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 53 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 (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.

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 number of visiting researchers per year tops > 1200, whose 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 proposals of 63 % have been achieved so far. 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 37 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. A new photoelectron momentum microscope (PMM) station for 3D momentum-resolved photoelectron spectroscopy is constructed at beamline BL6U.[1] The PMM, a combination of projection-type electron analyzer and photoelectron microscope, simultaneously realizes a microscope function for magnifying and observing minute parts of complicated- structured samples with element selectivity and a spectroscopy function for visualizing electron behavior (momentum) that determines the electronic properties of a functional materials. Microscopy with a spatial resolution of 50 nm and photoelectron spectroscopy (field of view: 2 μm) with energy/momentum resolutions of 20 meV / 0.01 $Å^{-1}$ at 9 K are successfully demonstrated (Figure 1). The momentum microscope opens the door to direct observation of the Fermi surface and band structure of μm-sized targets such as surface atomic sites, thin films and interfaces, molecular adsorbates, and polycrystals, which was difficult with conventional electron energy analyzers.

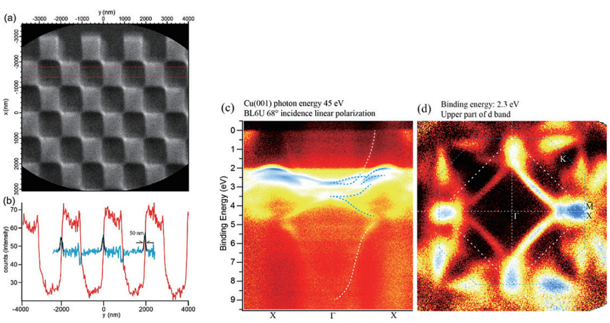

Figure 1. (a) A gold checkerboard pattern image obtained using Hg lamp. (b) Intensity profile indicating the spatial resolution of 50 nm was achieved.[1] (c) Cu valence band dispersion and iso-energy cross section.

Research Highlights

One of the highlights of the UVSOR research activities this year is the discovery of the ability of synchrotron radiation to perform coherent control.[2,3] Coherent control is a method to manipulate the populations and pathways in matters by light and is currently one of the most attractive research areas in optical physics and photochemistry. Lasers have been considered as unique light source enabling one to perform coherent control. Synchrotron radiation is usually considered as being of poor temporal coherence, therefore nobody thought that it has a hidden capability of coherent control. However, researchers have demonstrated the capability of synchrotron radiation on the coherent control using the double undulator system which is capable of producing light pulses with tailored waveform.

Figure 2 shows the schematic view of the double undulator system and the result of population control in the photoexcitation of helium atoms. The double undulator generated pairs of radiation wave packets in the extreme ultraviolet wavelength. The duration of each wave packet pair was a few femtoseconds and the time delay between them can be adjusted with attosecond precision. The individual excited states can be controlled by adjusting the interference between the electron wave packets produced in the atomic system. Moreover, the researchers succeeded also in controlling the shape and orientation of the electron cloud in a helium atom, formed as a coherent superposition state, by tuning the time delay between the circularly polarized radiation wave packets on the attosecond level.

In contrast to standard laser technology, there is no technical restriction on the extension of this method to shorter wavelengths. This new capability of synchrotron radiation not only advance the frontier of coherent control technology, but may also open up new applications in the development of functional materials and electronic devices in the future.

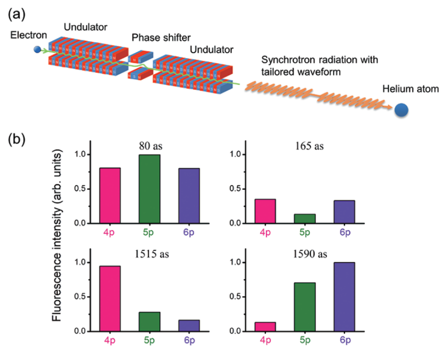

Figure 2. (a) Double undulator and produced pairs of radiation wave packets with tailored waveform. (b) Populations of 1snp states at four different time delays between the radiation wave packets.

References

1) F. Matsui *et al.*, *Jpn. J. Appl. Phys.* **59**, 067001 (2020).
2) Y. Hikosaka *et al.*, *Nat. Commun.* **10**, 4988 (2019).
3) T. Kaneyasu *et al.*, *Phys. Rev. Lett.* **123**, 233401 (2019).