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 approximately 50 meters in circumference, is regularly operated in the top-up mode, in which the electron beam current is kept constant, 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 storage ring is normally operated under multi-bunch mode with partial filling. The single bunch top-up operation 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

Figure 1. UVSOR-III electron storage ring, radiation shield wall, and beamlines/endstations.

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

Beamline	Monochromator / Spectrometer	Energy Range	Targets	Techniques
BL1U	Free electron laser	1.6 - 13.9 eV	Gas Liquid Solid	Irradiation
BL1B	Martin-Puplett FT-FIR	0.5 - 30 meV	Solid	Reflection Absorption
BL2A	Double crystal	585 eV - 4 keV	Solid	Reflection Absorption
BL2B	18-m spherical grating (Dragon)	23 - 205 eV	Solid	Photoemission
BL3U	Varied-line-spacing plane grating (Monk-Gillieson)	60 - 800 eV	Gas Liquid Solid	Absorption Photoemission Photon-emission
BL3B	2.5-m off-plane Eagle	1.7 - 31 eV	Solid	Reflection Absorption
BL4U	Varied-line-spacing plane grating (Monk-Gillieson)	130 - 700 eV	Gas Liquid Solid	Absorption (Microscopy)
BL4B	Varied-line-spacing plane grating (Monk-Gillieson)	25 eV - 1 keV	Gas Solid	Photoionization Photodissociation Photoemission
BL5U	Varied-line-spacing plane grating (Monk-Gillieson)	20 - 200 eV	Solid	Photoemission
BL5B	Plane grating	6 - 600 eV	Solid	Calibration Absorption
BL6U*	Variable-included-angle varied-line-spacing plane grating	40 - 800 eV	Gas Solid	Photoionization Photodissociation Photoemission
BL6B	Michelson FT-IR	4 meV - 2.5 eV	Solid	Reflection Absorption
BL7U	10-m normal incidence (modified Wadsworth)	6 - 40 eV	Solid	Photoemission
BL7B	3-m normal incidence	1.2 - 25 eV	Solid	Reflection Absorption

Yellow columns represent undulator beamlines.
* In-house beamline.

(BL3U, BL4U, and BL6U) and the other three are vacuum/extreme ultraviolet (VUV/XUV or EUV) circular-polarized undulators (BL1U, BL5U, and BL7U). In total, fourteen beamlines are now operating. 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. 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. Since 2018, BL1U is partly opened for using as 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.

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 number of visiting researchers per year tops > 1200, whose come from > 60 different institutes. International collaboration is also pursued actively, and the number of visiting foreign researchers reaches ~70 from 11 countries. 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. The fruits of the research activities using UVSOR-III Synchrotron are published as the UVSOR ACTIVITY REPORT annually.

Recent Developments

Beamline BL4U has been open for users since 2013 and used as high-resolution X-ray transmission microscopy (STXM). The extension of the photon energy range is demanded to cover much broaden research field. Adopting Fresnel zone plate for low-energy range, we are approaching to get 50 eV which may cover Li K-edge. Although it is challenging how to optimize the optical parameters, BL4U will be an unique and attractive beamline for studying varisou novel materials including solid battery.

An acceptance-cone-tunable (ACT) electron spectrometer for the highly-efficient constant-energy photoelectron mapping of functional materials was developed at BL6U. The ACT spectrometer consists of the concentric hemispherical analyzer with the mesh-type electrostatic lens near the sample. The acceptance cone of the spectrometer is expanded by a factor of up to 3.3 by applying a negative bias to the sample and grounding the mesh lens and the analyzer entrance. The wide-angle observation of the valence band dispersion over full Brillouin zone can be easily achieved without rotating / tilting the sample nor analyzer.

The UVSOR accelerators have been operated for more than 35 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.

Reserch Highlights[1)]

X-ray microscopy has the following advantages for the observation of biological samples over other microscopic methods: Higher resolution than optical microscopy with respect to the diffraction limit; good absorption contrast in hydrated conditions with soft X-rays in an energy range, the so-called water window; better transmittance than electron microscopy; and the discrimination of biological molecules by spectro-microscopy, the combination of microscopy and spectroscopy using absorption of fine structures in biomolecules according to the energies of carbon, nitrogen, and oxygen absorption edges. Scanning transmission soft X-ray microscopy (STXM) was applied to study the quantitative distribution of DNA, RNA, histone, and proteins other than histone (represented by BSA) in mammalian cells, apoptotic nuclei, and a chromosome at BL4U. Quantities of nucleic acids and proteins were evaluated using characteristic absorption properties due to the 1s–π* transition of N=C in nucleic acids and amide in proteins, respectively, in the absorption spectra at the nitrogen K absorption edge. The results showed that DNA and histone were located in the nucleus. By contrast, RNA was clearly discriminated and found mainly in the cytoplasm. Interestingly, in a chromosome image, DNA and histone were found in the center, surrounded by RNA and proteins other than histone. The amount of DNA in the chromosome was estimated to be 0.73 pg, and the content of RNA, histone, and proteins other than histone, relative to DNA, was 0.48, 0.28, and 4.04, respectively. STXM could be a powerful approach for the quantitative molecular mapping of biological samples at high resolution.

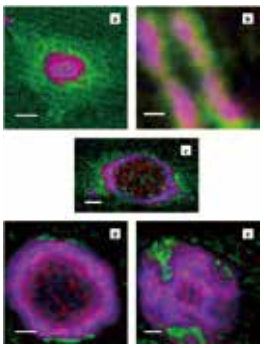

Figure 2. RGB expression of the images of the (a) CHO cell, (b) chromosome, (c) HeLa S3 cell, (d) isolated nucleus, and (e) apoptotic nucleus. DNA, RNA, and histone are displayed as red, green, and blue, respectively. Scale bars are (a) 5 μm, (b) 0.5 μm, (c) 2 μm, and (d, e) 1 μm.

Reference

1) K. Shinohara *et al.*, *Cells* **8**, 164 (2019).