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 2022, 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 39 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.

UVSOR has several ARPES undulator beamlines and users can choose proper beamline according to their purpose. We are putting effort into setting up state-of-the-art experimental stations that take 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 ARPES analyzer with the super quick deflector scan mode, users can perform ARPES measurements on small samples or inhomogeneous samples without changing the sample position. At BL7U, high-energy resolution ARPES is available with extremely low energy of photons (6 eV~) using low-temperature 6-axis manipulator with sample temperature 4 K. In 2021, the latest version of ARPES analyzer has been installed so that users can easily perform a quick Fermi surface mapping. In BL6U, "photoelectron momentum microscope (PMM)" has been installed in February 2020.[1,2] PMM is a new concept device based on photoelectron spectroscopy and photoelectron microscopy techniques to visualize electronic states in real and reciprocal lattice space in selected small regions. It was upgraded to a double hemispherical analyzer with spin filter and spin rotator in May 2022.

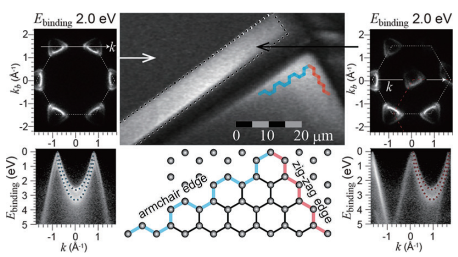

Figure 1. μm-photoelectron spectroscopy of graphite edge facet by PMM.

Reserch Highlights

At BL1U, new light sources such as coherent synchrotron radiation, free electron lasers, high-order harmonic generation, optical vortex and vector beams, and ultrashort pulsed gamma rays have been developed. As the energy of ultrashort pulsed gamma rays is 6.6 MeV, positrons are generated inside materials when they are irradiated. Positron annihilation spectroscopy is a powerful analytical tool for nondestructive measurement of atomic-scale defects. Positron annihilation spectroscopy using ultrashort pulsed gamma rays is available at BL1U.[3] In positron annihilation spectroscopy, the annihilation gamma rays produced when a positron annihilates are measured numerous times to determine the positron lifetime and the energy spread of the positron annihilation. Therefore, it is important to increase the counting rate of annihilation gamma rays in order to complete the measurement in a short time. To increase the counting rate of annihilation gamma rays, the intensity of ultrashort pulsed gamma rays should be increased. The intensity of gamma rays can be increased by colliding the electron beam and the laser in a focused state.

Until March 2021, gamma ray was generated using an optical window that allowed the laser to be injected from the vertical direction. The laser size at this time was 1 mm. The other side of the incident window is not a window but stainless steel, which generates gas when the laser hits it. The laser size could not be focused to a smaller size because of the problem of background bremsstrahlung gamma rays due to the increased gas generation when the laser is focused.

In April 2021, a new vacuum chamber for laser injection, shown in Figure 2, was installed in the electron storage ring. This vacuum chamber has optical windows at each end of the horizontal and vertical directions, which allows the laser to collide with the electron beam in a focused state. The intensity of the gamma rays can be improved as the laser can be injected from the horizontal direction. During installation of the vacuum chamber, 1/4 circumference of the electron storage ring was opened to the atmosphere.

The laser size at the electron beam interaction point with the new vacuum chamber is 15 μm at full width at half maximum. The gamma-ray intensity was increased by a factor of 40 due to the smaller laser size and the horizontal injection of the laser. Using this ultrashort pulse gamma-ray source, experiments such as analysis of atomic-scale defects in scintillators and photocatalysts, in-situ measurement of defect formation in iron-based materials under stress loading, and magnetic Compton scattering are underway.

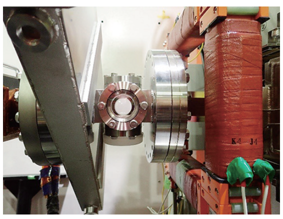

Figure 2. A new vacuum chamber for laser injection installed in the electron storage ring.

References

1) F. Matsui *et al.*, *Jpn. J. Appl. Phys.* **59**, 067001 (2020).
2) F. Matsui *et al.*, *J. Phys. Soc. Jpn.* **91**, 094703 (2022).
3) M. Kitaura *et al.*, *Opt. Mater.: X* **14**, 100156 (2022).