

A large, white, stylized Roman numeral 'II' is centered in the upper half of the page. The background is a vibrant teal color with a complex pattern of overlapping circles and lines, creating a sense of depth and motion. The circles are arranged in concentric rings, and the lines are straight and radiating, suggesting a technical or scientific theme.

Current Status of
Light Sources and
Beamlines

Light Source in 2019

1. Status of UVSOR Accelerators

In the fiscal year 2019, 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 June we had a trouble in the vacuum chamber of the booster synchrotron. Since we had another trouble on the beam-line vacuum in the same week, we canceled users operation for one week, which was compensated with a machine study week which had been scheduled in the latter half of the year. In cases of other minor troubles, we extended the operation time for compensation. We had a scheduled shutdown period in April for 4 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. We had 4 weeks for machine conditionings and studies, in the latter half of the year, although one week was replaced with users run as described above. 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.

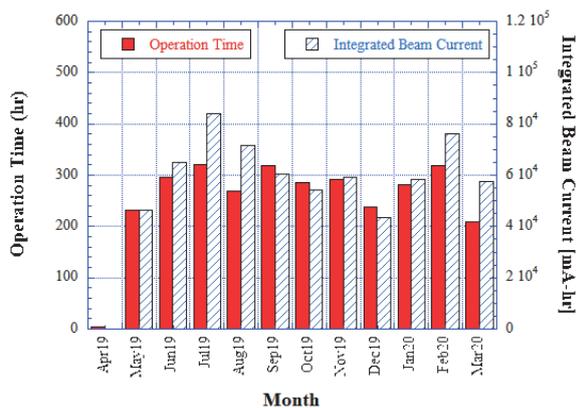


Fig. 1. Monthly statistics in FY2018.

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 9 am to 9 pm, the machine is operated for users. From Thursday 9 am to Friday 9 pm, 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 vacuum leakage trouble at the booster synchrotron. We quickly localized the leaking position, which was on the vacuum chamber at a bending magnet. Fortunately, we could stop the leakage by using a liquid vacuum seal.



Fig. 2. Sextupole coil for multipole magnets.

The cooling water leakage from the sextupole coils wound on the pole faces of the multipole (quadrupole/sextupole) magnets have been getting more serious. As cutting the hollow conductor which was removed, from the magnet, it was confirmed that the walls of the hollow conductor have been eroded by the water flow during the fifteen year operation. In the spring shutdown 2019, we applied liquid sealant for all the coils for life prolonging. However, even after this, some coils started leaking. In parallel with repairing the leaking coils, we have constructed new coils for a half of the 32 multipole magnets in FY2019. We have started the replacement in March, 2020. The coils for the half of the magnets will be replaced by the end of April 2020. Those of another half will be replaced by the end of April 2021.

2. Improvements and Developments

The pulse magnet power supplies for the injection kickers of the booster-synchrotron malfunction a few times in a year. It has been recognized that the IGBT in the power supply caused the trouble. We have started replacing them one after another with more robust ones for high voltage.

The vacuum data acquisition system was replaced after nearly 15 year operation, which has been collecting the vacuum pressure for all part of the accelerator system and beam-line front ends. The PLCs were replaced and the data display ability was improved.

The timing system of the linear accelerator was improved. Now the trigger of the electron gun and that of the klystron can be adjusted independently from the control room.

The access bridge to the inside of the storage ring was replaced to create a space for a new beam-line. The pulse motor of an undulator U6, which was constructed in 2002, has been replaced to be compatible with the new control system.

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 beams, such as optical vortex beams and optical vector beams, from undulators in collaboration with Hiroshima U., Nagoya U. and other institutes. Moreover, we have demonstrated a novel method to utilize temporal structure of undulator radiation for coherent control of atoms. BL1U is a unique beam-line, which enables us to use the direct

beam from a tandem undulator system for coherent control experiments, which are described in these reports.

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. At BL1U, we have a special port for the laser injection for 90 degree Thomson scattering, which enable us to generate short gamma-ray pulses of sub-picosecond order. With this novel light source, we have started new experiments on positron lifetime spectroscopy in collaboration with Yamagata U., Nagoya U. and AIST.

Masahiro KATOH
(UVSOR Synchrotron)

UVSOR Accelerator Complex

Injection Linear Accelerator

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

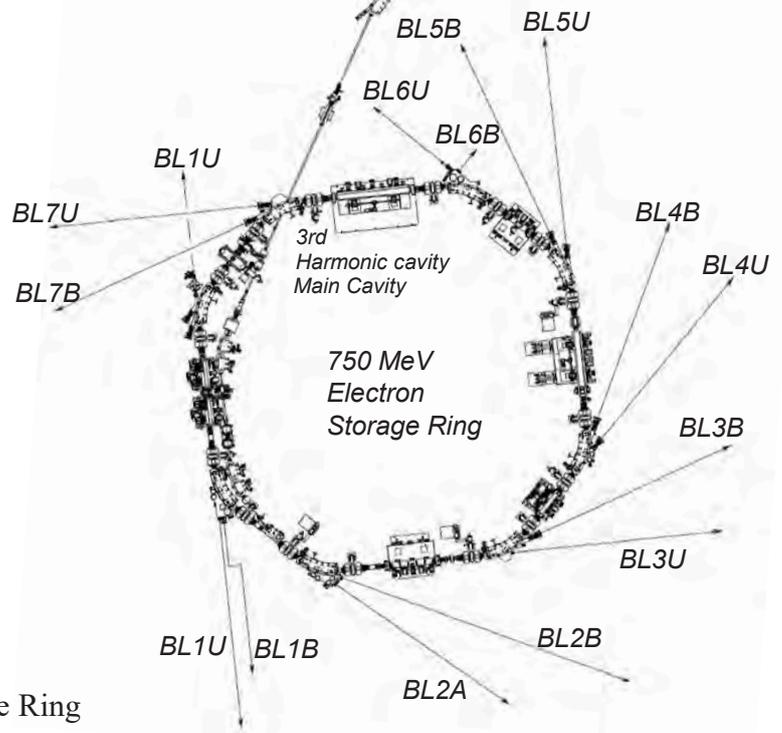
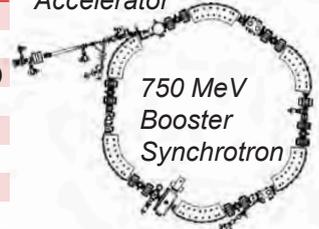
UVSOR-III Storage-Ring

Energy	750 MeV
Injection Energy	750 MeV
Maximum Storage Current	500 mA (multi bunch) 100 mA (single bunch)
Normal operation current (Top-up mode)	300 mA (multi bunch) 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 $\times 4$
Straight Section	(4 m \times 4)+(1.5 m \times 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

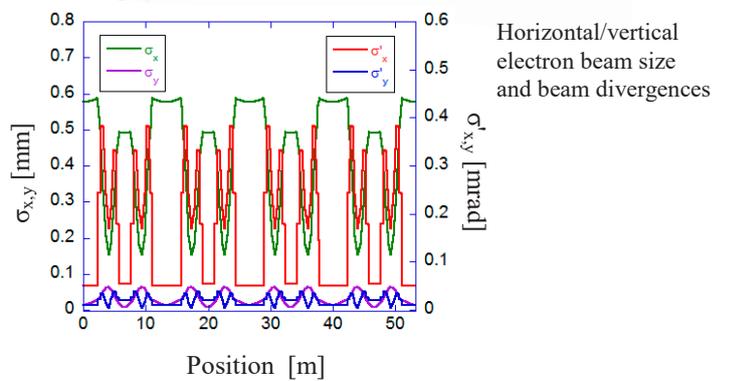
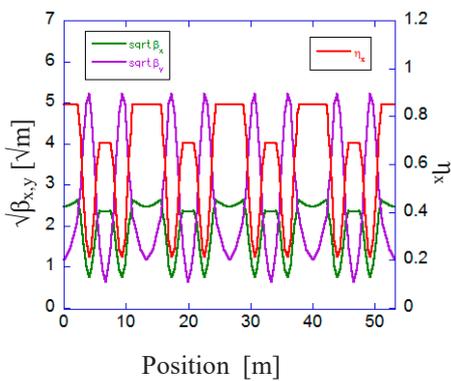
Booster Synchrotron

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 $\times 8$
Betatron Tune	
Horizontal	2.25
Vertical	1.25
Momentum Compaction	0.138
Repetition Rate	1 Hz (750 MeV)

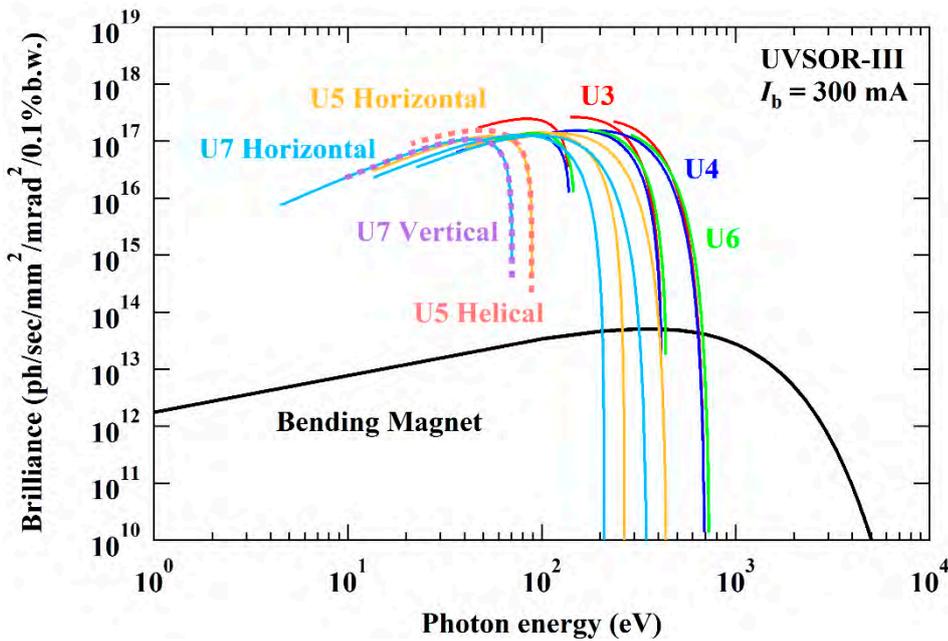
15 MeV
Linear
Accelerator



Electron Beam Optics of UVSOR-III Storage Ring



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. Helical)

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 2019

Kiyohisa TANAKA

UVSOR synchrotron Facility, Institute for Molecular Science

UVSOR is one of the highest-brilliance light sources in the extreme-ultraviolet region among the synchrotron radiation facilities with electron energies of less than 1 GeV. 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 2018 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 2019. The details of the updates for several beamlines are the followings.

BL4U, equipped with a scanning transmission soft X-ray microscope (STXM), is popular not only for academic users but also many industrial users. In FY2019, a new Fresnel zone plate, whose focal length is different from the previous one, was prepared to perform measurements with energy of photons from 55 eV. This zone plate makes users possible to perform Li K-edge measurements, which is important to study all solid state Li batteries.

BL5U has been officially opened for users from 2016 as high energy resolution angle-resolved photoemission spectroscopy (ARPES) beamline. In FY2019, the latest version of ARPES analyzer has been installed (MB

Scientific AB, A-1 analyzer Lens#5). Users can now use so-called “deflector mapping” for all kinetic energies and lens modes. By combining with the micro-focused beam (23 x 40 μm), users can perform measurements on small samples or inhomogeneous samples without changing sample position.

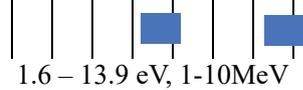
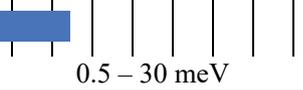
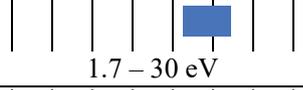
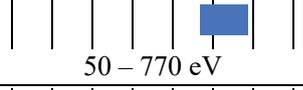
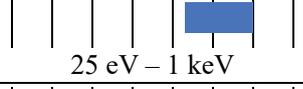
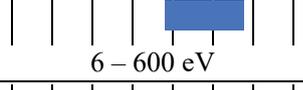
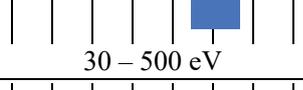
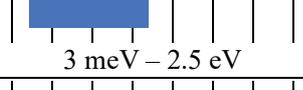
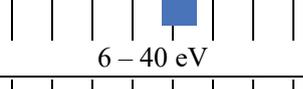
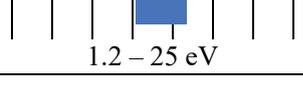
In BL6U, which is one of the in-house beamlines, so-called “Momentum microscope (MM)”, which is an electronic spectroscopy with both the real space and momentum space resolution, has been installed in February 2020 (SPECS Surface Nano Analysis GmbH, KREIOS 150 MM). It will be upgraded to double hemispherical analyzer in FY2020 and will also be upgraded for spin-resolved measurements in the future.

In June 2019, a serious vacuum leakage accident occurred from water cooling line at M0 mirror located at upstream of BL7B. It was installed 20 years ago, and cooling water made a hole through 1 mm thick copper pipe. Although the accident occurred during user operation, fortunately, the upper most valves of beamline was closed because of the vacuum interlock system and the effect was very limited to the storage ring. Since it was hard to repair the copper pipe quickly because of the limited space during the user operation, we decided to shut down BL7B during FY2019. In the meantime, we pumped the water cooling line with vacuum to stop the water leakage and investigated the stability of the beam spot position at endstation without water cooling of M0 mirror. According to the investigation, we concluded that the manual adjustment of M0 mirror angle for every 3 hours can make users perform experiments. BL7B will start to accept users from FY2020.

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

II

Beamline	Monochromator / Spectrometer	Energy Range	Targets	Techniques	Contact
BL1U	Free electron laser, Tandem undulator, LSC Gamma-rays	 1.6 – 13.9 eV, 1-10MeV		(Irradiation)	Y. Taira yostaira@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)	 24 – 205 eV	Solid	Photoemission	S. Kera kera@ims.ac.jp
BL3U	Varied-line-spacing plane grating (Monk-Gillieson)	 60 – 800 eV	Gas Liquid Solid	Absorption Photoemission Photon-emission	M. Nagasaka nagasaka@ims.ac.jp
BL3B	2.5-m off-plane Eagle	 1.7 – 30 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 [†])	 5 – 250 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	 30 – 500 eV	Gas Solid	Photoionization Photodissociation Photoemission	F. Matsui matui@ims.ac.jp
BL6B	Michelson FT-IR	 3 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.

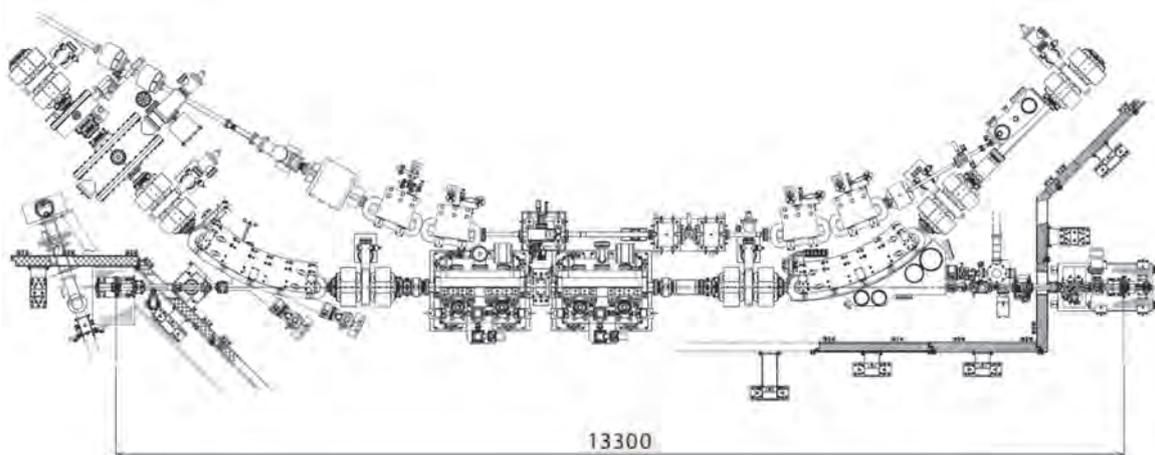


Fig. 1. Configuration of the free electron laser (under reconstruction)



Fig. 2. Twin Apple-II Undulator

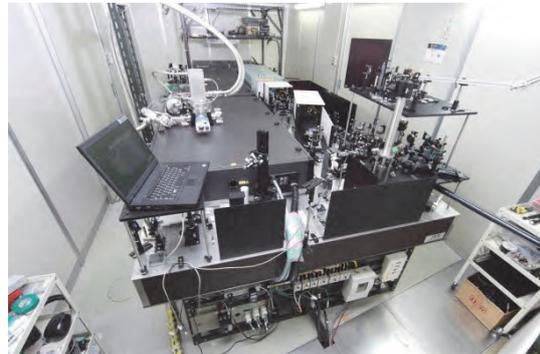


Fig. 3. Accelerator synchronized Laser System

▼ Technical Data of FEL

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

▼ 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

II

▼ 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 BL431R 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} ($h\nu = 500 \mu\text{eV}$ -30 meV). There is a reflection/absorption spectroscopy (RAS) end-station for large samples (\sim several mm). At the RAS end-station, a liquid-helium-flow type cryostat with a minimum temperature of 4 K is installed.

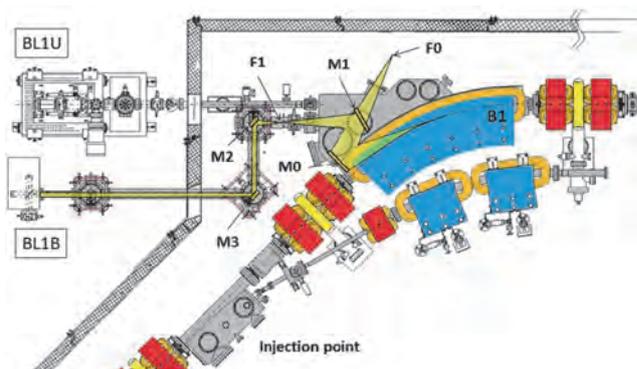


Fig. 1. Schematic top view of the beam extraction part of the THz-CSR beamline, BL1B. The three-dimensional magic mirror (3D-MM, M0) and a plane mirror (M1) are located in the bending-magnet chamber. A parabolic mirror (M2) is installed to form a parallel beam. The straight section (BL1U) is used for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

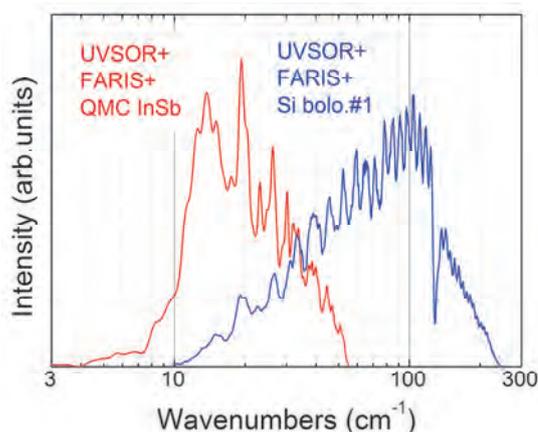


Fig. 2. Obtained intensity spectra with the combination of a light source (UVSOR), interferometer (FARIS-1), and detectors (Si bolometer and InSb hot-electron bolometer).

▼ 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

▼ Description

BL2A 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 beryl, KTP (KTiOPO₄), InSb, and Ge. The throughput spectra measured using a Si photodiode (AXUV-100, IRD Inc.) are shown in Fig. 1. The typical energy resolution ($E / \Delta E$) of the monochromator is approximately 1500 for beryl and InSb.

There is a small vacuum chamber equipped with an electron multiplier (EM) detector. Photoabsorption spectra for powdery samples are usually measured in total electron yield mode, with the use of the EM detector. In addition, a hemispherical electron analyzer for photoelectron spectroscopy is equipped.

Recently, a new omnidirectional photoelectron acceptance lens (OPAL) has been developed aiming to realize 2π -steradian photoelectron spectroscopy and photoelectron holography [2]. As shown in Fig. 2, by combining OPAL and the existing hemispherical electron analyzer, a photoelectron spectrometer with high energy resolution can be realized, and a full range ($\pm 90^\circ$) 1D angular distribution can be measured at once. This upgrade is currently in the commissioning phase.

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

[2] H. Matsuda and F. Matsui, Jpn. J. Appl. Phys. **59** (2020) 046503.

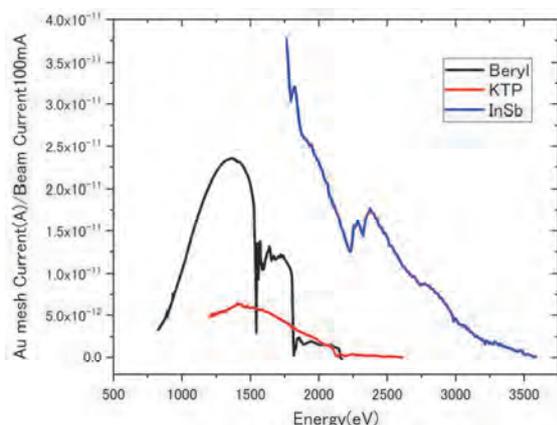


Fig. 1. Throughput spectra of the double-crystal monochromator at BL2A.

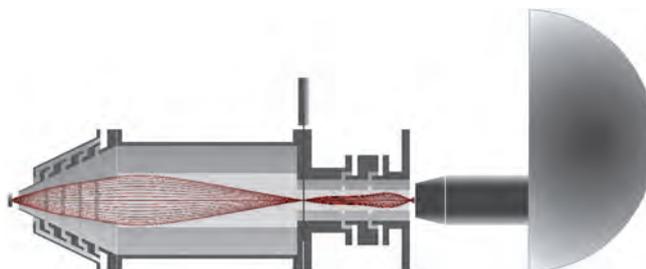


Fig. 2. Schematic diagram of Omnidirectional photoelectron acceptance lens (OPAL) and projection-type analyzer.

▼ Technical Data

Monochromator	Double crystal monochromator
Monochromator crystals: (2d value, energy range)	beryl (15.965 Å, 826–2271 eV), KTP (10.95 Å, 1205–3310 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

II

▼ 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.

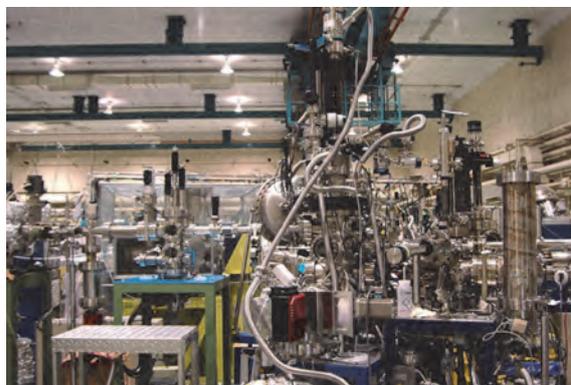


Fig. 2. End station of BL2B for photoelectron spectroscopy of molecular solids.

▼ 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 $0.2 \times 0.2 \text{ mm}^2$ 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.

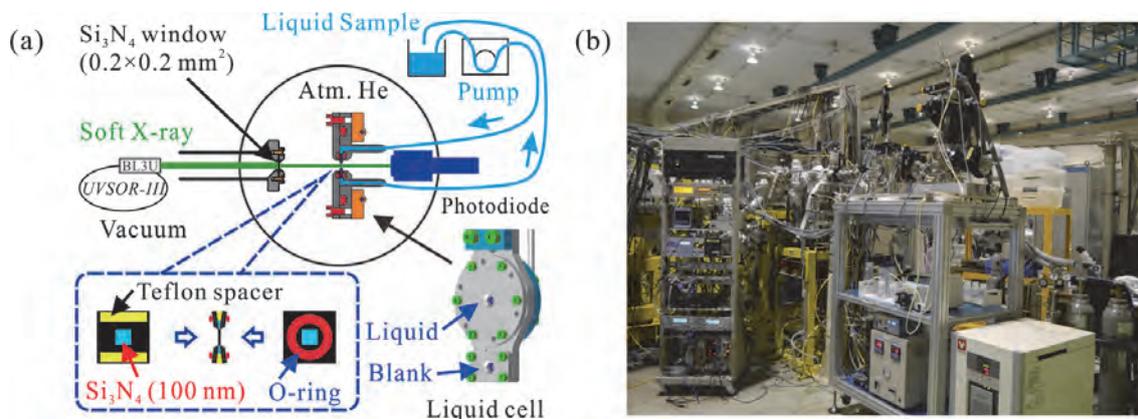


Fig. 1. (a) Schematics of a liquid cell for XAS in transmission mode settled in BL3U. The blowup shows a thin liquid layer assembled by two Si_3N_4 membranes with the thickness of 100 nm. (b) Photograph of a XAS measurement system for liquid samples at the end station of BL3U.

▼ 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) \times 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 \sim 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 $E / \Delta E$ 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.

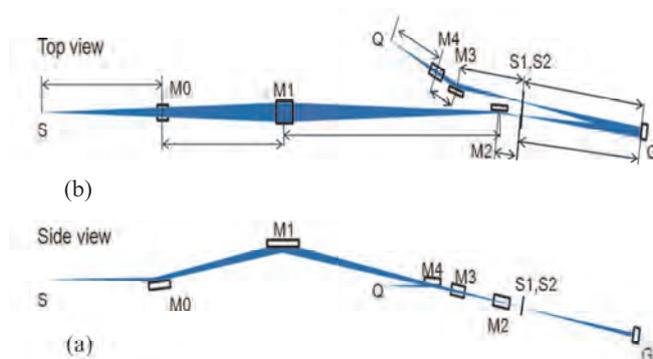


Fig. 1. Schematic layout of the BL3B (a) side view and (b) top view.

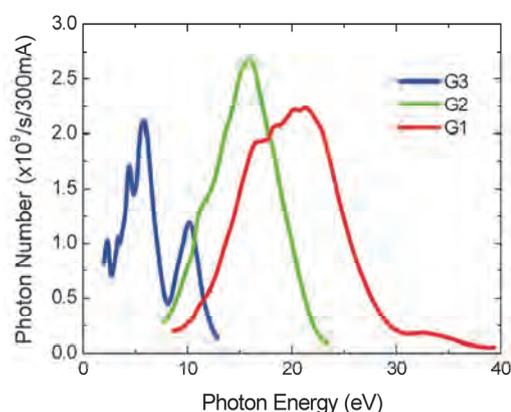


Fig. 2. Throughput spectra for each grating (G1:1200 l/mm, G2:600 l/mm and G3:300 l/mm) with $S1 = S2 = 0.1$ mm.

▼ Technical Data

Monochromator	-2.5 m normal-incidence monochromator
Energy range	1.7-31 eV (40~730 nm)
Resolution ($\Delta h\nu / h\nu$)	≥ 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

▼ 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 ($E/\Delta E$) 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.

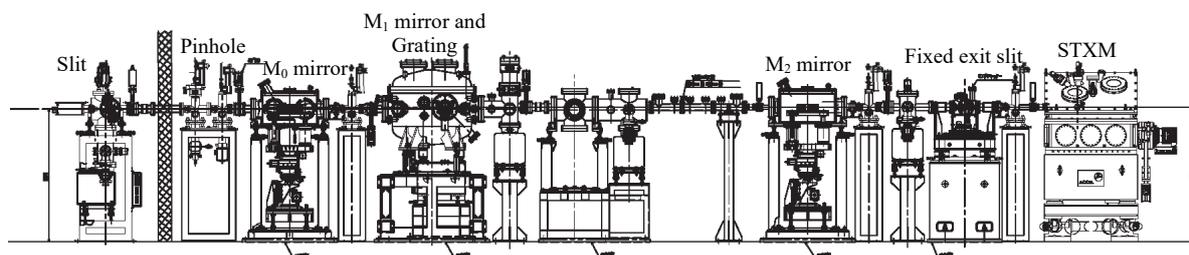


Fig. 1. Schematic image of BL4U

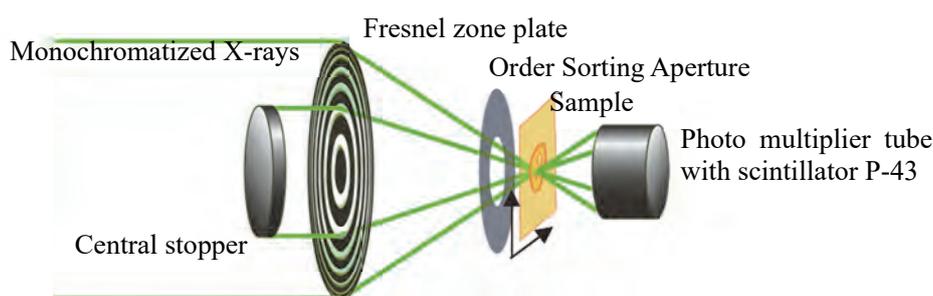


Fig. 2. Schematic image of STXM

▼ Technical Data

Energy range (E)	50 -770 eV
Resolving power ($E/\Delta E$)	$\sim 6,000$
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

II

▼ 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 SiO₂ 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).

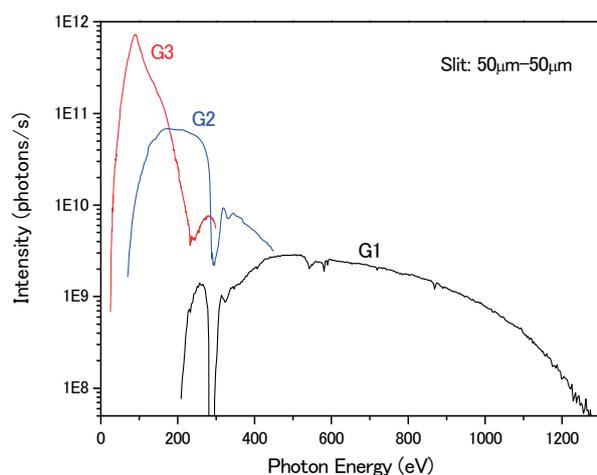


Fig. 1. Throughput from the VLS-PGM monochromator on BL4B.



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 ($\sim 50 \mu\text{m}$). 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 ($\lambda_u = 60 \text{ mm}$, $N = 38$) vertical/horizontal, right/left circular (depending on $h\nu$)
Monochromator	Monk-Gillieson VLS-PGM
Energy Range	20-200 eV
Resolution	$h\nu / \Delta E > 10,000$ for $< 10 \mu\text{m}$ slits
Experiment	ARPES, Space-resolved ARPES, Spin-resolved ARPES
Flux	$< 10^{12}$ photons/s for $< 10 \mu\text{m}$ 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

II

▼ 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).

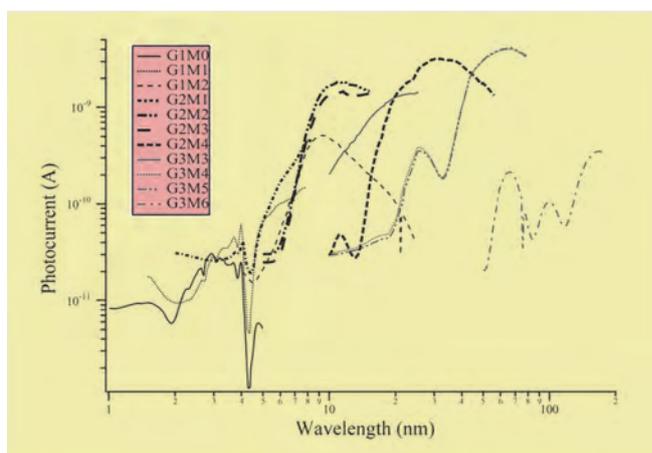


Fig. 1. Throughput spectra for possible combinations of gratings and mirrors at BL5B measured by a gold mesh.

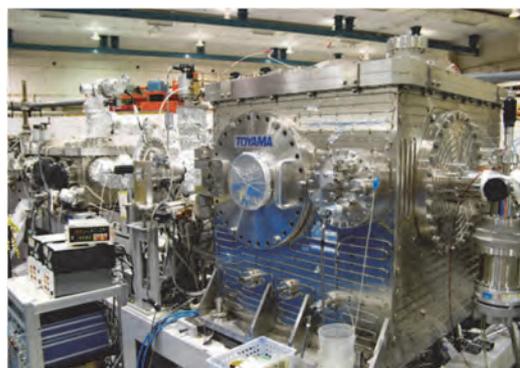


Fig. 2. A side view of the experimental chamber for calibration measurements.

▼ Technical Data

Monochromator	Plane Grating Monochromator
Energy range	6-600 eV (2-200 nm)
Resolution	$E / \Delta E \sim 500$
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.

A new Momentum Microscope experimental station for photoelectron spectroscopy resolved in 3D momentum space with a microscopic field of view has been built at BL6U (SPECS KREIOS 150 MM). A momentum resolution of 0.01 \AA^{-1} in k_x/k_y , as well as k_z is achieved. A spatial resolution of 50 nm, an energy resolution of 20 meV at 9 K, and a field of view of 2 μm for ARPES are successfully demonstrated. This experimental station specializes in characterizing the electronic structure of surface atomic sites, thin films, molecular adsorbates, and bulk crystals. This method opens the door to direct observation of the Fermi surface of μm -sized crystals, which was difficult with conventional ARPES-type hemispherical analyzers.

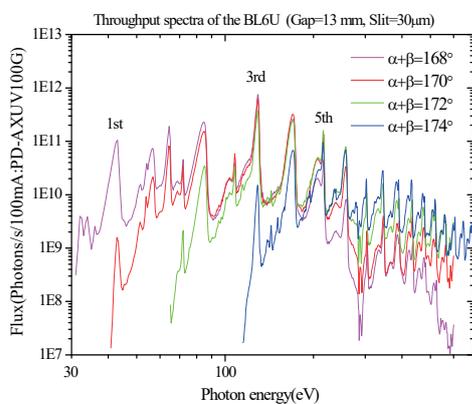


Fig. 1. Throughput spectra of the BL6U monochromator at various included angles.

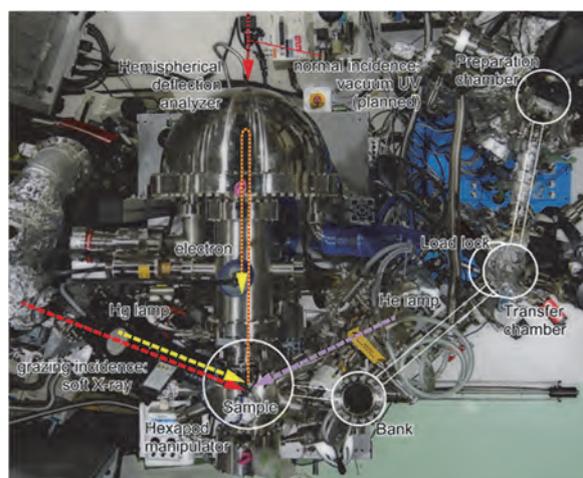


Fig. 2. Photograph of BL6U end station

▼ 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

II

▼ 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 ($215 \text{ (H)} \times 80 \text{ (V)} \text{ mrad}^2$) 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} ($h\nu = 4 \text{ meV} - 2.5 \text{ eV}$), 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} ($h\nu = 45 \text{ meV} - 1.8 \text{ eV}$), has been available for IR microscopy imaging measurements from FY2014. One can also perform ATR measurements using diamond ATR prism.

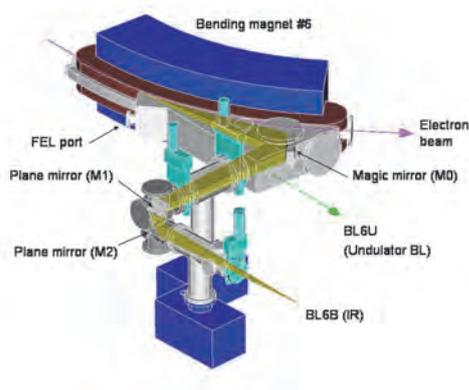


Fig. 1. Design of the optics and front end of BL6B.

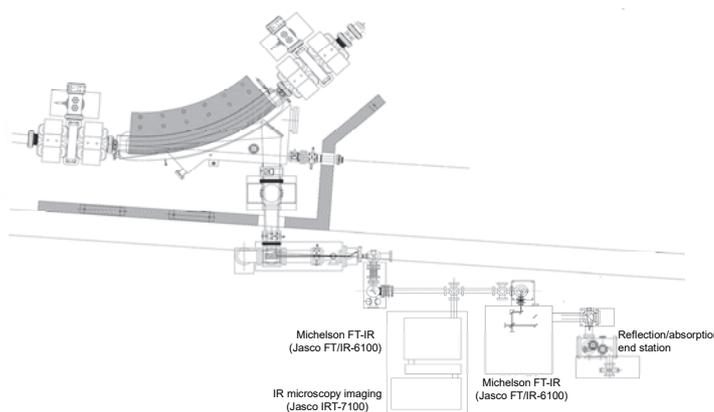


Fig. 2. Schematic top view of BL6B.

▼ 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-1 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.

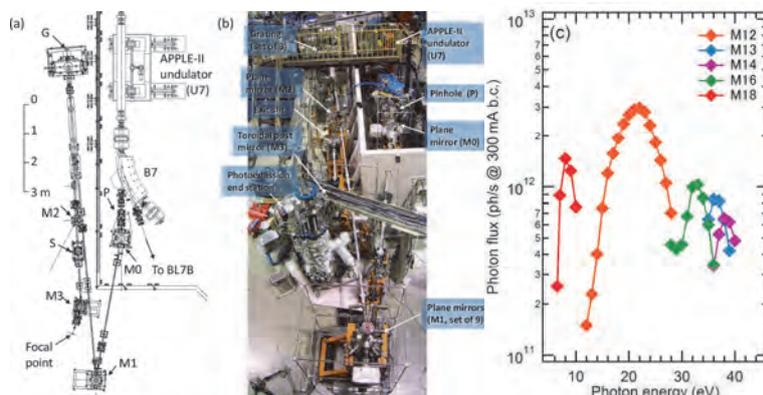


Fig. 1. SAMRAI beamline [(a), (b)] consisting of an APPLE-II type undulator (U7), a modified Wadsworth type monochromator (M0-S), and a high-resolution photoemission analyzer at the focal point. The monochromator has five major optical components: two plane mirrors (M0 and M1) with water cooling, one 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 ($\lambda_u = 76$ 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 ($\lambda = 30 - 200$ nm)
Resolution ($h\nu/\Delta h\nu$)	$E / \Delta E > 10000$ - 50000
Photon flux on sample	$\geq 10^{11}$ - 10^{12} ph/s (depending on $h\nu$)
Beam size on sample	200 (H) \times 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

II

▼ 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 MgF₂ 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.

The cooling system for the pre-focusing mirror has been removed, resulting in longer beam settling times. Currently, BL7B is opened during single bunch mode, but limited use is possible during multi bunch mode.

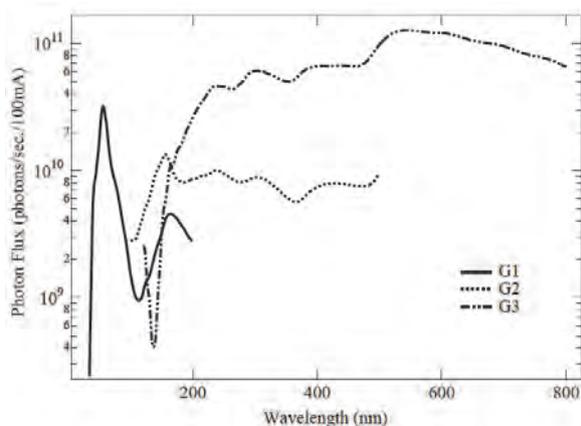


Fig. 1. Throughput spectra of BL7B measured using a silicon photodiode.



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