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

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.

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). In total, fourteen beamlines are now operating and except for BL1U and BL6U they are so-called "public beamlines," which are open to scientists from universities, governmental research institutes, public and private enterprises, and also to overseas scientists. Other two beamlines 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. Since 2018, BL1U is partly opened for using as public beamline.

From the viewpoint of photon energies, we have 1 SX station equipped with a double-crystal monochromator, 7 SX stations with a grazing incidence monochromator, 3 VUV stations with a normal incidence monochromator, two IR/THz stations equipped with Fourier transform interferometers and 1 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 13 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

A soft X-ray beamline BL5U has been open for users since 2016 and used as high-energy resolution ARPES beamline. By introducing a final focusing mirror close to the sample position (~50 mm), the synchrotron light whose original size was 400 (H) × 120 (V) is successfully focused to 23 (H) × 40 (V) μm. ARPES study on small samples or inhomogeneous samples is now available.

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.

The UVSOR accelerators have been operated for more than 30 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)]

Understanding the mechanism of charge transfer in functional molecular solids, the electronic structure measurement, especially of the energy-band dispersion, is requested for molecular materials. However the electronic structure measurement has not been well achieved due to experimental difficulties for the molecular solids. More importantly, the dynamic interaction between the traveling charges and the molecular vibrations is critical for the charge transport in organic semiconductors. However, a direct evidence of the expected impact of the charge–phonon coupling on the band dispersion of organic semiconductors is yet to be provided. We reported on the electronic properties of rubrene single crystal as investigated by angle resolved ultraviolet photoelectron spectroscopy using low-excitation photon energy. A gap opening and kink-like features in the rubrene electronic band dispersion are observed thanks to high-energy and momentum resolutions in BL7U. In particular, the latter results in a large enhancement of the hole effective mass, well above the limit of the theoretical estimations. The results are consistent with the expected modifications of the band structures in organic semiconductors as introduced by hole–phonon coupling effects and represent an important experimental step toward the understanding of the charge localization phenomena in organic materials.

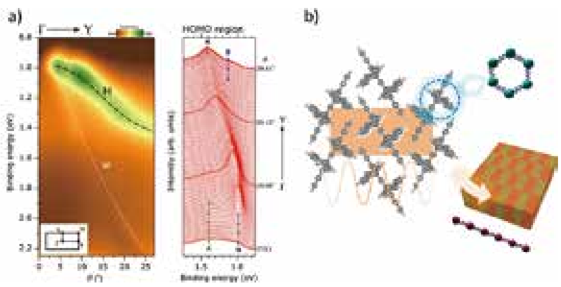

Figure 2. Renormalization of the energy-band dispersion of highest-occupied molecular orbital (HOMO) band of rubrene single crystal at 300 K by coupling collective phonons and intramolecular vibrations. a) Angle-resolved photoelectron spectra recorded along ΓY direction of the single crystal. The intensity map as a function of the emission angle θ is also shown (left). The HOMO (H) dispersion is indicated by dash dotted black curve as guides for the eye. The feature W due to secondary electron emission which reflects the density of states and band dispersion of unoccupied states is superimposed. b) Schematic of the molecular orientation in the crystalline a-b plane of rubrene single crystal. Images of collective phonon in the crystal and local intramolecular vibration are also shown.

Reference

1) F. Bussolotti *et al.*, *Nat. Commun.* **8**, 173–179 (2017).