UVSOR Synchrotron Facility

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Outline of the UVSOR Synchrotron Facility

Since the first light in 1983, the UVSOR Synchrotron Facility has been successfully operated as one of the major synchrotron light sources in Japan. After the major upgrade of accelerators in 2003, UVSOR Synchrotron was renamed to UVSOR-II Synchrotron and became one of the world's brightest low energy synchrotron light sources. In 2012, it was upgraded again and has been renamed to be UVSOR-III Synchrotron. The brightness of the electron beam was increased further. Today, six undulators are installed in total, and the storage ring, that is *ca.* 53 meters in circumference, is regularly operated in the top-up mode, irrespective of multi bunches or single bunch.

The UVSOR accelerator complex consists of a 15 MeV injector LINAC, a 0.75 GeV booster synchrotron, and a 0.75 GeV storage ring. The magnet lattice of the storage ring consists of four extended double-bend cells with distributed dispersion function. The single bunch top-up operation (176 ns, 5.6 MHz) for time-resolved measurements or low current measurements is also conducted for two weeks per year.

Six undulators and eight bending magnets provide synchrotron radiation (SR). The bending magnet, its radius of 2.2 m, produces SR with the critical energy of 425 eV. There are eight bending magnet beamlines (Table. 1). Three of the six undulators are in-vacuum soft X-ray (SX) linear-polarized undulators (BL3U, BL4U, and BL6U) and the other three are vacuum/extreme ultraviolet (VUV/XUV or EUV) circular-polarized undulators (BL1U, BL5U, and BL7U). Two beamlines, BL1U and BL6U, are so-called "in-house beamlines," which are dedicated to strategic projects conducted by internal IMS groups in tight collaboration with domestic and foreign scientists. The BL1U can produce pulsed γ-ray radiation by laser Compton scattering technique. In 2021, it was developed by constructing a laser transport system to generate high-intense γ-ray beams. Other twelve beamlines are so-called "public beamlines," which are open to scientists from universities, governmental research institutes, public and private enterprises, and also to overseas scientists. After each development, the in-house beamline will be opened for use as a public beamline.

From the viewpoint of photon energies, we have one SX station equipped with a double-crystal monochromator, seven SX stations with a grazing incidence monochromator, three VUV stations with a normal incidence monochromator, two IR/THz stations equipped with Fourier transform interferometers and one beamline for light source development without any monochromators.

Table 1. List of beamlines at UVSOR-III Synchrotron.

Beamline	Optics	Energy Range	Targets	Techniques
BL1B	Martin-Puplett FT-FIR	0.5-30 meV	Solid	Reflection/Adsorption
BL6B	Michelson FT-IR	4 meV-2.5 eV	Solid	Reflection/Adsorption
BL7B	3-m normal incidence	1.2-25 eV	Solid	Reflection/Adsorption
BL3B	2.5-m off-plane Eagle	1.7-31 eV	Solid	Reflection/Absorption
BL5B	Plane grating	6-600 eV	Solid	Calibration/Absorption
BL2B	18-m spherical grating (Dragon)	23-205 eV	Solid	Photoionization Photodissociation
BL4B	Varied-line-spacing plane grating (Monk-Gillieson)	25 eV-1 keV	Gas, Liq. Solid	Photoionization, XAFS Photodissociation, XMCD
BL2A	Double crystal	585 eV-4 keV	Solid	Reflection/XAFS
BL1U	Tandem undulators/ Free electron laser	1.6-13.9 eV	Gas Solid	Laser Compton Scattering Orbital Momentum Light
BL7U	10-m normal incidence (modified Wadsworth)	6-40 eV	Solid	Photoemission
BL5U	Varied-line-spacing plane grating (Monk-Gillieson)	20-200 eV	Solid	ARPES Spin-resolved ARPES
BL6U	Variable-inc.-angle-varied-line-spacing plane grating	40-700 eV	Solid	ARPES XAFS / XPD
BL4U	Varied-line-spacing plane grating (Monk-Gillieson)	50-700 eV	Gas, Liq. Solid	XAFS Microscopy (STXM)
BL3U	Varied-line-spacing plane grating (Monk-Gillieson)	60-800 eV	Gas, Liq. Solid	XAFS / Photoemission Photon-emission

Inter-University and International Collaboration Programs

A variety of molecular science and related subjects have been carried out at UVSOR Synchrotron Facility by IMS and external/overseas researchers. The cumulative total number of visiting researchers (person-days) per year tops > 4000, who come from > 60 different institutes. International collaborations are also pursued actively, and the number of visiting foreign researchers reaches ~70. UVSOR-III Synchrotron invites new/continuing research proposals twice a year. The proposals both for academic and public research (charge-free) and for private enterprises (charged) are acceptable. COVID-19 issue has a serious impact on user activity, the overseas activity was almost dropped especially. The fruits of the research activities using UVSOR-III Synchrotron are published as the UVSOR ACTIVITY REPORT annually.

Recent Developments

The UVSOR accelerators have been operated for 38 years. We have been upgrading and replacing the machine components, such as magnet power supplies or RF power amplifiers, to continue the stable operation. In these years, troubles occurred on some core components, such as the vacuum chambers and the magnets. We are carefully planning their replacements with short shutdown periods and under the limitation of the facility budget.

On the other hand, we are also putting effort into setting up state-of-the-art experimental stations that takes advantage of our unique beamline performance. BL5U is an angle-resolved photoemission spectroscopy (ARPES) beamline with micro-focused beam (23×40 μm). By combining the latest version of ARPES analyzer (MB Scientific AB, A-1 analyzer Lens#5) with the super quick deflector scan mode, users can perform ARPES measurements on small samples or inhomogeneous samples without changing the sample position. In 2020, a new spin-resolved ARPES system with multi-channel detection (we call "image-spin" detection) has been installed. As shown in Figure 1, we successfully obtained spin-resolved ARPES image of Rashba spin splitting in Au(111) surface states, which was taken at once. According to the rough estimation, the efficiency is 100 times better and the momentum resolution is several times better than the current synchrotron-based ARPES with single-channel detection in the world.

UVSOR has several ARPES beamlines and users can choose proper beamline according to their purpose. At BL7U, high-energy resolution ARPES is available with extremely low energy of photons (6 eV~) using low-temperature 6-axis manipulator (4 K~). In BL6U, photoelectron momentum microscope (PMM), which is an electronic spectroscopy with both the real space and momentum space resolution, has been installed in February 2020 (SPECS Surface Nano Analysis GmbH, KREIOS 150 MM).[1] It will be upgraded to a double hemispherical analyzer in FY2021 and will have spin-resolved function in the future.

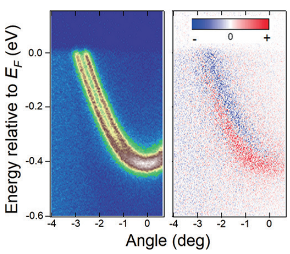

Figure 1. Rashba spin splitting in Au(111) surface states (left) and spin-resolved ARPES image showing the spin polarization (right).

Reserch Highlights

One of the highlights of the UVSOR research activities this year is the discovery of an ultrathin liquid cell for X-ray absorption spectroscopy (XAS) in the low-energy region at BL3U. Recently, we have investigated local structures of several aqueous solutions and various chemical processes in solution such as catalytic and electrochemical reactions and laminar flows in microfluidics by using *operando* XAS in C, N, and O K-edges.[2,3] On the other hand, the low-energy region below 200 eV is important for chemical research since it includes K-edges of Li and B and L-edges of Si, P, S, and Cl. BL3U has an advantage to measure XAS in the low-energy region with a high photon flux. Recently, we have established an argon gas window that is effective from 60 to 240 eV with the removal of high order X-rays.[4] The SX transmission calculation proposed that XAS in the low-energy region needs an ultrathin liquid cell with the 2.6 mm optical length of Ar gas.

Figure 2 shows the XAS measurement system including the ultrathin liquid cell. The ultrathin liquid cell is in an atmospheric Ar condition and is separated from the beamline and a photodiode detector under ultrahigh vacuum conditions with Si_3N_4 membranes (0.2 × 0.2 mm^2). The 2.6 mm optical length of argon gas has been realized owing to the ultrathin liquid cell. XAS spectra of 2 M LiCl solutions at Li K-edge and Cl L-edge were successfully obtained by using this liquid cell. In the future, XAS in the low-energy region will be applied to various chemical processes in solution, such as a Li-ion battery, Ni-borate electrocatalysts, and organic reactions with organosilicons, organolithiums, and organoboranes.

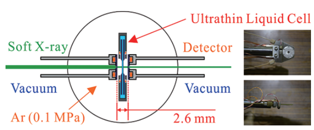

Figure 2. A schematic of the XAS measurement system in the low-energy region including the ultrathin liquid cell. Photographs of the ultrathin liquid cell are also shown.

References

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2) M. Nagasaka *et al.*, *Anal. Sci.* **36**, 95 (2020).
3) M. Nagasaka and N. Kosugi, *Chem. Lett.* **50**, 956 (2021).
4) M. Nagasaka, *J. Synchrotron Radiat.* **27**, 959 (2020).

Awards

NAKAMURA, Eiken; The Chemical Society of Japan Award for Technical Achievements for 2020 (2021).
NAKAMURA, Eiken; The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology Outstanding Support for Research Award (2021).