II

Current Status of Light Sources and Beamlines

Light Source in 2018

1. Status of UVSOR Accelerators

In the fiscal year 2018, we had scheduled to operate UVSOR-III from May to March, for 36 weeks for users. We had several machine troubles as described later. In July we had a trouble in the linac and we could not operate the machine in the top-up mode almost for one week, in adding to 12 hour loss. In cases of other minor troubles, we extended the operation time for compensation. We had a scheduled shutdown period in April and May for about 6 weeks. This was mainly for the scheduled maintenance works. We had one week shut down period in August and October, two week one around the New Years day and one week one at the end of March. We had 2 weeks for machine and beamline conditioning in May after the spring shut down. In addition, we had 4 weeks for machine conditionings and studies, in October, November, January and March. The machine study week in November was mainly for the machine conditioning after the annual planned power outage.

We operated the machine for 34 weeks in the multi-bunch top-up mode at 300 mA, and 2 weeks in the single-bunch top-up mode at approximately 40 mA. The monthly statistics of the operation time and the integrated beam current are shown in Fig. 1.

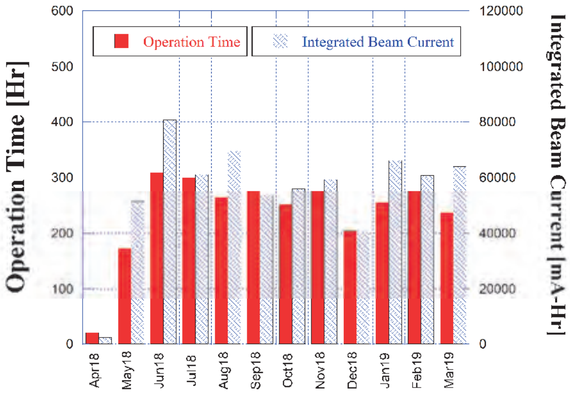


Fig. 1. Monthly statistics in FY2018.

The weekly operation schedule is as follows. On Monday, from 9 am to 9 pm, the machine is operated for machine conditionings and studies. On Tuesday and Wednesday, from 9am to 9pm, the machine is operated for users. From Thursday 9am to Friday 9pm, the machine is operated for 36 hours continuously for users. Therefore, the beam time for users in a week is 60 hours. In the single bunch operation weeks, the machine is operated for 12 hours per day from Tuesday to Friday.

We had a trouble in the high voltage power supplies and the cooling water system for the linac in July. The former case, it took about several days to completely repair the power supply. In the latter, the chilling water unit was malfunctioned. We gave up to use it and alternatively we started supplying the chilling water to the linac from the cooling water system for other part of accelerator system. It has been working well without any trouble.

In February 2018, a cooling water leakage was found at a sextupole coil wound on a pole face of a multipole (quadrupole/sextupole) magnet. After about one year, we have found similar leakage on nine of same coils. The hollow conductor used for these coils has relatively thin wall. It is supposed that, after the installation in 2003, the walls have been eroded by the water flow. In the spring shutdown 2019, we are applying liquid sealant for all the coils for life prolonging. In parallel, we have started constructing coils for replacement.

Fig. 2. The sextupole main coil wound on the pole face of a quadrupole magnet.

2. Improvements and Developments

In the UVSOR accelerator system, there are still some components which have been used since the construction of the facility early in 1980's. This year, after more than 35 year operation, the pulse transformer for the klystron modulator of the linac was replaced (Fig. 3). The cooling water system for the RF cavity in the booster synchrotron was also replaced with the one which has a good temporal stability of 0.1 degree C. The control system of the undulator U6 was replaced after 15 year operation. The signal generator as the master oscillator of the accelerator complex was also replaced this year.

The chilling water system for the linac had troubles several times in the past, which were mainly due to the unstable cooling water supply from the facility. This system provided 20 degree chilling water to the temperature control system of the linac. We tried to use about 25 degree water from the facility instead of the 20 degree chilling water and found that the linac could be operated stably without any problem. We stopped using the chilling water system.

Fig. 3 New pulse transformer for the klystron modulator of the linac.

Fig. 4. New Control system for the undulator U6

Light Source Developments and Beam Physics Studies

We continue the efforts to develop novel light sources technologies and their applications such as free electron lasers, coherent harmonic generation, coherent synchrotron radiation, laser Compton scattering gamma-rays, intense polarized and vortex UV radiation at the source development station BL1U, which was constructed under the support of Quantum Beam Technology Program by MEXT/JST. In these years, we continued studying the generations of structured light beam from undulators in collaboration with Hiroshima U., Nagoya U. and other institutes. Since the UVSOR electron beam is diffraction-limited in the UV range, we could precisely investigate the optical properties of the vortex beams from undulators using conventional optical components. Moreover, we succeeded in producing optical vector beam which has a tailored distribution of the polarization in the transverse plane.

The laser Compton scattering gamma-rays are powerful tools for nuclear science and technologies. By using various external lasers, we have demonstrated generating quasi-monochromatic gamma-rays in the energy range from 1MeV to around 10MeV. We continue the experiments in collaboration with Kyoto U., AIST and QST towards imaging applications. We started new experiments on positron lifetime spectroscopy experiments in collaboration with Yamagata U., Nagoya U. and AIST.

Masahiro KATOH
(UVSOR Synchrotron Facility)

UVSOR Accelerator Complex

Injection Linear Accelerator

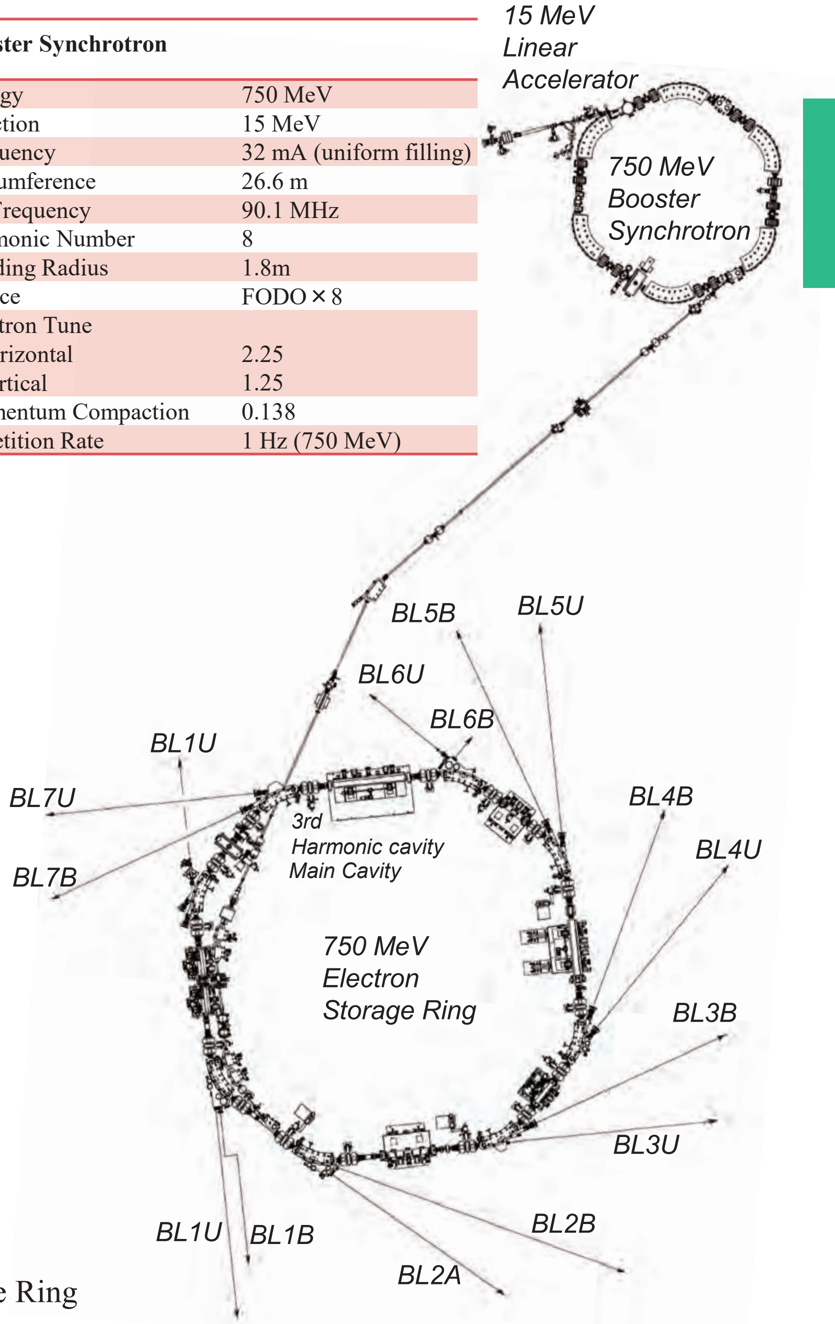
Energy	15 MeV
Length	2.5 m
Frequency	2856 MHz
Accelerating RF Field	2π/3 Traveling Wave
Klystron Power	1.8 MW
Energy Spread	~1.6 MeV
Repetition Rate	2.6 Hz

UVSOR-III Storage-Ring

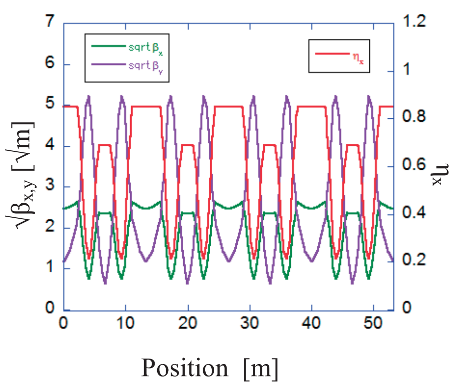
Energy	750 MeV
Injection Energy	750 MeV
Maximum Storage Current	500 mA (multi bunch)
	100 mA (single bunch)
Normal operation current	300 mA (multi bunch)
(Top-up mode)	50 mA (single bunch)
Natural Emittance	17.5 nm-rad
Circumference	53.2 m
RF Frequency	90.1 MHz
Harmonic Number	16
Bending Radius	2.2 m
Lattice	Extended DBA × 4
Straight Section	(4 m × 4)+(1.5 m × 4)
RF Voltage	120 kV
Betatron Tune	
Horizontal	3.75
Vertical	3.20
Momentum Compaction	0.030
Natural Chromaticity	
Horizontal	-8.1
Vertical	-7.3
Energy Spread	5.26×10^{-4}
Coupling Ratio	1%
Natural Bunch Length	128 ps

Booster Synchrotron

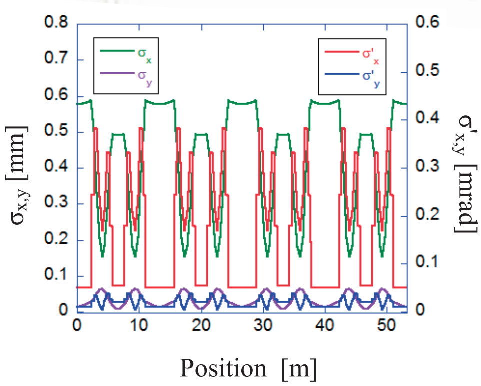
Energy	750 MeV
Injection	15 MeV
Frequency	32 mA (uniform filling)
Circumference	26.6 m
RF Frequency	90.1 MHz
Harmonic Number	8
Bending Radius	1.8m
Lattice	FODO × 8
Betatron Tune	
Horizontal	2.25
Vertical	1.25
Momentum Compaction	0.138
Repetition Rate	1 Hz (750 MeV)



Electron Beam Optics of UVSOR-III Storage Ring

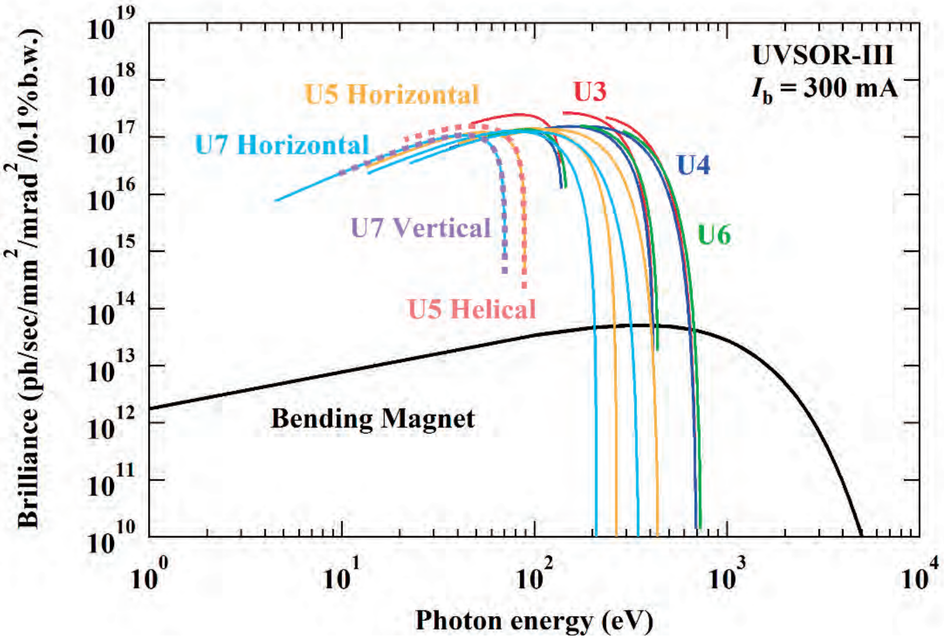


Horizontal/vertical betatron functions and dispersion function



Horizontal/vertical electron beam size and beam divergences

Insertion Device



Brilliance of radiation from the insertion devices (U3, U4, U5, U6 and U7) and a bending magnet of UVSOR-III

U1 Apple-II Undulator / Optical Klystron

Number of Periods	10+10
Period length	88 mm
Pole Length	0.968 m + 0.968 m
Pole Gap	24-200 mm
Deflection Parameter	7.36 (Max. Horizontal) 4.93 (Max. Vertical) 4.06 (Max. Herical)

U3 In-vacuum Undulator

Number of Periods	50
Period length	38 mm
Pole Length	1.9 m
Pole Gap	16.5-40 mm
Deflection Parameter	1.8-0.24

U4 In-vacuum Undulator

Number of Periods	26
Period length	38 mm
Pole Length	0.99 m
Pole Gap	13-40 mm
Deflection Parameter	2.4-0.19

U5 Apple-II Variable Polarization Undulator

Number of Periods	38
Period length	60 mm
Pole Length	2.28 m
Pole Gap	24-190 mm
Deflection Parameter	3.4 (Max. Horizontal) 2.1 (Max. Vertical) 1.8 (Max. Helical)

U6 In-vacuum Undulator

Number of Periods	26
Period length	36 mm
Pole Length	0.94 m
Pole Gap	13-40 mm
Deflection Parameter	1.78 - 0.19

U7 Apple-II Variable Polarization Undulator

Number of Periods	40
Period length	76 mm
Pole Length	3.04 m
Pole Gap	24-200 mm
Deflection Parameter	5.4 (Max. Horizontal) 3.6 (Max. Vertical) 3.0 (Max. Helical)

Bending Magnets

Bending Radius	2.2 m
Critical Energy	425 eV

Beamlines in 2018

Kiyohisa TANAKA
UVSOR synchrotron Facility, Institute for Molecular Science

Among the synchrotron radiation facilities with electron energies of less than 1 GeV, UVSOR is one of the highest-brilliance light sources in the extreme-ultraviolet region. The natural emittance of the UVSOR-III storage ring is as low as 17.5 nm-rad after the successful completion of the storage ring upgrade project (the UVSOR-III project) in 2012.

Eight bending magnets and six insertion devices are available as synchrotron light sources at UVSOR. As of 2017 there are a total of fourteen operational beamlines, which are classified into two categories. Twelve of them are the so-called “Open beamlines”, which are open to scientists from universities and research institutes belonging to the government, public organizations, private enterprises and also those from foreign countries. The remaining two beamlines are the “In-house beamlines”, and are dedicated to the use of research groups within Institute for Molecular Science (IMS).

There is one soft X-ray station equipped with a double-crystal monochromator, seven extreme ultraviolet and soft X-ray stations with grazing incidence monochromators, three vacuum ultraviolet (VUV) stations with normal incidence monochromators, two infrared (IR) stations equipped with Fourier-Transform interferometers, and one direct radiation station located after two undulators installed in tandem, as shown in the appended table (next page) for all available beamlines at UVSOR in 2018. The details of the updates for several beamlines are the followings.

BL1U, which is one of the in-house beamlines, has been partially open for general users from Oct. 2018. Users can use UV/VUV light and gamma rays for irradiation experiments.

In BL3B, a new sample stage has been developed. Samples can be heated up to ~500 K during the VIS-VUV photoluminescence and reflection/absorption spectroscopy measurements.

BL5U has been officially opened for users from 2016 as high energy resolution angle-resolved photoemission spectroscopy (ARPES) beamline. Using a new mirror located close to the sample position, the beam spot size is successfully focused to ~23 x 40 μm, which make users possible to perform measurements on small samples or inhomogeneous samples. A new software to precisely control the sample position has been developed, and users can easily take intensity image from sample with 10 μm step and move to some particular position of the sample in the obtained image.

In BL6U, which is one of the in-house beamlines, the latest version of ARPES analyzer was installed (MB Scientific AB, A-1 analyzer Lens#5). Manipulator was modified so that a mesh can be set in front of the sample and the sample can be biased voltages. By applying bias voltages to the sample, the wider acceptance angle (~ 60 deg.) with hν = 40-60 eV is available. We also have performed *in situ* cleaning of mirrors by exposure to oxygen at a pressure of $1x10^{-2}$ Pa under irradiation of non-monochromated synchrotron radiation (SR). As a result, the photon intensity around 280 eV has greatly been improved.

In BL7U, a high energy resolution ARPES beamline with low energy of photons, a new low temperature 6-axis manipulator was developed and installed from FY2018. Samples can be cooled down to 4.5 K with tilt angle -15 ~ 50 deg. and azimuth angle ± 120 deg..

UVSOR is now planning to introduce so-called “Momentum microscope (MM)”, which is an electronic spectroscopy with both the real space and momentum space resolution. The original plan has been modified and MM will be installed at BL6U. Tender process for MM analyzer has been concluded and it will be installed in FY2019.

All users are required to refer to the beamline manuals and the UVSOR guidebook (the latest revision in PDF format uploaded on the UVSOR web site in June 2018), on the occasion of conducting the actual experimental procedures. Those wishing to use the open and in-house beamlines are recommended to contact the appropriate beamline master (see next page). For updated information on UVSOR, please see http://www.uvsor.ims.ac.jp.

Beamlines at UVSOR

Beamline	Monochromator / Spectrometer	Energy Range	Targets	Techniques	Contact
BL1U	Free electron laser	1.6 – 13.9 eV		(Irradiation)	M. Fujimoto mfmoto@ims.ac.jp
BL1B	Martin-Puplett FT-FIR	0.5 – 30 meV	Solid	Reflection Absorption	K. Tanaka k-tanaka@ims.ac.jp
BL2A	Double crystal	585 – 4 keV	Solid	Reflection Absorption	K. Tanaka k-tanaka@ims.ac.jp
BL2B	18-m spherical grating (Dragon)	23 – 205 eV	Solid	Photoemission	S. Kera kera@ims.ac.jp
BL3U	Varied-line-spacing plane grating (Monk-Gillieson)	40 – 800 eV	Gas Liquid Solid	Absorption Photoemission Photon-emission	M. Nagasaka nagasaka@ims.ac.jp
BL3B	2.5-m off-plane Eagle	1.7 – 31 eV	Solid	Reflection Absorption Photon-emission	K. Tanaka k-tanaka@ims.ac.jp
BL4U	Varied-line-spacing plane grating (Monk-Gillieson)	50 – 770 eV	Gas Liquid Solid	Absorption (Microscopy)	T. Ohigashi ohigashi@ims.ac.jp
BL4B	Varied-line-spacing plane grating (Monk-Gillieson)	25 eV – 1 keV	Gas Solid	Photoionization Photodissociation Photoemission	H. Iwayama iwayama@ims.ac.jp
BL5U	Spherical grating (SGM-TRAIN†)	20 – 200 eV	Solid	Photoemission	K. Tanaka k-tanaka@ims.ac.jp
BL5B	Plane grating	6 – 600 eV	Solid	Calibration Absorption	K. Tanaka k-tanaka@ims.ac.jp
BL6U*	Variable-included-angle varied-line-spacing plane grating	45 – 600 eV	Gas Solid	Photoionization Photodissociation Photoemission	F. Matsui matui@ims.ac.jp
BL6B	Michelson FT-IR	4 meV – 2.5 eV	Solid	Reflection Absorption IR microscope	K. Tanaka k-tanaka@ims.ac.jp
BL7U	10-m normal incidence (modified Wadsworth)	6 – 40 eV	Solid	Photoemission	S. Ideta idetas@ims.ac.jp
BL7B	3-m normal incidence	1.2 – 25 eV	Solid	Reflection Absorption Photon-emission	K. Tanaka k-tanaka@ims.ac.jp

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

BL1U

Light Source Development Station

▼Description

BL1U is dedicated for developments and applications of various novel photon sources including free electron laser in the range from visible to deep UV, coherent harmonic generation in the deep UV and VUV, laser Compton scattering gamma-rays and undulator radiation with various polarization properties including optical vortex beam and optical vector beam.

The beam-line is equipped with a dedicated twin polarization variable undulator system with a buncher section, which can be used for a FEL oscillator and a VUV CHG. It is also equipped with a femto-second laser system synchronized with the accelerator, which is used for CHG, slicing, LCS and coherent THz radiation generation.

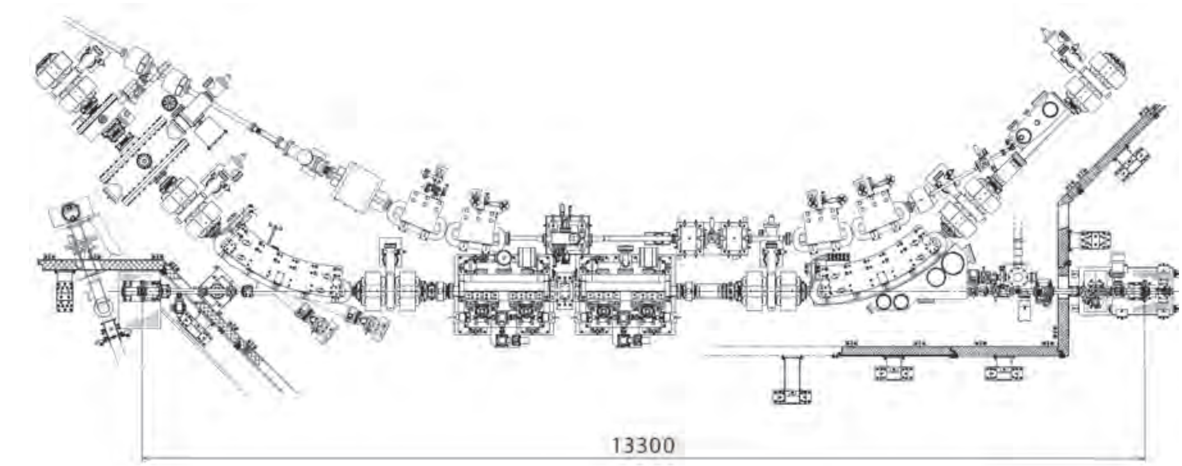


Fig. 1. Configuration of the free electron laser (under reconstruction)

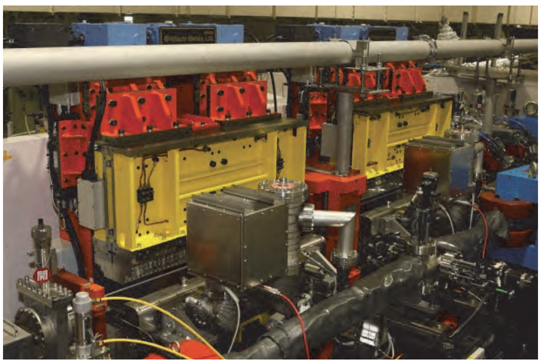


Fig. 2. Twin Apple-II Undulator

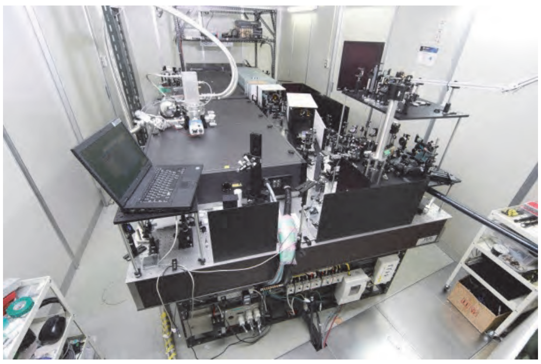


Fig. 3. Accelerator synchronized Laser System

▼Technical Data of FEL

Wave Length	199-800 nm
Spectral Band Width	~10^{-4}
Polarization	Circular/Linear
Pulse Rate	11.26 MHz
Max. Ave. Power	~1W

▼Technical Data of Ti:Sa Laser

Wave Length	800 nm		
Pulse Length	130 fsec		
Oscillator	90.1 MHz		
Pulse Energy	2.5mJ	10mJ	50mJ
Repetition Rate	1kHz	1kHz	10Hz

BL1B

Terahertz Spectroscopy Using Coherent Synchrotron Radiation

▼Description

Coherent synchrotron radiation (CSR) is a powerful light source in the terahertz (THz) region. This beamline has been constructed for basic studies on the properties of THz-CSR. However, it can be also used for measurements of reflectivity and transmission spectra of solids using conventional synchrotron radiation.

The emitted THz light is collected by a three-dimensional magic mirror (3D-MM, M0) of the same type as those already successfully installed at BL43IR in SPring-8 and BL6B in UVSOR-II. The 3D-MM was installed in bending-magnet chamber #1 and is controlled by a 5-axis pulse motor stage (x, z translation; θ_x, θ_y, θ_z rotation). The acceptance angle was set at 17.5-34 degrees (total 288 mrad) in the horizontal direction. The vertical angle was set at ±40 mrad to collect the widely expanded THz-CSR.

The beamline is equipped with a Martin-Puplett type interferometer (JASCO FARIS-1) to cover the THz spectral region from 4 to 240 cm^{-1} ($h\nu$ = 500 µeV-30 meV). There is a reflection/absorption spectroscopy (RAS) end-station for large samples (~ several mm). At the RAS end-station, a liquid-helium-flow type cryostat with a minimum temperature of 4 K is installed.

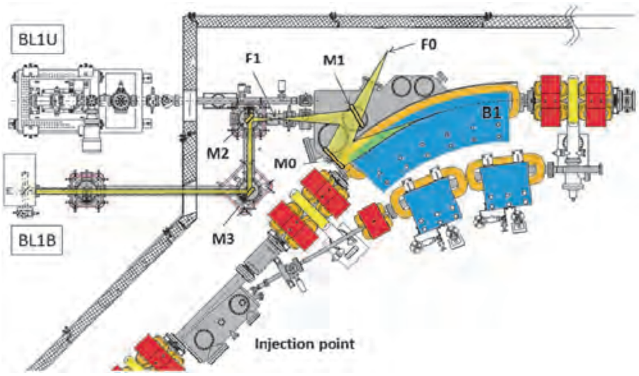


Fig. 1. Schematic top view of the beam extraction part of the THz-CSR beamline, BL1B. The three-dimensional magic mirror (3D-MM, M0) and a plane mirror (M1) are located in the bending-magnet chamber. A parabolic mirror (M2) is installed to form a parallel beam. The straight section (BL1U) is used for coherent harmonic generation (CHG) in the VUV region.

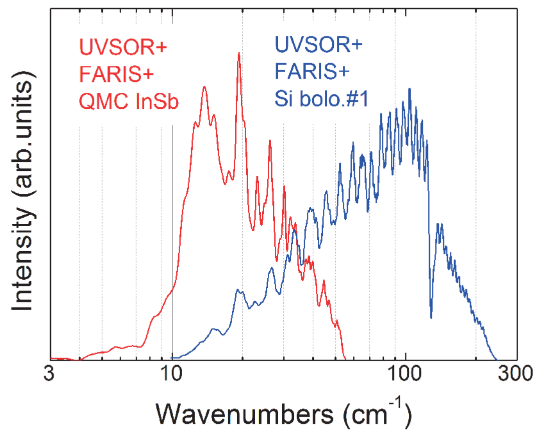


Fig. 2. Obtained intensity spectra with the combination of a light source (UVSOR), interferometer (FARIS-1), and detectors (Si bolometer and InSb hot-electron bolometer).

▼Technical Data

Interferometer	Martin-Puplett (JASCO FARIS-1)
Wavenumber range (Energy range)	4-240 cm^{-1} (500 µeV-30 meV)
Resolution in cm^{-1}	0.25 cm^{-1}
Experiments	Reflection/transmission spectroscopy
Miscellaneous	Users can use their experimental system in this beamline.

BL2A

Soft X-Ray Beamline for Photoabsorption Spectroscopy

II

▼Description

BL2A, which was moved its previous location as BL1A in 2011, is a soft X-ray beamline for photoabsorption spectroscopy. The beamline is equipped with a focusing premirror and a double-crystal monochromator [1]. The monochromator serves soft X-rays in the energy region from 585 to 4000 eV using several types of single crystals, such as β-Al_2O_3, beryl, KTP ($KTiOPO_4$), quartz, InSb, and Ge. The throughput spectra measured using a Si photodiode (AXUV-100, IRD Inc.) are shown in Fig. 1. The typical energy resolution (E / ΔE) of the monochromator is approximately 1500 for beryl and InSb.

A small vacuum chamber equipped with an electron multiplier (EM) detector is available. Photoabsorption spectra for powdery samples are usually measured in total electron yield mode, with the use of the EM detector. A silicon drift detector is also available for measuring partial fluorescence yields from solid samples.

[1] Hiraya *et al.*, Rev. Sci. Instrum. **63** (1992) 1264.

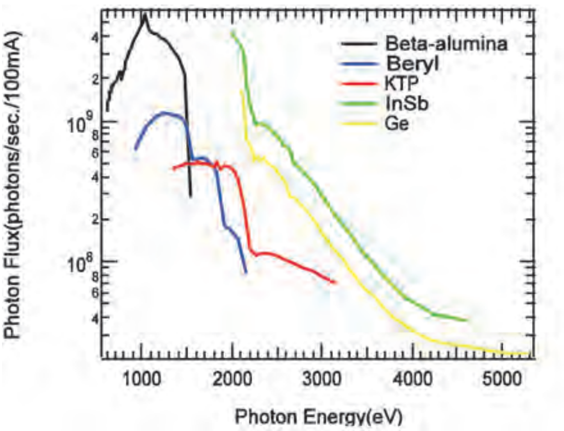


Fig. 1. Throughput spectra of the double-crystal monochromator at BL2A.

Fig. 2. Side view of BL2A.

▼Technical Data

Monochromator	Double crystal monochromator
Monochromator crystals: (2d value, energy range)	β-Al_2O_3 (22.53 Å, 585–1609 eV), beryl (15.965 Å, 826–2271 eV), KTP (10.95 Å, 1205–3310 eV), quartz (8.512 Å, 1550–4000 eV), InSb (7.481 Å, 1764–4000 eV), Ge (6.532 Å, 2094–4000 eV)
Resolution	$E/\Delta E$ = 1500 for beryl and InSb
Experiments	Photoabsorption spectroscopy (total electron yield using EM and partial fluorescence yield using SDD)

BL2B
Photoelectron spectroscopy of molecular solids

▼Description

This beamline previously dedicated for experiments in the field of gas phase photoionization and reaction dynamics. Then, the beamline has been reconstructed for photoelectron spectroscopy of molecular solids with a new end station, and experiments can be performed from May 2014. The monochromator is a spherical grating Dragon type with 18-m focal length. High throughput (1×10^{10} photons s^{-1}) and high resolution ($E/\Delta E$ = 2000 - 8000) are achieved simultaneously under the condition of the ring current of 100 mA [1]. The optical system consists of two pre-focusing mirrors, an entrance slit, three spherical gratings (G1 - G3), two folding mirrors, a movable exit slit, and a refocusing mirror [2]. The monochromator is designed to cover the energy range of 23–205 eV with the three gratings: G1 (2400 lines mm^{-1}, R = 18 m) at 80–205 eV; G2 (1200 lines mm^{-1}, R = 18 m) at 40–100 eV; G3 (2400 lines mm^{-1}, R = 9.25 m) at 23–50 eV. The percentage of the second-order light contamination at $h\nu$ = 45.6 eV is 23% for G2 or 7% for G3.

A UHV chamber is placed downstream of the refocusing mirror chamber and equipped silicon photodiode, sapphire plate Au mesh and filters for absolute photon flux measurement, monitor the photon-beam position, relative photon flux measurements and attenuate higher order light, respectively.

The new end station consists of a main chamber with a hemispherical analyzer (SCIENTA R3000) and a liquid-He-cooled cryostat (temperature range of 15-400 K) with 5-axis stage, a sample preparation chamber with a fast-entry load-lock chamber and a cleaning chamber with LEED, ion gun for sputtering and IR heating unit.

[1] M. Ono, H. Yoshida, H. Hattori and K. Mitsuke, Nucl. Instrum. Meth. Phys. Res. A **467-468** (2001) 577.
[2] H. Yoshida and K. Mitsuke, J. Synchrotron Radiation **5** (1998) 774.

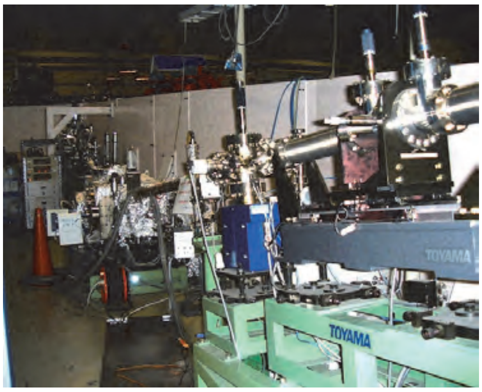


Fig. 1. 18 m spherical grating monochromator at BL2B.

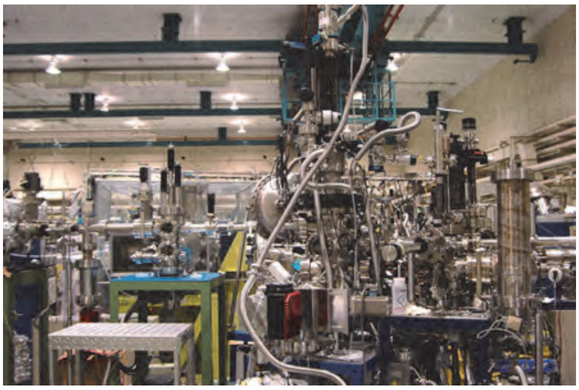


Fig. 2. End station of BL2B for photoelectron spectroscopy of molecular solids.

▼Technical Data

Monochromator	18 m spherical grating Dragon-type
Wavelength Range	23-205 eV
Resolution	2000–8000 depending on the gratings
Experiments	Angle-resolved ultraviolet photoelectron spectroscopy

BL3U

Varied-Line-Spacing Plane Grating Monochromator for Molecular Soft X-Ray Spectroscopy

▼Description

The beamline BL3U is equipped with an in-vacuum undulator composed of 50 periods of 3.8 cm period length. The emitted photons are monochromatized by the varied-line-spacing plane grating monochromator (VLS-PGM) designed for various spectroscopic investigations in the soft X-ray range. Three holographically ruled laminar profile plane gratings are designed to cover the photon energy range from 40 to 800 eV. The beamline has liquid cells for soft X-ray absorption spectroscopy (XAS) in transmission mode as shown in Fig. 1. The liquid cell is in the atmospheric helium condition, which is separated by a 100 nm thick Si_3N_4 membrane with the window size of 0.2 × 0.2 mm^2 from the beamline in an ultrahigh vacuum condition. The thin liquid layer is assembled by using two 100 nm thick Si_3N_4 membranes. The thickness of the liquid layer is controllable from 20 to 2000 nm by adjusting the helium pressures around the liquid cell in order to transmit soft X-rays. Liquid samples are exchangeable *in situ* by using a tubing pump. The liquid cell has two types of windows: one is the liquid part to obtain the soft X-ray transmission of liquid (I), and the other is the blank part to obtain the transmission without liquid (I_0). We can obtain the reliable XAS spectra based on the Lambert-Beer law $\ln(I_0/I)$. Since the liquid cell is in the atmospheric condition, we can measure XAS of liquid samples in the real environment. *Operando* XAS observation of several chemical reactions such as catalytic, electrochemical reactions are also possible by using our liquid cells developed for these purposes.

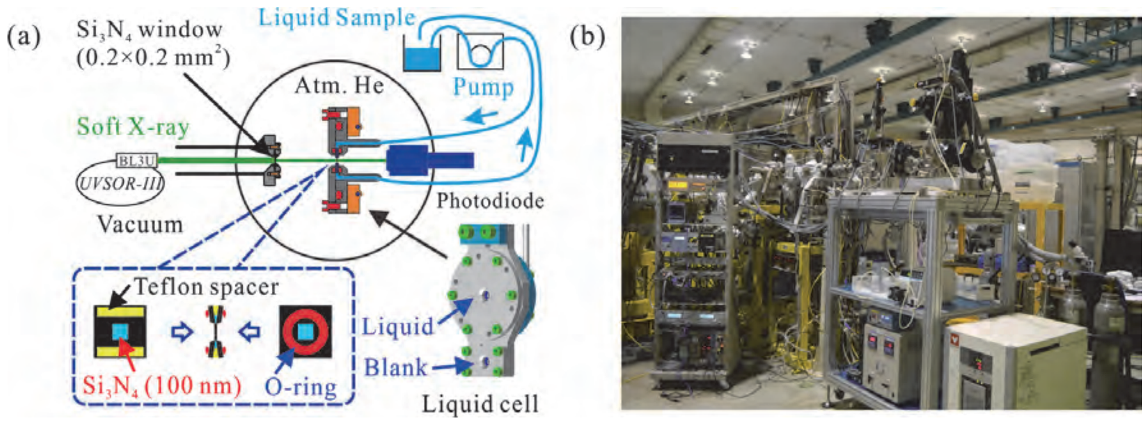


Fig. 1. (a) Schematics of a liquid cell for XAS in transmission mode settled in BL3U. The blowup shows a thin liquid layer assembled by two Si_3N_4 membranes with the thickness of 100 nm. (b) Photograph of a XAS measurement system for liquid samples at the end station of BL3U.

▼Technical Data

Monochromator	Varied-line-spacing plane grating monochromator
Energy Range	40-800 eV
Resolution	$E / \Delta E > 10\,000$
Experiments	Soft X-ray absorption spectroscopy of liquid in transmission mode

BL3B (HOTRLU)

VIS-VUV Photoluminescence and Reflection/Absorption Spectroscopy

▼Description

BL3B has been constructed to study photoluminescence (PL) in the visible (VIS) to vacuum ultraviolet (VUV) region. This beamline consists of a 2.5 m off-plane Eagle type normal-incidence monochromator, which covers the VUV, UV, and VIS regions, i.e., the energy (wavelength) region of 1.7-31 eV (40-730 nm), with three spherical gratings having constant grooving densities of 1200, 600, and 300 l/mm optimized at the photon energies of ~20, ~16, and ~6 eV, respectively. The schematic side view and top view layouts are shown in Figs. 1(a) and 1(b), respectively. The FWHM of the beam spot at the sample position is 0.25 mm (V) × 0.75 mm (H). Low energy pass filters (LiF, quartz, WG32, OG53) can be inserted automatically to maintain the optical purity in the G3 (300 l/mm) grating region (1.7~11.8 eV). Figure 2 shows the throughput spectra (photon numbers at a beam current of 300 mA) for each grating with entrance and exit slit openings of 0.1 mm (resolving power E / ΔE of ~2000 (G3, ~6.8 eV)). Since both slits can be opened up to 0.5 mm, a monochromatized photon flux of 10^{10} photons/s or higher is available for PL measurements in the whole energy region.

The end station is equipped with a liquid-helium-flow type cryostat for sample cooling and two detectors; one of which is a photomultiplier with sodium salicylate and the other a Si photodiode for reflection/absorption measurement. For the PL measurements in the wide energy region from VIS to VUV, two PL monochromators, comprising not only a conventional VIS monochromator but also a VUV monochromator with a CCD detector, are installed at the end station.

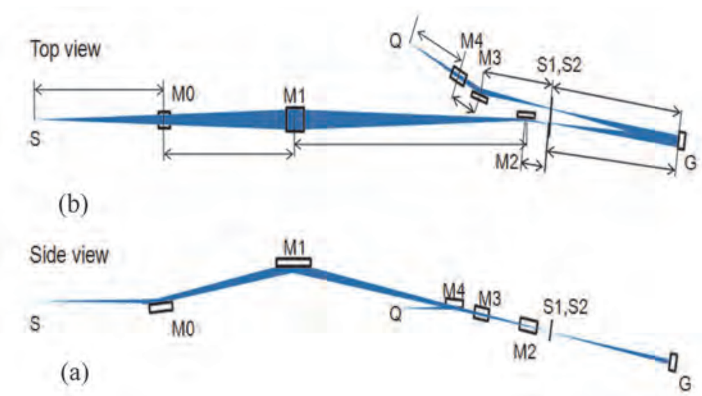


Fig. 1. Schematic layout of the BL3B (a) side view and (b) top view.

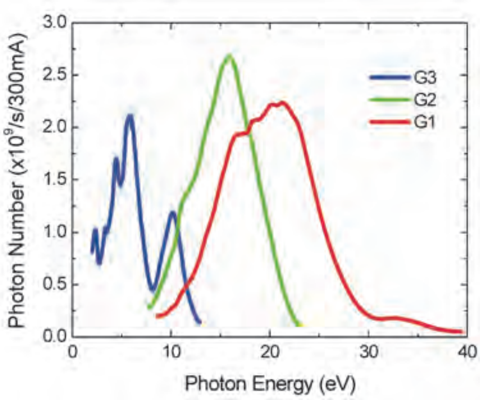


Fig. 2. Throughput spectra for each grating (G1:1200 l/mm, G2:600 l/mm and G3:300 l/mm) with S1 = S2 = 0.1 mm.

▼Technical Data

Monochromator	-2.5 m normal-incidence monochromator
Energy range	1.7-31 eV (40~730 nm)
Resolution (Δhν/ hν)	≥ 12000 (at ~ 6.9 eV, 0.02 mm slits, G1 (1200 l/mm)
Experiments	Photoluminescence, reflection, and absorption spectroscopy, mainly for solids

BL4U

Scanning Transmission X-ray Microscopy in the Soft X-ray Region

II

▼Description

In the soft x-ray region, there are several absorption edges of light elements and transition metals. The near edge X-ray absorption fine structure (NEXAFS) brings detailed information about the chemical state of target elements. A scanning transmission X-ray microscope (STXM) in the soft X-ray region is a kind of extended technique of the NEXAFS with high spatial resolution. The STXM has a capability of several additional options, for example, in-situ observations, 3-dimensional observation by computed tomography and ptychography, by utilizing the characteristics of the X-rays. The STXM can be applied to several sciences, such as polymer science, material science, cell biology, environmental science, and so on.

This beamline equips an in-vacuum undulator, a varied-line-spacing plane grating monochromator and a fixed exit slit. The soft X-ray energy range from 50 to 770 eV with the resolving power (E/ΔE) of 6,000 is available. The aperture size of the fixed exit slit determines not only the resolving power but also the size of a microprobe. A Fresnel zone plate is used as a focusing optical device through an order select aperture and its focal spot size of ~30 nm is available at minimum. An image is acquired by detecting intensities of the transmitted X-rays by a photomultiplier tube with scintillator with scanning a sample 2-dimensionally. By changing the energy of the incident beam, each 2-dimensional NEXAFS image is stacked. A main chamber of STXM is separated from the beamline optics by a silicon nitride membrane of 50-nm thickness; therefore, sample folders can be handled in vacuum or in helium.

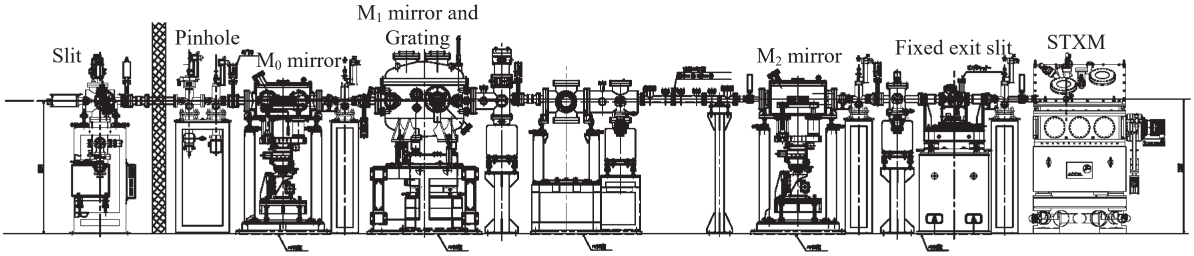


Fig. 1. Schematic image of BL4U

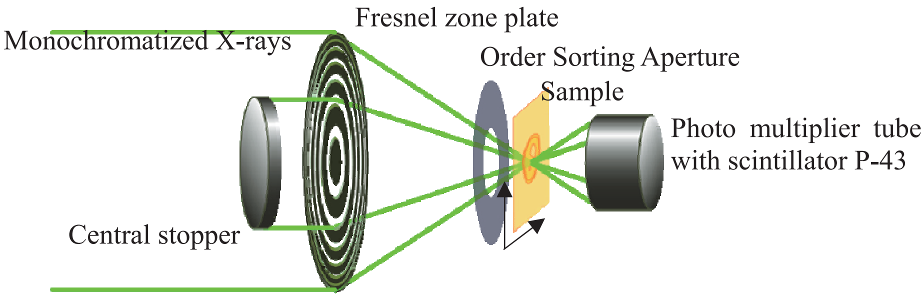


Fig. 2. Schematic image of STXM

▼Technical Data

Energy range (E)	50 -770 eV
Resolving power (E/ΔE)	~6,000
Focusing optical element	Fresnel zone plate
Spatial resolution	~30 nm
Experiments	2-dimensional absorption spectroscopy
Measurement environment	standard sample folder in vacuum or in helium, specially designed sample cell in ambient condition

BL4B

Varied-Line-Spacing Plane Grating Monochromator for Molecular Soft X-Ray Spectroscopy

▼Description

The beamline BL4B equipped with a varied-line-spacing plane grating monochromator (VLS-PGM) was constructed for various spectroscopic investigations in a gas phase and/or on solids in the soft X-ray range. Three holographically ruled laminar profile plane gratings with SiO_2 substrates are designed to cover the photon energy range from 25 to 800 eV. The gratings with groove densities of 100, 267, and 800 l/mm cover the spectral ranges of 25–100, 60–300, and 200-1000 eV, respectively, and are interchangeable without breaking the vacuum. Figure 1 shows the absolute photon flux for each grating measured using a Si photodiode (IRD Inc.), with the entrance- and exit-slit openings set at 50 and 50 µm, respectively. The maximum resolving power ($E/\Delta E$) achieved for each grating exceeds 5000.

There is no fixed endstation on this beamline. A small vacuum chamber equipped with an electron multiplier (EM) detector is available. Soft X-ray absorption spectra of solid samples are usually measured by means of the total electron yield method using EM, and the partial fluorescence yield method using a silicon drift detector (SDD).

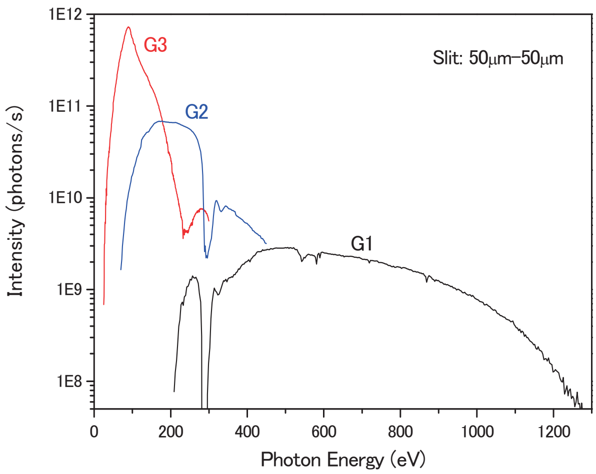


Fig. 1. Throughput from the VLS-PGM monochromator on BL4B.

Fig. 2. Photo of BL4B.

▼Technical Data

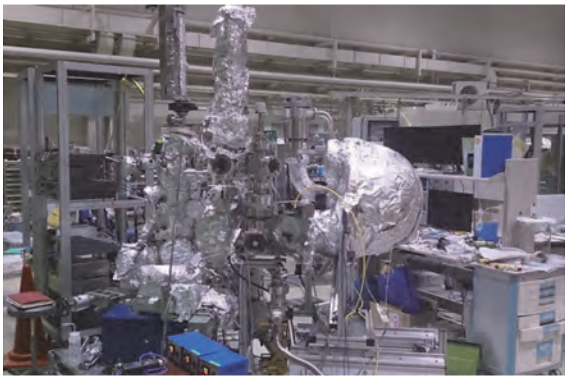
Monochromator	Varied-line-spacing Plane Grating Monochromator
Energy range	25-1000 eV
Resolution	$E / \Delta E > 5000$ (at maximum)
Experiments	Soft X-ray spectroscopy (mainly, photoabsorption spectroscopy for solid targets by means of total electron yield method using EM and partial fluorescence yield method using SDD)

BL5U

Photoemission Spectroscopy of Solids and Surfaces

▼Description

Since the monochromator of BL5U was an old-style spherical grating type SGMTRAIN constructed in 1990s and the throughput intensity and energy resolution were poor, the whole beamline has been replaced to state-of-the-art monochromator and end station. The new beamline has been opened to users from FY2016 as high-energy resolution ARPES beamline. Samples can be cooled down to 3.8 K with newly developed 5-axis manipulator to perform high energy resolution measurements. Users can also obtain spatial-dependence of the electronic structure of solids using micro-focused beam (~ 50 µm). The new electron lens system makes it possible to obtain ARPES spectra without moving samples. This beamline will also have new capability to perform high-efficient spin-resolved ARPES in the future.



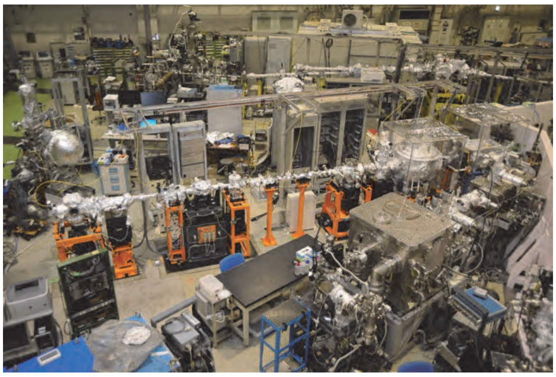


Fig. 1. Pictures of BL5U.

▼Technical Data (Expected Performance)

Light source	APPLE-II type undulator (λ_u = 60 mm, N = 38) vertical/horizontal, right/left circular (depending on *hν*)
Monochromator	Monk-Gillieson VLS-PGM
Energy Range	20-200 eV
Resolution	$h\nu/\Delta E$ > 10,000 for < 10 µm slits
Experiment	ARPES, Space-resolved ARPES, Spin-resolved ARPES
Flux	$<10^{12}$ photons/s for <10 µm slits (at the sample position)
Beam spot size	23 (H) x 40 (V) µm
Main Instruments	Hemispherical photoelectron analyzer with deflector scan (MBS A-1 Lens#4), Liq-He flow cryostat with 5-axis manipulator (3.8 K-350 K)

BL5B

Calibration Apparatus for Optical Elements and Detectors

▼Description

BL5B has been constructed to perform calibration measurements for optical elements and detectors. This beamline is composed of a plane grating monochromator (PGM) and three endstations in tandem. The most upstream station is used for the calibration measurements of optical elements, the middle one for optical measurements for solids, and the last for photo-stimulated desorption experiments. The experimental chamber at the most downstream station is sometimes changed to a chamber for photoemission spectroscopy. The calibration chamber shown in Fig. 2 is equipped with a goniometer for the characterization of optical elements, which has six degrees of freedom, X-Y translation of a sample, and interchanging of samples and filters. These are driven by pulse motors in vacuum. Because the polarization of synchrotron radiation is essential for such measurements, the rotation axis can be made in either the horizontal or vertical direction (s- or p-polarization).

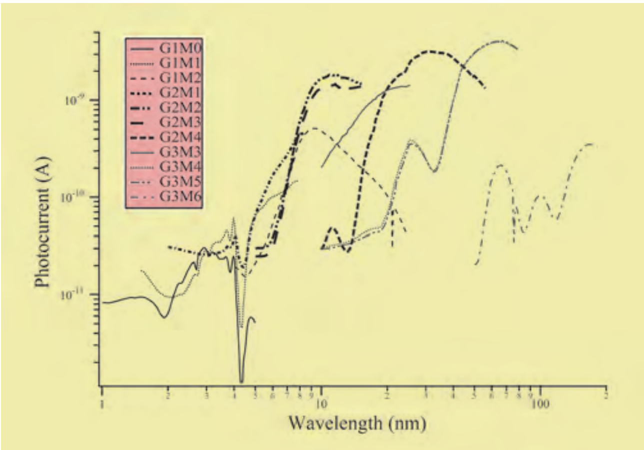


Fig. 1. Throughput spectra for possible combinations of gratings and mirrors at BL5B measured by a gold mesh.

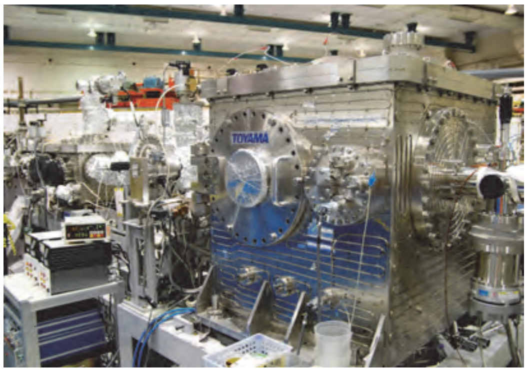


Fig. 2. A side view of the experimental chamber for calibration measurements.

▼Technical Data

Monochromator	Plane Grating Monochromator
Energy range	6-600 eV (2-200 nm)
Resolution	$E / \Delta E$ ~500
Experiments	Calibration of optical elements, reflection and absorption spectroscopy mainly for solids

BL6U

Variable-Included-Angle / Variable-Line-Spacing Plane Grating Monochromator for Soft X-Ray photoelectron Spectroscopy

▼Description

The beamline BL6U equipped with a variable-included-angle Monk-Gillieson mounting monochromator with a varied-line-spacing plane grating was constructed for various spectroscopic investigations requiring high-brilliance soft X-rays on solid surfaces. Through a combination of undulator radiation and sophisticated monochromator design (entrance slit-less configuration and variable-included-angle mechanism), using a single grating, the monochromator can cover the photon energy ranging from 40 to 500 eV, with resolving power of greater than 10000 and photon flux of more than 10^{10} photons/s. Figure 1 shows an example of the monochromator throughput spectra measured using a Si photodiode, with the exit-slit opening set at 30 µm, which corresponds to the theoretical resolving power of 10000 at 80 eV.

The end station is equipped with an electron energy analyzer for angle-resolved photoelectron spectroscopy (MB Scientific AB, A-1 analyzer Lens#5). This spectrometer consists of a hemispherical electron analyzer with a mechanical deflector and a mesh electrostatic lens near the sample to make the acceptance cone tunable. A constant energy angular distribution of the valence band dispersion cross section in the large **k** range can be efficiently obtained by applying a negative bias voltage to the sample and using the mechanical deflector.

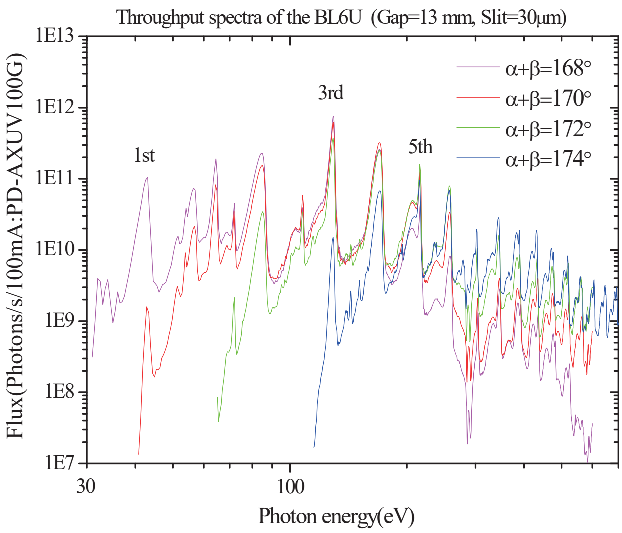


Fig. 1. Throughput spectra of the BL6U monochromator at various included angles.

Fig. 2. Photograph of BL6U end station.

▼Technical Data

Monochromator	Variable-included-angle Varied-line-spacing Plane Grating Monochromator
Energy range	45-600 eV(practical)
Resolution	$E / \Delta E > 10000$ (at maximum)
Experiments	High-resolution soft X-ray spectroscopy (photoelectron spectroscopy for solid surfaces)

BL6B

Infrared and Terahertz Spectroscopy of Solids

▼Description

Synchrotron radiation (SR) has good performance (high brilliance and high flux) not only in the VUV and soft X-ray (SX) regions but also in the infrared (IR) and THz regions. BL6B covers the IR and THz regions. The previous beamline, BL6A1, which was constructed in 1985, was the pioneer in IRSR research. The beamline was deactivated at the end of FY2003 and a new IR/THz beamline, BL6B (IR), was constructed in FY2004. The front-end part including bending duct #6 was replaced with a new part having a higher acceptance angle (215 (H) × 80 (V) mrad^2) using a magic mirror, as shown in Fig. 1.

There are two Michelson type interferometers in this endstation; with first one (Bruker Vertex70v), which covers a wide spectral region from 30 to 20,000 cm^{-1} ($h\nu$ = 4 meV-2.5 eV), reflection/absorption spectroscopy measurements of large samples (up to several mm) and IR/THz microscopy measurements of tiny samples (up to several tens of μm) can be performed. For reflection/absorption spectroscopy measurements, a liquid-helium-flow type cryostat with a minimum temperature of 4 K is installed. The other interferometer (Jasco FT/IR-6100), which covers 350 to 15,000 cm^{-1} ($h\nu$ = 45 meV-1.8 eV), has been available for IR microscopy imaging measurements from FY2014. One can also perform ATR measurements using diamond ATR prism.

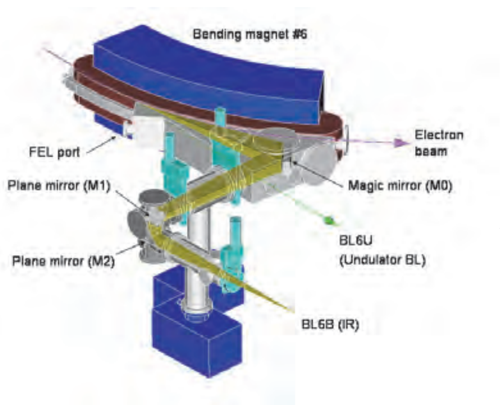


Fig. 1. Design of the optics and front end of BL6B.

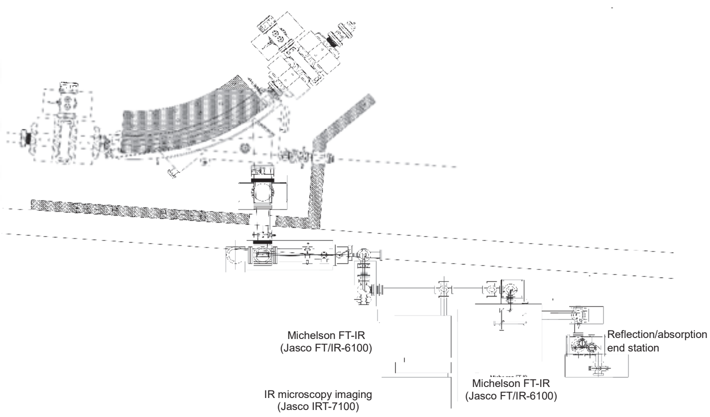


Fig. 2. Schematic top view of BL6B.

▼Technical Data

Interferometer	Michelson (Bruker Vertex70v)	Michelson (Jasco FT/IR-6100)
Wavenumber Range (Energy range)	30-20,000 cm^{-1} (4 meV-2.5 eV)	350-15,000 cm^{-1} (45 meV-1.8 eV)
Resolution in cm^{-1}	0.1 cm^{-1}	0.5 cm^{-1}
Experiments	Reflectivity and transmission spectroscopy THz Microspectroscopy	IR microscopy imaging (JASCO IRT-7000) ATR spectroscopy

BL7U (SAMRAI)

Angle-Resolved Photoemission of Solids in the VUV Region

▼Description

Beamline 7U, named the Symmetry- And Momentum-Resolved electronic structure Analysis Instrument (SAMRAI) for functional materials, was constructed to provide a photon flux with high energy resolution and high flux mainly for high-resolution angle-resolved photoemission spectroscopy, so-called "ARPES", of solids [1]. An APPLE-II-type variable-polarization undulator is installed as the light source. The undulator can produce intense VUV light with horizontal/vertical linear and right/left circular polarization. The undulator light is monochromatized by a modified Wadsworth type monochromator with three gratings (10 m radius; 1200, 2400, and 3600 lines/mm optimized at $h\nu$ = 10, 20, and 33 eV). The energy resolution of the light ($h\nu/\Delta h\nu$) is more than 10^4 with a photon flux of 10^{11}-10^{12} ph/s or higher on samples in the entire energy region. The beamline has a photoemission end-station equipped with a 200 mm-radius hemispherical photoelectron analyzer (MB Scientific AB, A-l analyzer) with a wide-angle electron lens and a liquid-helium-cooled cryostat with 6-axis pulse motor control. The main function of the beamline is to determine the electronic structure of solids and its temperature dependence in order to reveal the origin of their physical properties.

[1] S. Kimura, T. Ito, M. Sakai, E. Nakamura, N. Kondo, K. Hayashi, T. Horigome, M. Hosaka, M. Katoh, T. Goto, T. Ejima and K. Soda, Rev. Sci. Instrum. **81** (2010) 053104.

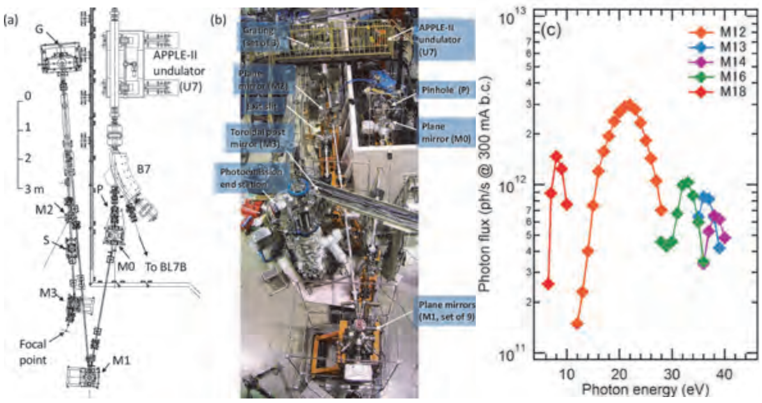


Fig. 1. SAMRAI beamline [(a), (b)] consisting of an APPLE-II type undulator (U7), a modified Wadsworth type monochromator (M0-S), and a high-resolution photoemission analyzer at the focal point. The monochromator has five major optical components: two plane mirrors (M0 and M1) with water cooling, one set of three spherical gratings (G), an exit slit (S), and one toroidal refocusing mirror (M3). (c) Example of flux intensity *versus* photon energy [1]

▼Technical Data

Light source	APPLE-II type undulator (λ_u = 76 mm, N = 36) vertical/horizontal, right/left circular (depending on $h\nu$)
Monochromator	10 m normal-incidence monochromator (modified Wadsworth type)
Photon energy range	6 – 40 eV (λ = 30 – 200 nm)
Resolution ($h\nu/\Delta h\nu$)	$E / \Delta E$ > 10000-50000
Photon flux on sample	≥ 10^{11}-10^{12} ph/s (depending on $h\nu$)
Beam size on sample	200 (H) × 50 (V) μm^2
Experiments	Angle-resolved photoemission of solids (MV Scientific A-1 analyzer, acceptance angle: ± 18 deg)

BL7B
3 m Normal-Incidence Monochromator for Solid-State Spectroscopy

▼Description

BL7B has been constructed to provide sufficiently high resolution for conventional solid-state spectroscopy, sufficient intensity for luminescence measurements, wide wavelength coverage for Kramers–Kronig analyses, and minimum deformation to the polarization characteristic of incident synchrotron radiation. This beamline consists of a 3-m normal incidence monochromator, which covers the vacuum ultraviolet, ultraviolet, visible, and infrared, i.e., the wavelength region of 50–1000 nm, with three gratings (1200, 600, and 300 l/mm). Two interchangeable refocusing mirrors provide two different focusing positions. For the mirror with the longer focal length, an LiF or a MgF_2 window valve can be installed between the end valve of the beamline and the focusing position. Figure 1 shows the absolute photon intensity for each grating with the entrance and exit slit openings of 0.5 mm. A silicon photodiode (AXUV-100, IRD Inc.) was utilized to measure the photon intensity and the absolute photon flux was estimated, taking the quantum efficiency of the photodiode into account.

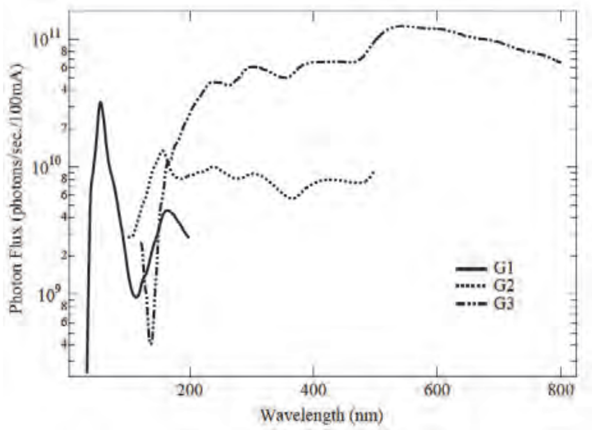


Fig. 1. Throughput spectra of BL7B measured using a silicon photodiode.

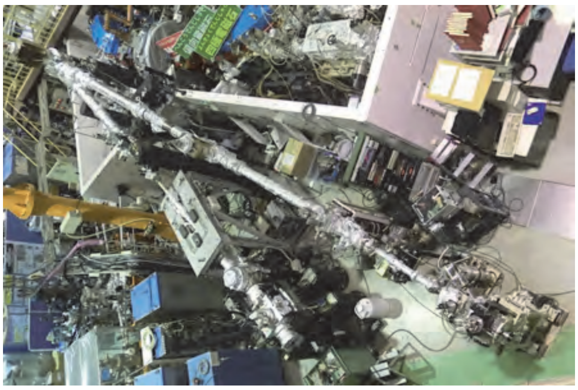


Fig. 2. Photo of BL7B.

▼Technical Data

Monochromator	3 m Normal-Incidence Monochromator
Wavelength Range	50-1000 nm (1.2-25 eV)
Resolution	$E / \Delta E$ = 4000-8000 for 0.01 mm slits
Experiments	Absorption, reflection, and fluorescence spectroscopy, mainly for solids