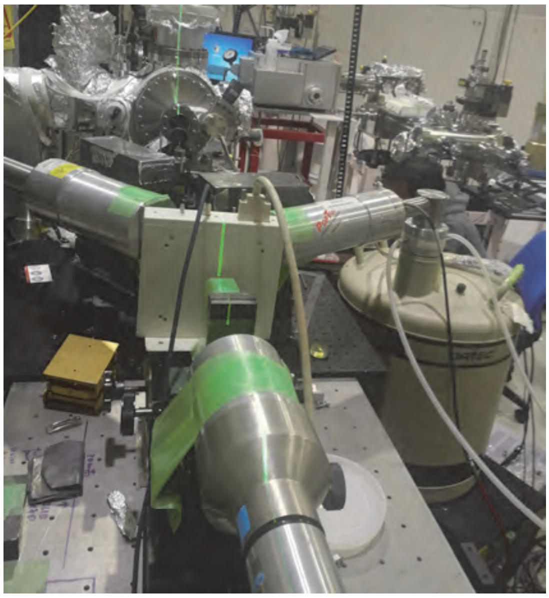

Fig. 1. BL1U LCS gamma-ray beamline with the setup for NRF-CT measurement.

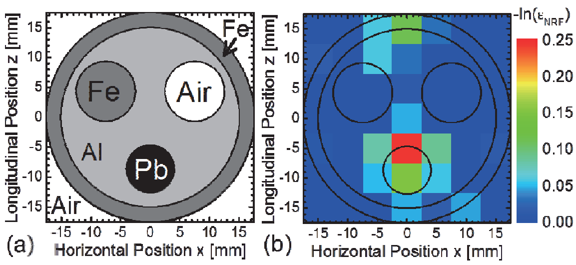

Fig. 2. (a) Arrangement of the sample target. (b) Result of NRF-CT measurement.

BL1U

Study on Oxygen Vacancy in TiO_2 Using Photon Induced Positron Annihilation Spectroscopy at UVSOR-BL1U

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Titanium dioxide (TiO_2) is one of the most important catalysts and catalyst supports for industrial use. It is sometimes used under harsh chemical or physical conditions, such as in water or chemical vapors under high temperature and pressure. We have been interested in a mechanism of catalytic activity of TiO_2 to improve its performance.

Our recent studies showed formation of oxygen vacancies and titanium ions (Ti^{3+}) gave strong effect on the surface wettability and catalytic activity of TiO_2 under irradiation of UV light or gamma-rays [1]. It is also recently reported that very high oxidative decomposition activity for organic molecules such as toluene was observed by an excitation of valence electrons with applying heat, instead of light or ionizing radiation [2]. While these mechanisms are not understood in detail yet, we believe oxygen vacancy plays an important role.

Our research proposal is to study the mechanism of the catalytic activity of TiO_2 under heat application, by an observation of oxygen vacancy concentration as a function of temperature of sample material. In this study, a contactless and noninvasive material analysis method, so called the photon induced positron annihilation spectroscopy method was applied [3]. The method is based on a positron annihilation gamma-ray spectroscopy, triggered by a high-energy photon beam incident on a sample material.

When photons of a few MeV or higher are incident on a sample material, a part of them decays into electron-positron pair (pair creation), and intense monochromatic gamma-rays of 511 keV are emitted following to the positron annihilation with their counterpart electrons (positron annihilation). In the present research study, we measured an energy spread of annihilation gamma-rays, which contains information on the atomic vacancy concentration of the sample material.

While the energy of the annihilation gamma-rays is simply monochromatic, it slightly shifts as the momentum of the counterpart electrons with which the positrons annihilate. It is called the doppler broadening of the annihilation gamma-rays. When a momentum of the counterpart electrons was large, the energy spread of the annihilation gamma-rays is also large, and it is small when the momentum was small. The energy spread is usually small, typically on the order of keV, and it can be measured with high energy-resolution gamma-ray spectrometer, such as high-purity germanium detector (HPGe).

We have set up a gamma-ray spectroscopy system at the laser-Compton scattering (LCS) beamline of BL1U at UVSOR-III [4], and measured the energy spectra of the annihilation gamma-rays as we changed the sample temperature, from room temperature to 600 degree Celsius. The data acquisition was successful, and their analysis is being undergone. We also prepare for the experiment of the positron lifetime measurement in next fiscal year, to study the mechanism in detail.

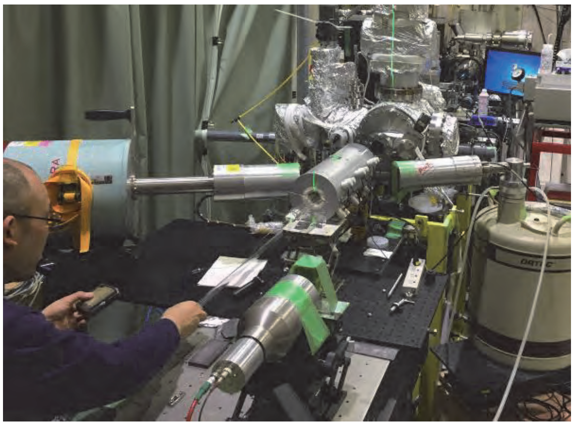

Fig. 1. Measurement system for doppler broadening spectroscopy at LCS beamline at BL1U in UVSOR-III.

[1] S. Dohshi *et al.*, Top Catal. **35** (2005) 327.
[2] H. Nishikawa, Appl. Surf. Sci. **225** (2009) 7468.
[3] H. Toyokawa *et al.*, Proc. AccApp'07 (2007) 331.
[4] H. Zen *et al.*, Energy Procedia **89** (2016) 335.

BL2A

Unprecedented Data of the Solar Corona Taken by a High-Speed X-ray CMOS Camera aboard FOXSI-3 Sounding Rocket

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The solar corona is full of dynamic phenomena. They are accompanied by interesting physical processes, namely, magnetic reconnection, particle acceleration, shocks, waves, flows, evaporation, heating, cooling, and so on. The understandings of these phenomena and processes have been progressing step-by-step with the evolution of the observation technology in EUV and X-rays from the space. But, there are fundamental questions remain unanswered, or haven't even addressed so far. Our scientific objective is to understand underlying physics of dynamic phenomena in the solar corona, covering some of the long-standing questions in solar physics such as particle acceleration in flares and coronal heating. In order to achieve these science objectives, we identify the imaging spectroscopy (the observations with spatial, temporal and energy resolutions) in the soft X-ray range (from ~0.5 keV to ~10 keV) is a powerful approach for the detection and analysis of energetic events [1]. This energy range contains many lines emitted from below 1 MK to beyond 10 MK plasmas plus continuum component that reflects the electron temperature.

The soft X-ray imaging spectroscopy is realized with the following method. We take images with a short enough exposure to detect only single X-ray photon in an isolated pixel area with a fine pixel Silicon sensor. So, we can measure the energy of the X-ray photons one by one with spatial and temporal resolutions. When we use a high-speed soft X-ray camera that can perform the continuous exposure with a rate of more than several hundred times per second, we can count the photon energy with a rate of several 10 photons / pixel / second. This high-speed exposure is enough to track the time evolution of spectra generated by dynamic phenomena in the solar corona, whose lifetimes are about form several ten seconds to several minutes.

For the first imaging spectroscopic observation of the solar corona in soft X-ray range, we launched a NASA's sounding rocket (FOXSI-3) on September 7th, 2018 [2] and successfully obtained the unprecedented data (see Fig. 1) [3] using a high speed X-ray camera with a back-illuminated CMOS sensor [4].

The performances (especially, the photon counting capability) of this CMOS sensor was evaluated at UVSOR BL2A [5]. We deeply thank Mr. Kondo, Mr. Nakamura and Dr. Tanaka for their kind help.

[1] N. Narukage *et al.*, White paper of the "soft X-ray imaging spectroscopy", arXiv:1706.04536 (2017).
[2] Web Release:
https://hinode.nao.ac.jp/en/news/topics/foxsi-3-180907/
[3] Web Release:
https://hinode.nao.ac.jp/en/news/topics/foxsi-3-data-release-en-20190115/
[4] S. Ishikawa *et al.*, Nucl. Instrum. Methods Phys. Res. Sec. A **912** (2018) 191.
[5] N. Narukage and S. Ishikawa, UVSOR Activity Report **45** (2017) 33.

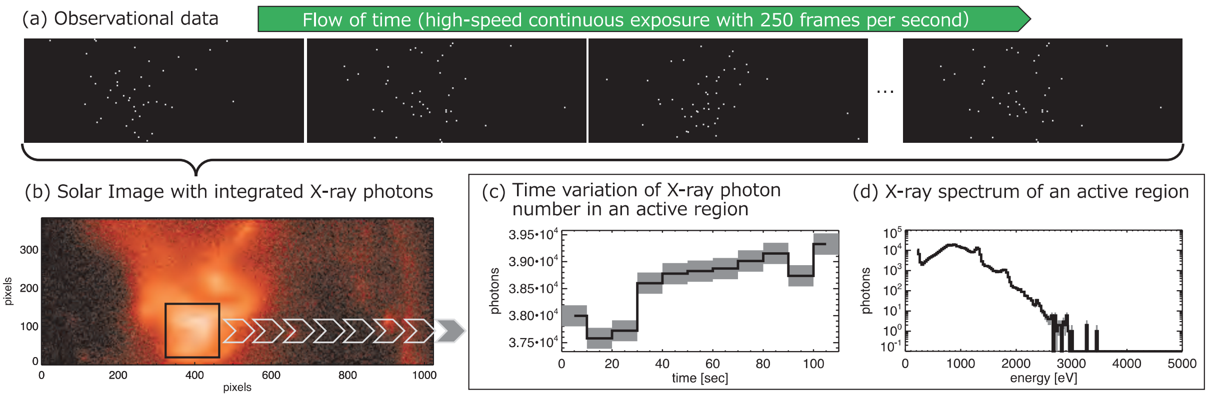

Fig. 1. Focusing imaging spectroscopic data in soft X-rays obtained by the FOXSI-3 sounding rocket. Panel (a) shows real FOXSI data. Each white dot in these images is an individual X-ray photon. From these images, we can simultaneously obtain information about the position, timing, and energy of each X-ray photon. Using this information, we can construct a solar corona image (see Panel (b)). We can also investigate the temporal evolution and spectrum of the X-ray photons, as shown in Panels (c) and (d), respectively.

BL4U

Development of a Secondary Electron Detector for a Scanning Transmission X-ray Microscope

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Analysis of interactions of X-ray with matters, such as absorption, scattering, fluorescence, photoemission, phase transition, photo- and secondary electron etc., brings unique information according to its mechanism. Basically, a scanning transmission X-ray microscope (STXM) uses X-ray absorption to acquire integrated information of a sample along its optical axis (i.e. bulk information) and sometimes uses X-ray fluorescence or photo- and secondary electron to obtain additional information simultaneously. Detection of the electrons is useful to analyze near surface information of the sample since escape depth of the electrons is limited to a few nm. Furthermore, the detection of the electrons also enables to measure a thick sample which cannot be penetrated by the X-rays. STXM beamline BL4U can use low energy region from 50 to 770 eV [1] so that the detection of the secondary electrons is more suitable than that of X-ray fluorescence in regard to their yields. Therefore, we have been developing an optical system for STXM with using a channeltron to detect the secondary electrons.

A schematic image of an optical system of STXM with a channeltron (C4831, Photonis Inc.) is shown in Fig. 1. Typically, the channeltron for STXM is placed downstream of the sample in parallel with a detector for a transmitted X-ray [2] because gap between an order select aperture (OSA) and the sample is not enough to set the channeltron to detect the electrons from top surface of the sample. Even though, in this report, the channeltron was placed upstream of the sample, set toward between the sample and OSA, to analyze front-surface of the sample. A focusing element, a Fresnel zone plate, with outermost zone width of 45 nm and diameter of 240 µm was used for longer focal length instead of higher spatial resolution. Then, the gap between the OSA and the sample was about 1 mm at the X-ray energy of 400 eV.

An ultra thin section of blended polymer supported by a copper grid was used as a test sample. The sample was tilted about 30° towards the channeltron. 50 V for input end and 2000 V for output end were applied to the channeltron. Degree of vacuum was ~3×10^{-6} mbar. A secondary electron image by the channeltron and an X-ray transmission image were obtained simultaneously (shown in Fig. 2). Then, energy of the X-ray was 400 eV and dwell time per a pixel was 500 ms. From edge profiles of the copper grid in each image, spatial resolutions are almost similar. In the secondary electron image in Fig. 2 (b), open space shown by a dashed circle, where signals should be zero, produces some signals more than the polymer. This result is under discussion.

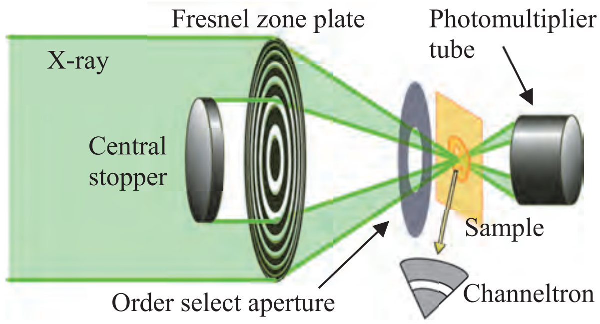

Fig. 1. A schematic image of a optical system of STXM with a channeltron.

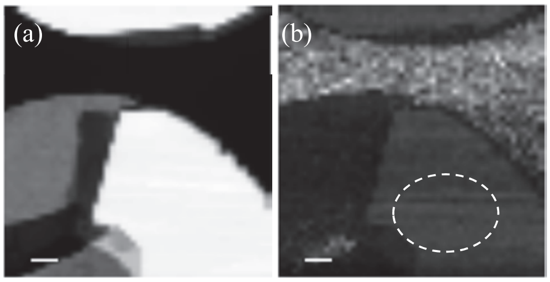

Fig. 2. (a) An X-ray transmission and (b) a secondary electron images of a thin section of blended polymer on a copper grid. White color shows more signals. Scale bars are 5 µm.

[1] See beamline section of this activity report
[2] C. Hub, W. Wenzel, J. Raabe, H. Ade and R. H. Fink, Rev. Sci. Instrum. **81** (2010) 033704.

BL7B

Pre-flight Verification of CLASP2 Throughput

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We have developed a high precision (<0.1%) UV spectro-polarimeter called Chromospheric LAyer Spectro-Polarimeter (CLASP2), and it is in a final step for the launch whose expected date is on April 1st, 2019. CLASP2 is a NASA sounding rocket experi- ment, which aims to advance our knowledge of the magnetic fields in the upper solar chromosphere by spectro-polarimetric observations at the Mg II h & k lines (near 280 nm) and imaging observation with high cadence at the Lyman-alpha line (121.6 nm) [1]. For this, the high throughput of the instrument in both the UV lines is required.

To obtain the high throughput of CLASP2, we had carried out a dual-band pass “cold mirror” coating targeting at both the lines to the primary mirror of the telescope, and also performed the high reflectivity (R) mirror coating (Al+MgF_2) to other mirrors. After coating, we have frequently checked its coating performance at UVSOR [2], and monitored their reflectivity by using the witness samples (WSs) which are 1-inch flat mirrors coated simultaneously with the flight mirrors.

On November, 2018, we moved our instrument from Japan to USA for the final preparation of the launch. At that time, we attached six WSs on our instrument to monitor the contamination during the transportation and experiment. We brought the monitored WSs back to Japan, and carried out the pre-flight verification of the healthiness of the CLASP2 flight mirrors at the UVSOR BL7B by using the WSs. In particular, we measured the reflectivity of each WS not only near 280 nm (G3 grating) but also at 121.6 nm (G2 grating). Finally, we compared the results with those of previous UVSOR measurements and derived the final throughput of CLASP2.

Figure 1(a) shows one of the results of our reflectivity measurement of the primary mirror (M1) from the 115 nm to the 850 nm wavelengths. The measured reflectivity is 50% at the 121.6 nm and 71% near the 280 nm wavelengths, both of which meet the specification. The average reflectivity in the visible light is about 5%. The difference between this measurement and the previous measurement is only about 1% near the 280 nm and about 3% at the 121.6 nm wavelengths. It indicates that the dual-band pass cold mirror coating performed on the M1 still keeps sufficient performance even 15 months after the coating.

We also confirmed that the coating performance of other flight mirrors is well maintained as our required specification. Figure 1(b) presents results of reflect- ivity of each mirror, and Table 1 represents the results in detail.

Finally, we calculated throughput of the spectro-polarimeter and updated the radiometry of CLASP2 based on our measurements at the UVSOR. From the calculation of radiometry, we confirmed that our minimum required time for the observations of each target is still less than the planned observing time.

In summary, we have measured the reflectivity of WSs which were simultaneously coated with flight mirrors and accompanied with the instrument during the integration in Japan and shipment from Japan to USA through the UVSOR experiment. From this experiment, we confirmed: (1) There is no significant degradation of the coating performance of all the flight mirrors. (2) The final throughput of SP is satisfied for the solar observations we required.

Recently, we moved our instrument of CLASP2 to the launch site "US White Sands Missile Range" in New Mexico. It is ready for the launch.

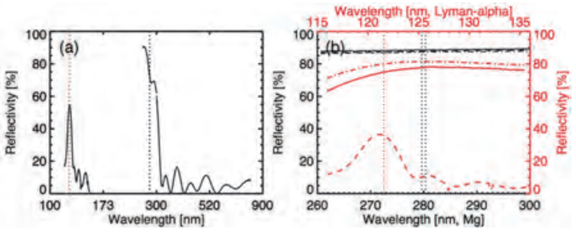

Fig. 1. Measured reflectivity of witness samples of (a) the primary mirror (M1) and (b) other mirrors: M3 - Off-axis parabolic mirror (black solid line), M4 - Hyperbolic Mirror (back dashed line), M5 - Folder mirror (black dot-dashed line), Grating (black three dots-dashed line), Slit mirror (red solid line), Slit-jaw cold coating mirror (red dashed line), and M2 – Secondary mirror of telescope (red dot-dashed line). Red doted lines represent the Lyman-alpha line and black doted lines show the Mg II line near 280 nm wavelength.

Table 1. Reflectivity of CLASP2’s flight mirrors: Spec.: specification, Prev.: previous UVSOR measurements, and U#38: pre-flight measurements (M1 & M2 are flight mirrors of telescope, From M3 to M5 and Grating are SP mirrors, SM and SC represent a slit mirror and a slit-jaw cold mirror). Note that, black color indicates the value of reflectivity at 280 nm and red color represents the values of reflectivity at 121.6 nm

	M1	M2/ M3	M4	M5	SM	SC	Grating
Spec.	>70% >40%	>80% >80%	>80%	>80%	>75%	>35%	-
Prev.	72% 53%	89% 84%	87%	87%	78%	36%	89% (HJY)
U#38	71% 50%	88% 80%	88%	87%	76%	36%	84%

[1] N. Narukage *et al.,* SPIE **9905** (2016) 99052U.
[2] D. Song *et al*., UVSOR Activity Report 2017 **45** (2018) 36.

BL7B

The Composite Type Measurement System for VIS-VUV Complex Refractive Index

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Since the ultraviolet (UV) - vacuum UV (VUV) region generally has strong absorption, for example, the correct complex refractive index (CRI) of the photodetector material is necessary, for example, for the design of the UV - VUV region photodetector. Based on the instrument designed by Saito *et al.* [1], we have developed a synchrotron radiation (SR) dedicated visible (VIS) - VUV spectroscopic ellipsometer (SE) which is installed at BL7B. Although this type of SE has an advantage in obtaining not only optical constants of the sample, but also Stokes parameters of the incident beam [2], but in principle the wavelength continuous complex refractive spectrum can not be measured. Furthermore, ellipsometry requires a layered model of the sample to calculate the CRI from the measured ellipsometric parameters. Another way to obtain the wavelength continuous CRI spectrum is the Kramers - Kronig transformation method applied to the reflectance spectrum (KK method). In this method, it is not difficult to measure the wavelength continuous reflectance spectrum and KK method does not require the layered model, but it is not so easy to measure the reflectance spectrum quantitatively. In short, it can be seen that the SE method and KK method are complementary to each other. Then, we have been reconstructing our VIS-VUV SE to the composite type measurement system for VIS - VUV CRI. In this report, we will discuss the mechanical remodeling in our VIS - VUV SE by the incorporating a reflectometer. Specifically, in addition to the insertion of the reflectometer, the sample alignment mechanism was redesigned that does not interfere with the reflectometer rotation.

Figure 1 shows the schematic layout of VIS - VUV SE with the incorporated reflectometer. In order to cancel the wavelength sensitivity dependence of the photodiode, both light source and reflected light from the sample must be measured with the same photodiode. The 3D layout of the reflectometer considering the above condition is shown in fig. 2a. All parts of this reflectometer are equipped on one ICF203 flange. The renewed sample position adjustment mechanism with the sample holder is shown in fig. 2b. Precise rotation and translation adjustments of the sample can be made with the rotary ball spline device (red color part). Figure. 2c represents the positional relationship in the main chamber of our SE among the reflectometer, the sample alignment mechanism with the sample holder, and the β rotation mechanism. Figures 3a and 3b shows the experimental results of the ellipsometric parameters and the reflectivity under the same experimental conditions (without the incidence angle) after reconstruction, respectively. Since sample is 1 μm AlN thin film, interference is clearly observed at the lower photon energy side of fig. 3b. We are currently working on the establishment of analytical methods for deriving the CRI from the measurement results of ellipsometory and reflection measurement.

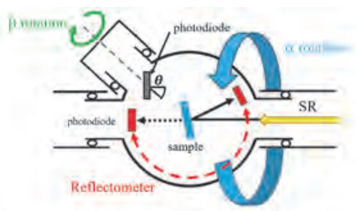

Fig. 1. Schematic layout of VIS-VUV SE.

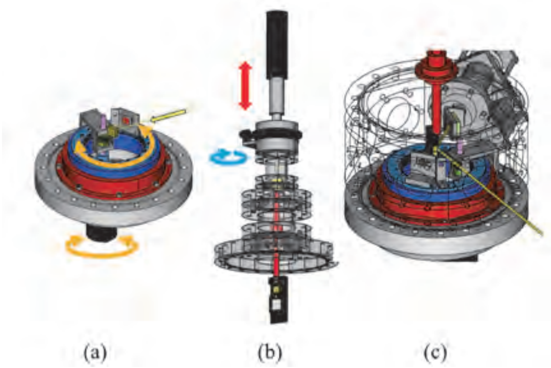

Fig. 2. 3D layouts of reflectometer (a), sample mechanism (b), and their relationship (c).

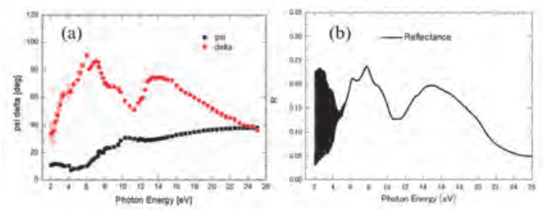

Fig. 3. Experimental results. (a) ellipsometric parameters, (b) reflectance

[1] T. Saito, M. Yuri and H. Onuki, Rev. Sci. Instrum. **66** (1995) 1570.

[2] F. Sawa *et al.*, UVSOR Activity Report 2017 **45** (2018) 37.

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