Light Sources in 2011

1. Status of UVSOR Accelerators

In FY2011, the UVSOR-II accelerators were in operation from May 2011 to March 2012. A total of 36 weeks were devoted to user operations, consisting of 34 weeks in multi-bunch mode and two weeks in single-bunch/multi-bunch hybrid mode, in which the machine is operated in single-bunch mode during the daytime and in multi-bunch mode at night. Four weeks were dedicated to machine studies this year. We had a two-month shutdown starting from April 2011, for the installation of a new undulator and construction of two new beamlines. There was also a one-week shutdown in September and a two-week shutdown around the New Year period.

The monthly statistics of the operation time and the integrated beam current are shown in Fig. 1. The high integrated beam current in June was due to vacuum conditioning.

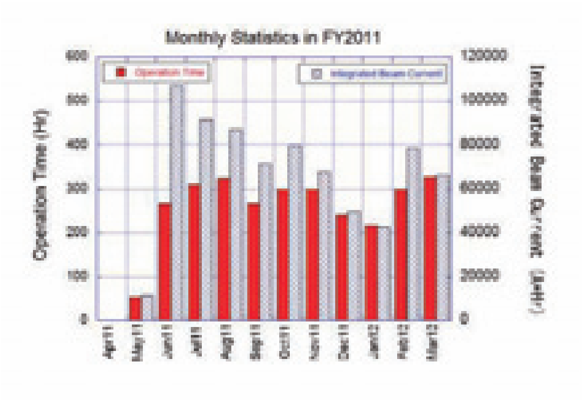


Fig. 1. Monthly statistics in FY2011 (upper) for the operation time (red bars) and integrated beam current (blue dashed bars).

The weekly operation schedule is as follows. On Monday, the machine is operated for machine studies from 9 a.m. to 9 p.m. On Tuesday and Wednesday, the machine is operated for users from 9 a.m. to 9 p.m. From Thursday 9 a.m. to Friday 9 p.m., the machine is operated for 36 hours continuously for users. Thus, the beam time available to users is 60 hours per week. Since last year, we have been operating the machine in top-up mode for 100% of the users' time. The beam current is maintained at 300 mA in multi-bunch mode and 50 mA in single-bunch mode.

This fiscal year, we had a few problems with the pulse magnet power supplies for the booster synchrotron, which may have been due to the increased operation time of the beam injection system caused by the start of the top-up operation. We also encountered a problem with the programmable logic controller (PLC) for the magnet power supplies in the storage ring, which was caused by an instantaneous electricity shortage. Fortunately, in all cases the beam time for users could be secured by extending the operation time in the same weeks.

2. Improvements and Developments

New bending magnet for UVSOR-III

The magnetic lattice of UVSOR was modified in 2003, by replacing all the focusing magnets (quadrupoles and sextupoles). In 2012, we are going to replace all of the bending magnets (dipoles) with newly designed combined-function magnets. The new

Fig. 2. New combined-function bending magnet (a lower half is shown).

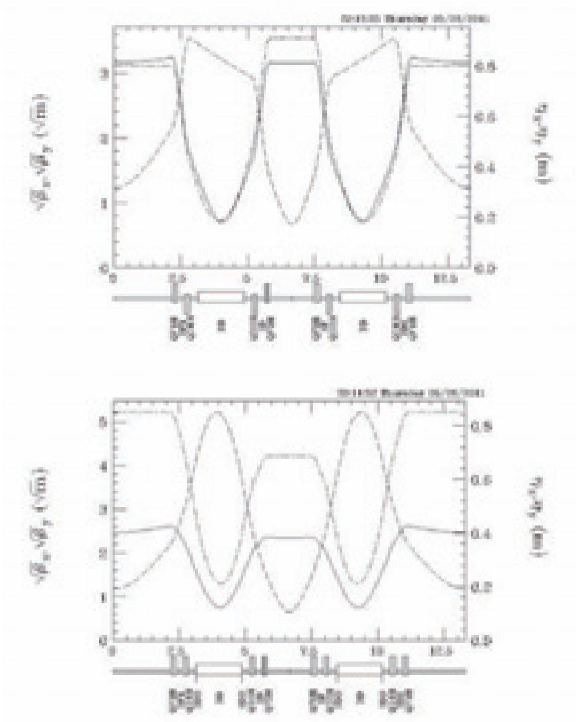


Fig. 3. Lattice functions of UVSOR-II (upper) and UVSOR-III (lower). The emittance is 27nm-rad and ~15nm-rad, respectively.

magnets have specially designed pole shapes and edge shapes as shown in Fig. 2, to produce dipole, quadrupole, and sextupole fields.

By this lattice modification, the emittance will be reduced from 27 nm-rad to around 15 nm-rad. The old and new lattice functions are shown in Fig. 3. The construction of the bending magnets and the field measurements were completed by the middle of March, 2012. In April 2012, the reconstruction work is scheduled to start. The commissioning of the new lattice will begin in June. After commissioning has been successfully completed, the ring will be called UVSOR-III.

Design and construction of in-vacuum undulator for STXM beamline

We designed and constructed an in-vacuum undulator for the new scanning transmission soft X-ray microscope (STXM) beamline (BL4U), which will be constructed in 2012. The magnetic period length is 38 mm and the pole length is about 1 m. This will be the third in-vacuum device in this ring. The basic design is similar to that of the U3 and U6 devices. The undulator will be installed in the ring in May 2012.

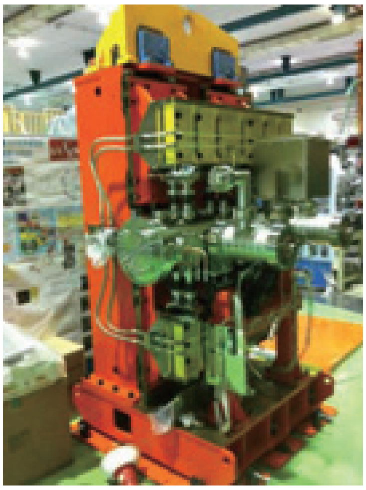


Fig. 4. New in-vacuum undulator for BL4U STXM beamline.

Design and construction of optical klystron

We installed a new undulator system (optical klystron) at the 4 m-long straight section (S1), which was newly created by moving the injection point in 2010. The optical klystron consists of two identical helical undulators (APPLE-II type) of 1 m in length, with a buncher (wiggler) in between. Because of the delay in the construction of these devices due to the earthquake last year, one undulator was installed in May and the other in September. The installation of the buncher took place in December.

This optical klystron will be used for generating coherent synchrotron radiation in the terahertz (THz) region and coherent harmonics in the vacuum ultraviolet (VUV) region, as well as for driving a free electron laser in the visible and UV regions. The first experiment on THz coherent synchrotron radiation was successfully carried out in February 2012.

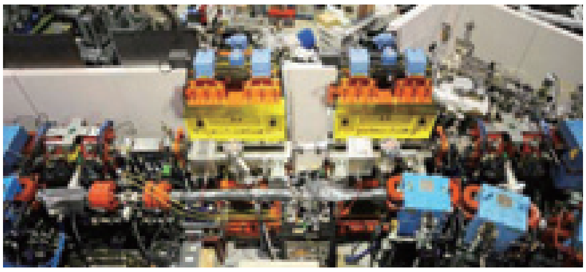


Fig. 5. New undulator system for coherent light source development installed at the straight section, S1.

Laser Compton scattering of gamma rays

Generation of polarized gamma rays based on the laser Compton scattering technique has been investigated, in which polarized laser photons are injected into the storage ring and Compton back-scattered. The photon energy was increased by the square of the Lorentz factor (~1500 for UVSOR-II), while preserving the polarity of the photons. By controlling the polarity of the laser photons, we can control that of the gamma rays. We have succeeded in observing the changes in the special distribution of the gamma rays depending on the polarization, which was well reproduced by numerical simulation [1]. Direct measurement of the polarization will be carried out in the future.

References
[1] Y. Taira *et al*., in this report.

Masahiro Katoh (UVSOR Facility)

UVSOR Accelerator Complex

Injection Linear Accelerator

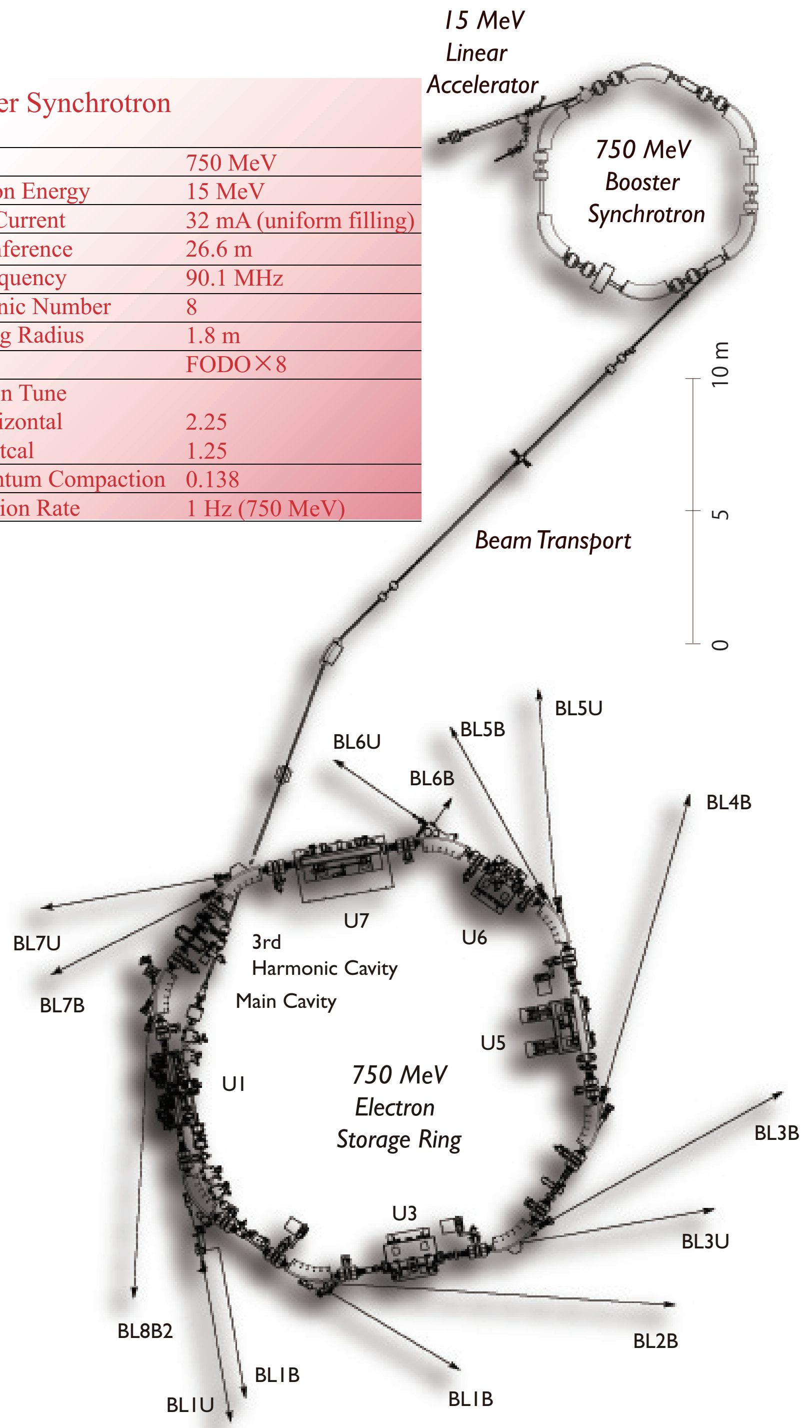
Energy	15 MeV
Length	2.5 m
Frequency	2856 MHz
Accelerating RF Field	2π/3 Traveling Wave
Klystron Power	1.8 MW
Energy Spread	~1.6 MeV
Repetition Rate	2.6 Hz

Booster Synchrotron

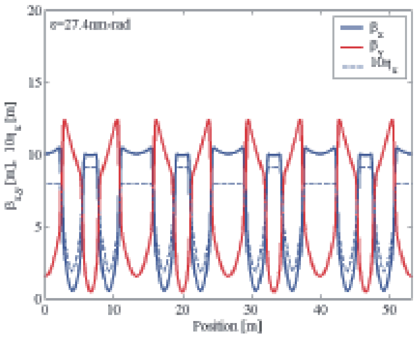
Energy	750 MeV
Injection Energy	15 MeV
Beam Current	32 mA (uniform filling)
Circumference	26.6 m
RF Frequency	90.1 MHz
Harmonic Number	8
Bending Radius	1.8 m
Lattice	FODO×8
Betatron Tune	
Horizontal	2.25
Veritcal	1.25
Momentum Compaction	0.138
Repetition Rate	1 Hz (750 MeV)

UVSOR-II Storage Ring

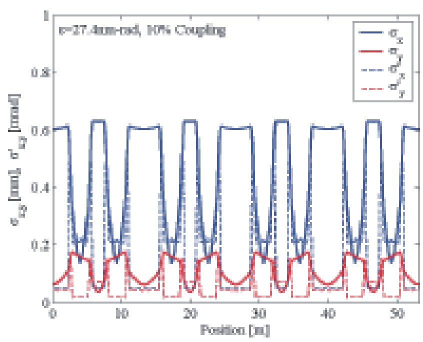
Energy	750 MeV
Injection Energy	750 MeV
Maximum Stored Current	500 mA (multi bunch) 100 mA (single bunch)
Natural Emittance	27.4 nm-rad
Circumference	53.2 m
RF Frequency	90.1 MHz
Harmonic Number	16
Bending Radius	2.2 m
Lattice	Extended DBA×4
Straight Section	(4 m×4)+(1.5 m×4)
RF Voltage	100 kV
Betatron Tune	
Horizontal	3.75
Veritcal	3.20
Momentum Compaction	0.028
Natural Chromaticity	
Horizontal	-8.1
Vertical	-7.3
Energy Spread	4.2×10^{-4}
Natural Bunch Length	108 ps



Electron Beam Optics of UVSOR-II Storage Ring



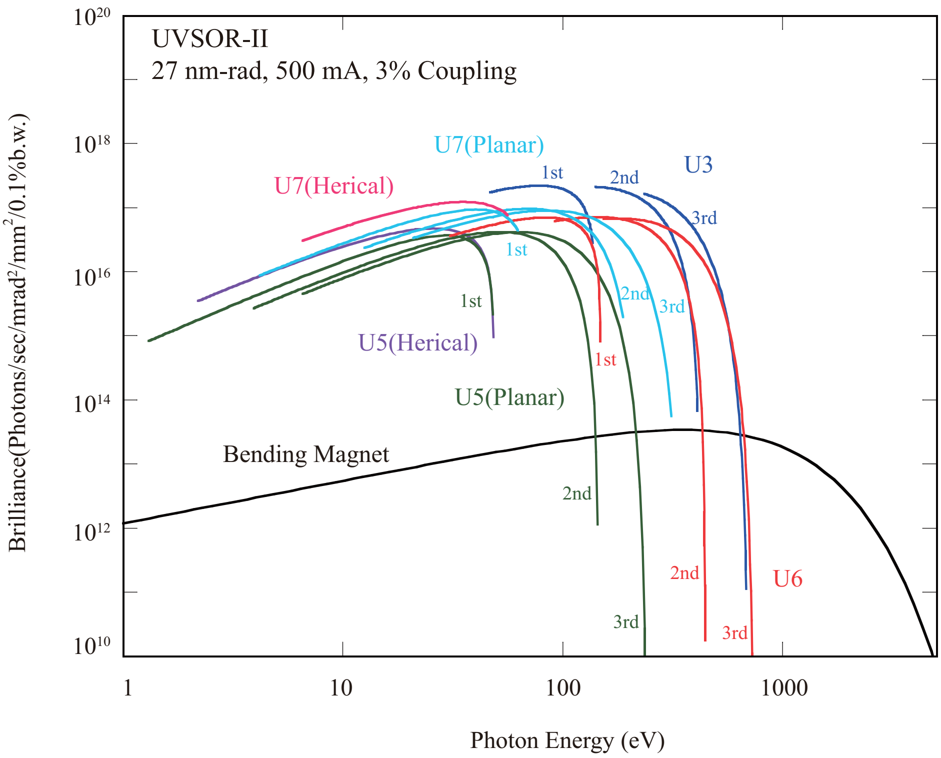
Horizontal /vertical betatron functions and dispersion function



Horizontal /vertical electron bem sizes and beam divergences

Insertion Devices

Brilliance of Radiation



Brilliance of radiation from the insertion devices (U3, U5, U6 and U7) and a beding magnet of UVSOR-II

U3 In-vacuum Undulator

Number of Periods	50
Period Length	38 mm
Pole Length	1.9 m
Pole Gap	15 - 40 mm
Deflection Parameter	2.00 - 0.24

U6 In-vacuum Undulator

Number of Periods	26
Period Length	36 mm
Pole Length	0.94 m
Pole Gap	15 - 40 mm
Deflection Parameter	1.78 - 0.19

U5 Herical Undulator / Optical Klystron

Number of Periods	21 / 9+9 (Opt. Kly.)
Period Length	110 mm
Pole Length	2.35 m
Pole Gap	30 - 150 mm
Deflection Parameter	4.6 - 0.07 (Helical) 8.5 - 0.15 (Linear)

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 2011

The UVSOR facility has been widely recognized as one of the highest brilliance extreme ultraviolet (EUV) radiation sources among synchrotron radiation facilities with an electron energy of less than 1 GeV, after the successful accomplishment of the upgrade project on the storage ring (UVSOR-II Project). Eight bending magnets and four insertion devices are available for the utilization of synchrotron radiation at UVSOR. There has been a total of twenty operational beamlines in 2011, which are classified into two categories. A total of 14 beamlines were operational in 2011, classified into two categories. Nine are so-called "open beamlines," which are open to scientists of universities and research institutes belonging to the government, public organizations, private enterprises, and those of foreign countries. The remaining five beamlines are so-called "in-house beamlines," which are dedicated to the use of research groups within IMS.

The improvements and upgrades of the beamlines at UVSOR have been continuously discussed with users in a series of UVSOR workshops. The newly constructed (BL3U, BL7U, and BL6U) as well as upgraded (BL5U and BL6B) beamlines synchronized with the UVSOR-II Project have been routinely operated, and a number of outcomes have emerged through the utilization of these beamlines. We had one soft X-ray station equipped with a double-crystal monochromator, seven EUV and soft X-ray stations with a grazing incidence monochromator, three vacuum ultraviolet (VUV) stations with a normal incidence monochromator, and one infrared (IR) station equipped with Fourier-transform interferometers, as shown in the appended table (next page) for all available beamlines at UVSOR in 2011.

“Development and Application of Light Source Technology Based on Electron Storage Ring and Laser” proposed by the UVSOR Machine Group was accepted in 2008 as a research program in the Quantum Beam Technology Project conducted by the Japan Science and Technology Agency (JST) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT). In this connection, the straight section U1 will be used for generating coherent terahertz (THz) and VUV radiation, with two beamlines to be constructed there. As a consequence of this, BL1A and BL1B must be moved to vacant sites. Since spectroscopic research work on solids has been carried out very actively at these beamlines, it is essential that all of the users’ activities there be continued smoothly at their new locations. Based on the results of discussions at the users’ meetings, which were organized by the UVSOR User’s Union, it was decided that BL1A will be moved to the location of the previous BL2A without any changes to the beamline components, and that BL1B will be newly constructed at the site of the previous BL3B. For the monochromator at BL3B, a 2.5 m off-plane Eagle type has been chosen. The relocation and construction of the related beamlines, as well as the relocation of the Ti:Sa laser system for the Machine Group to the downstream site of BL8B, were successfully completed in 2011. Actual operation of the new BL3B for users was initiated in January 2012.

A supplementary budget for upgrading the UVSOR Facility, which had been originally submitted as one of the budget requests of NINS, was approved in the autumn of 2010. The supplementary budget includes the cost for constructing a new soft X-ray microscopy beamline at BL4U, where a short in-vacuum type undulator with a total length of about 1 m is available as a light source. The period length chosen for this undulator, U4, is 38 mm, which is the same value as that for U3. The spectral region from 60 eV to 800 eV will be covered by the first and higher harmonic radiation. In order to cover a wide photon energy region with one single grating, and to keep the monochromator throughput as high as possible, a variable-included-angle Monk-Gillieson mounting with an entrance slit-less configuration has been selected. A scanning transmission soft X-ray microscope (STXM) will be installed at the exit slit position of the new BL4U. A new assistant professor, who is in charge of the installation, commissioning, and maintenance of the STXM beamline, arrived in the summer of 2011. The installation of the beamline components including STXM will start during the shutdown term before the summer of 2012, and practical operation of BL4U is due to begin around the end of the year. The introduction of photoemission electron microscopy to a branch beamline of BL4U as well as upgrades of the undulator U5 and the SGM-TRAIN monochromator at BL5U are still at the planning stage. Further discussions will be continued toward formulating a basic plan for beamline construction with users.

All users are required to refer to the beamline manuals and the UVSOR guidebook (the latest revision in PDF format uploaded on the UVSOR website in June 2010), at the time of conducting actual experimental procedures. Those wishing to use the open and in-house beamlines are recommended to contact the relevant beamline master (see next page). For updated information on UVSOR, please see the following site: http://www.uvsor.ims.ac.jp

Eiji Shigemasa (UVSOR Facility)

Beamline List

Beamline	Monochromator/ Spectrometer	Energy Range	Targets	Techniques	Contact
BL1U*	Free electron laser	1.6-13.9 eV			M. Katoh mkatoh@ims.ac.jp
BL1B	Martin-Puplett FT-FIR	0.5-30 meV	Solids	Reflection Absorption	S. Kimura kimura@ims.ac.jp
BL2A	Double crystal	585 eV-4 keV	Solids	Reflection Absorption	N. Kondo nkondo@ims.ac.jp
BL2B*	18 m spherical grating (Dragon)	24-205 eV	Gases	Photoionization Photodissociation	H. Katayanagi kata@ims.ac.jp
BL3U*	Varied-line-spacing plane grating (Monk-Gillieson)	60-800 eV	Gases Liquids Solids	Absorption Photoemission Photon-emission	N. Kosugi kosugi@ims.ac.jp
BL3B	2.5 m off-plane Eagle	1.7-30 eV	Solids	Reflection Absorption	M. Hasumoto hasumoto@ims.ac.jp
BL4B*	Varied-line-spacing plane grating (Monk-Gillieson)	25 eV-1 keV	Gases Solids	Photoionization Photodissociation Photoemission	E. Shigemasa sigemasa@ims.ac.jp
BL5U	Spherical grating (SGM-TRAIN†)	5-250 eV	Solids	Photoemission	M. Sakai sakai@ims.ac.jp
BL5B	Plane grating	6-600 eV	Solids	Calibration Absorption	M. Hasumoto hasumoto@ims.ac.jp
BL6U*	Variable-included-angle varied-line-spacing plane grating	30-500 eV	Gases Solids	Photoionization Photodissociation Photoemission	E. Shigemasa sigemasa@ims.ac.jp
BL6B	Michelson FT-IR	3 meV-2.5 eV	Solids	Reflection Absorption	S. Kimura kimura@ims.ac.jp
BL7U	10 m normal incidence (modified Wadsworth)	6-40 eV	Solids	Photoemission	M. Matsunami matunami@ims.ac.jp
BL7B	3 m normal incidence	1.2-25 eV	Solids	Reflection Absorption	M. Hasumoto hasumoto@ims.ac.jp
BL8B	Plane grating	1.9-150 eV	Solids	Photoemission	S. Kimura kimura@ims.ac.jp

BL4U is under construction.
Yellow columns represent undulator beamlines.
* In-house beamline.
† Spherical grating monochromator with translating and rotating assembly including normal incidence mount.

BL1U

Free Electron Laser

The free electron laser (FEL) at UVSOR-II is being moved to a dedicated long straight section (S1). The FEL is equipped with a variably polarized optical klystron of 3 m in length and an optical cavity of 13.3 m in length. By using various multilayer mirrors for the cavity, the FEL can provide coherent light in a wide wavelength range from 800 nm to 199 nm. The pulse duration is typically several tens of picoseconds. The repetition rate is approximately 11 MHz. The average output power depends on the wavelength but its typical value is several hundred milliwatts. Output power higher than 1 W was recorded at 230 nm and 570 nm. The FEL can be operated in top-up injection mode. Users can use the FEL for several hours with quasi-constant output power. The laser pulses are naturally synchronized with the synchrotron radiation pulses that are provided at other synchrotron radiation beamlines. The laser beam can be transported to the beamlines using a mirror system for pump and probe experiments if requested.

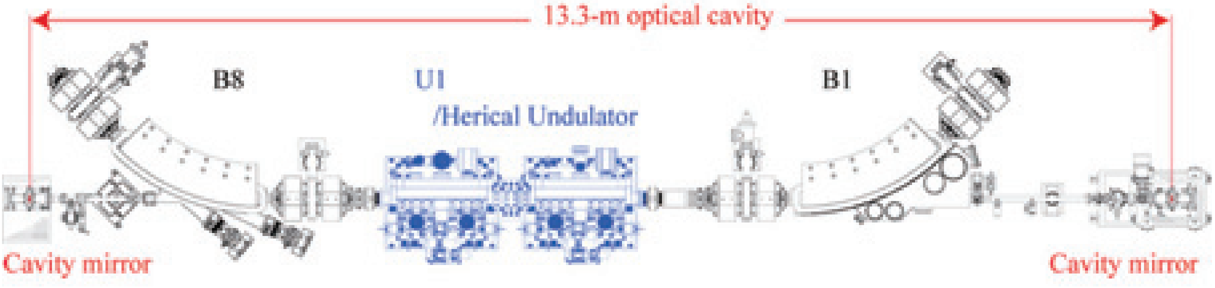


Fig. 1. Schematic of the 13.3 m-long optical cavity.

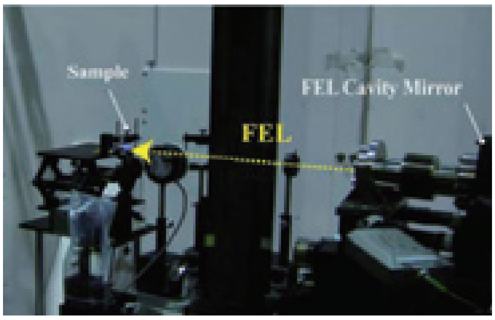


Fig. 2. Left and right circularly polarized FEL being delivered to B4 for an application experiment.

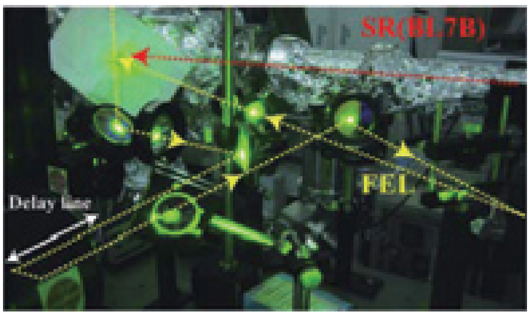


Fig. 3. The FEL is delivered to BL7B. The FEL is irradiated on a target simultaneously with the SR .

FEL Specifications

Wavelength	199-800 nm
Spectral band width	~10^{-4}
Polarization	Circular/linear
Pulse rate	11.26 MHz
Max. average power	~1 W
Cavity type	Fabry-Perot
Cavity length	13.3 m
Cavity mirror	HfO_2, Ta_2O_5, Al_2O_3 multilayer

BL1B

Terahertz Spectroscopy Using Coherent Synchrotron Radiation

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.

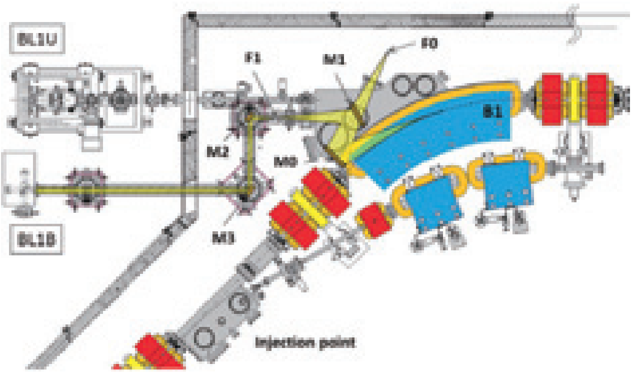


Fig. 1. Schematic top view of the beam extraction part of the THz-CSR beamline, BL1B. The three-dimensional magic mirror (3D-MM, M0) and a plane mirror (M1) are located in the bending-magnet chamber. A parabolic mirror (M2) is installed to form a parallel beam. The straight section (BL1U) is used for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

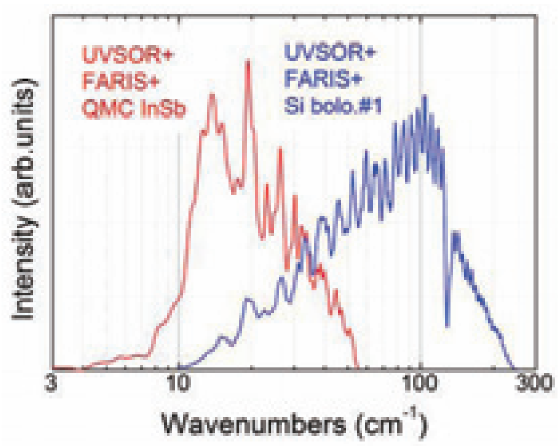


Fig. 2. Obtained intensity spectra with the combination of a light source (UVSOR), interferometer (FARIS-1), and detectors (Si bolometer and InSb hot-electron bolometer).

Beamline Specifications

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

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. There are no experimental setups that are specific to this beamline, except for 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.

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

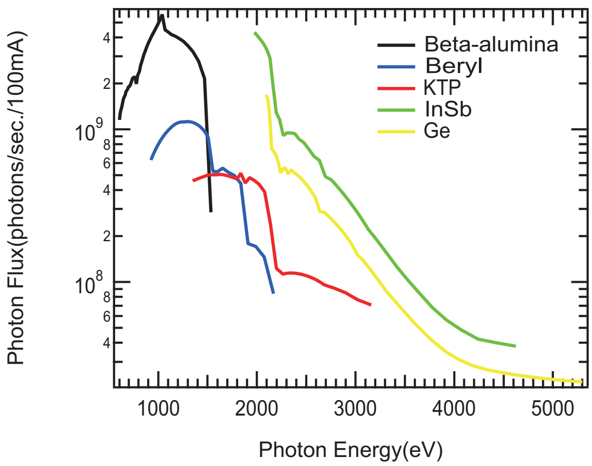


Fig. 1. Throughput spectra of the double-crystal monochromator at BL2A.

Fig. 2. Side view of BL2A.

Beamline Specifications

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

BL2B

Beamline for Gas Phase Photoionization and Reaction Dynamics

This beamline has been developed to study ionization, excitation, and decay dynamics involving inner-valence electrons, 2*p* electrons of the third row atoms, and 4d electrons of the lanthanides. 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.

We have been measuring the yield curves of various fullerene ions [3]. Geometrical structures and electronic properties of fullerenes have attracted widespread attention because of their novel structures, novel reactivity, and novel catalytic behaviors as typical nanometer-size materials. However, spectroscopic information was very limited in the extreme UV region, owing to difficulties in acquiring sufficient sample amounts. This situation has rapidly changed since the start of this century, because the techniques related to syntheses, isolation, and purification have advanced so rapidly that an appreciable amount of fullerenes can now be readily obtained.

[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.
[3] J. Kou, T. Mori, Y. Kubozono and K. Mitsuke, Phys. Chem. Chem. Phys. **7** (2005) 119.

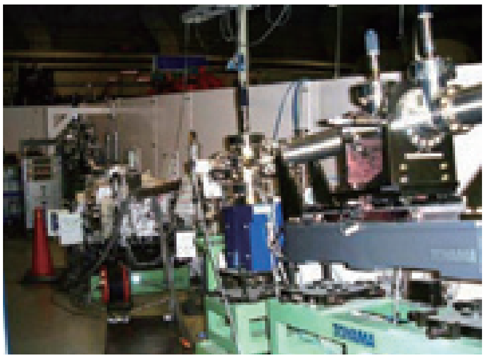


Fig. 1. 18 m spherical grating monochromator at BL2B.

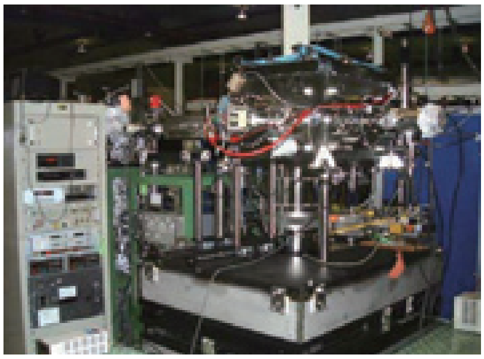


Fig. 2. End station of BL2B for gas phase spectroscopy of refractory materials.

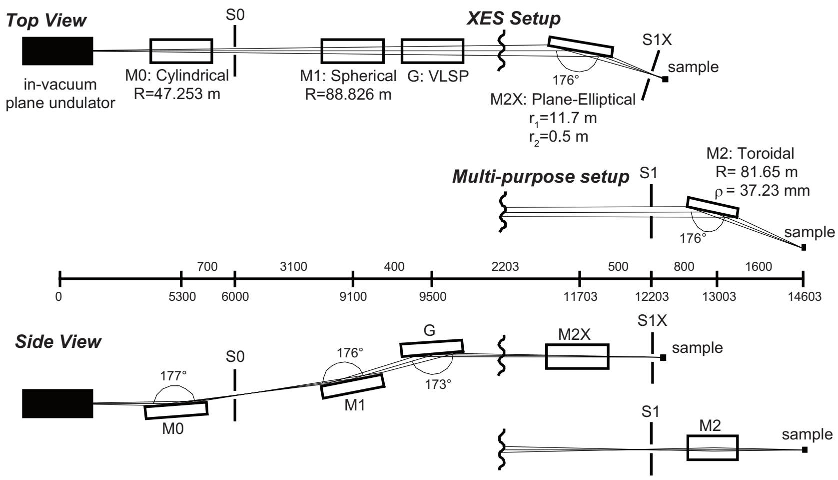
Beamline Specifications

Monochromator	18 m spherical grating Dragon-type
Wavelength Range	6-55 nm; 24-205 eV
Resolution	2000–8000 depending on the gratings
Experiments	Mass spectrom.; photoelectron spectrosc.; momentum imaging spectrosc.; e^--ion coincidence spectrosc.; fullerene beam source

BL3U

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

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 including soft X-ray emission studies. Three holographically ruled laminar profile plane gratings are designed to cover the photon energy range from 60 to 800 eV. The beamline has two endstations, namely, XES setup and multi-purpose setup. The XES setup is used for soft X-ray emission spectroscopy. The beam is horizontally focused onto the sample position by a plane-elliptical mirror, M2X. In the multi-purpose setup, the beam is focused by the toroidal mirror M2. Between the sample position and M2, the differential pumping is placed.



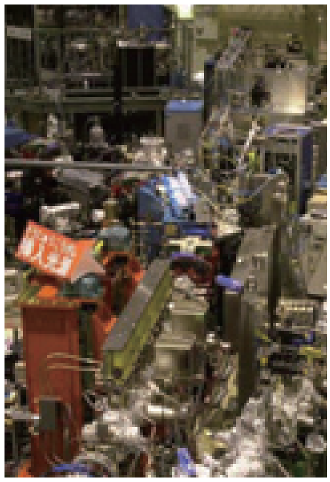


Fig. 1. Schematic layout (left) and the photography (right) of the BL3U. The distances along the beam from the center of the in-vacuum plane undulator are shown in millimeters. S1X and M2X can be replaced with the other exit slit S1 so that experiments can be carried out at either the XES or the multipurpose endstation. In the XES setup, the sample is placed 5–10 mm downstream of S1X.

Beamline Specifications

Monochromator	Varied-line-spacing plane grating monochromator
Energy Range	60-800 eV
Resolution	$E / \Delta E > 10\,000$
Experiments	Soft X-ray spectroscopy (XPS, XES, XAS)
Beam Size (XES Endstation)	Gaussian shape Vertical 5-20 μm; Horizontal 41 μm (FWHM)

BL3B (HOTRLU)

VIS-VUV Photoluminescence and Reflection/Absorption Spectroscopy

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 $E / \Delta E$ 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.

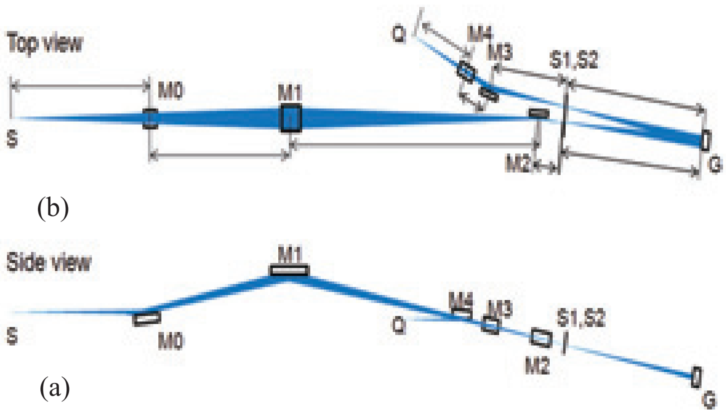


Fig. 1. Schematic layout of the BL3B (a) side view and (b) top view.

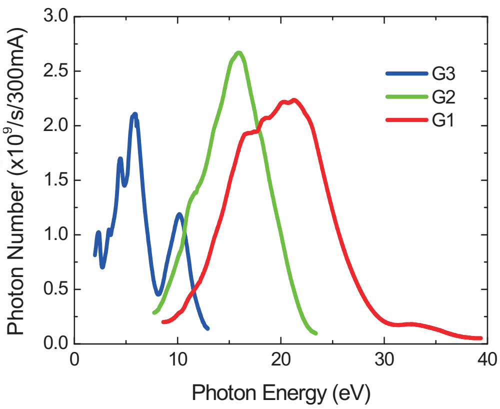


Fig. 2. Throughput spectra for each grating (G1:1200 l/mm, G2:600 l/mm and G3:300 l/mm) with S1 = S2 = 0.1 mm.

Beamline Specifications

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

BL4B

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

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. Fig. 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.

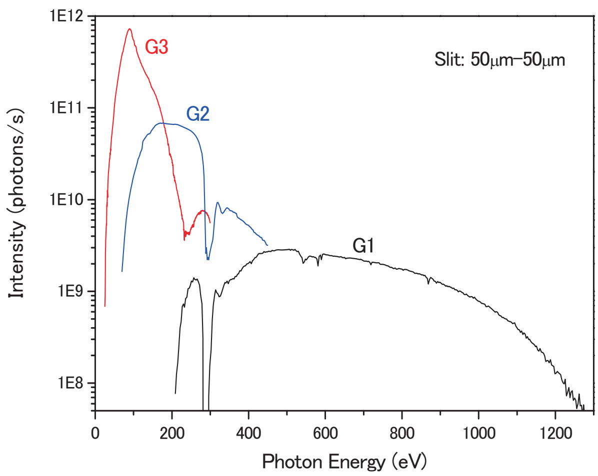


Fig. 1. Throughput from the VLS-PGM monochromator on BL4B.

Fig. 2. Photo of BL4B.

Beamline Specifications

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, angle-resolved photoion spectroscopy for gaseous targets and photoelectron spectroscopy for gaseous and solid targets)

BL5U

Photoemission Spectroscopy of Solids and Surfaces

This beamline is designed for high-resolution angle-resolved photoemission study of solids and surfaces with horizontal-linearly and circularly (CW, CCW) polarized synchrotron radiation from a helical undulator. The beamline consists of a Spherical Grating Monochromator with a Translational and Rotational Assembly Including a Normal incidence mount (SGM-TRAIN) and a high-resolution angle-resolved photoemission spectrometer.

The SGM-TRAIN is an improved version of a constant-length SGM that aims at realizing the following points: (1) covering the wide energy range of 5–250 eV, (2) high energy resolving power, (3) use of linearly and circularly polarized undulator light, (4) reduction of higher-order light, and (5) two driving modes (rotation and translation of gratings) by computer control. The second-order light is well suppressed using laminar profile gratings and combinations of mirrors and gratings.

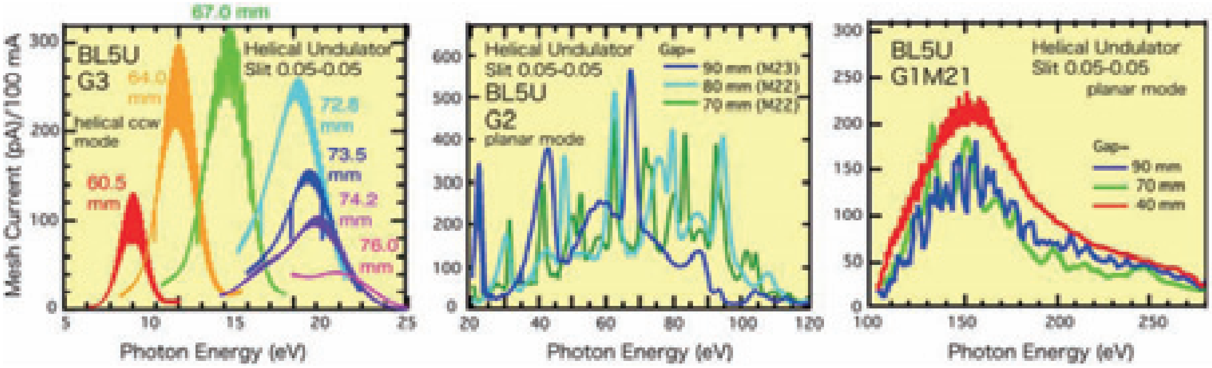


Fig. 1. Throughput spectra from the SGM-TRAIN monochromator at BL5U.

Beamline Specifications

Monochromator	SGM-TRAIN
Energy Range	5-250 eV
Resolution	$h\nu / \Delta E > 2{,}000$ for < 40 μm slits
Experiment	ARPES, AIPES, XAS
Flux	$<10^{11}$ photons/s for <40 μm slits (in the sample position)
Main Instruments	Hemispherical photoelectron analyzer (MBS-Toyama 'Peter' A-1), LEED of reverse type (OMICRON), Liq-He flow cryostat (5-400 K)

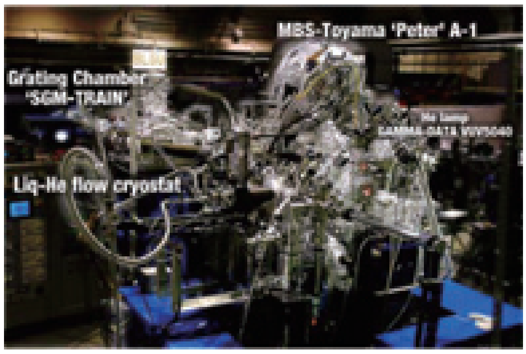


Fig. 2. High-resolution angle-resolved photoemission apparatus at BL5U.

BL5B

Calibration Apparatus for Optical Elements and Detectors

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).

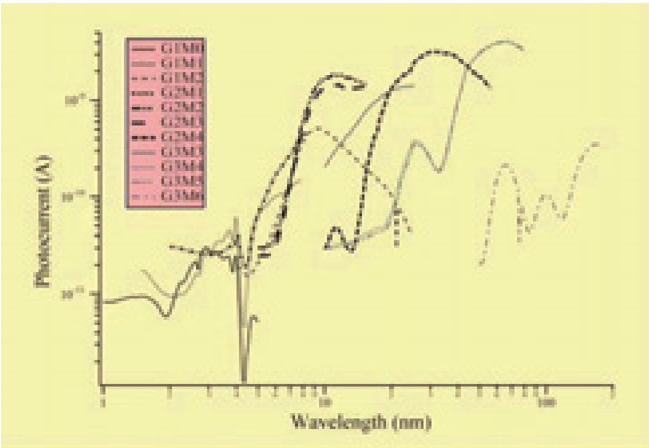


Fig. 1. Throughput spectra for possible combinations of gratings and mirrors at BL5B measured by a gold mesh.

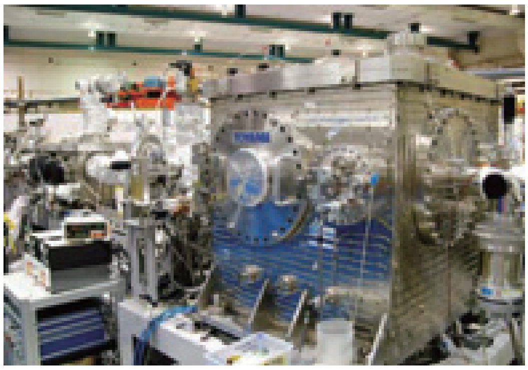


Fig. 2. A side view of the experimental chamber for calibration measurements.

Beamline Specifications

Monochromator	Plane Grating Monochromator
Energy range	6-600 eV (2-200 nm)
Resolution	$E / \Delta E$~500
Experiments	Calibration of optical elements, absorption of solids, photo-stimulated desorption from rare-gas solids

BL6U

Variable-Included-Angle VLS-PGM for Molecular Soft X-Ray Spectroscopy

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 in a gas phase and/or on solids. 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 30 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.

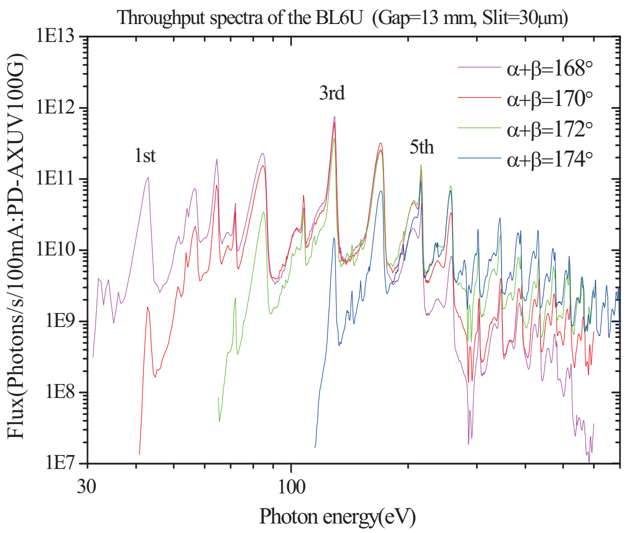


Fig. 1. Throughput spectra of the BL6U monochromator at various included angles.

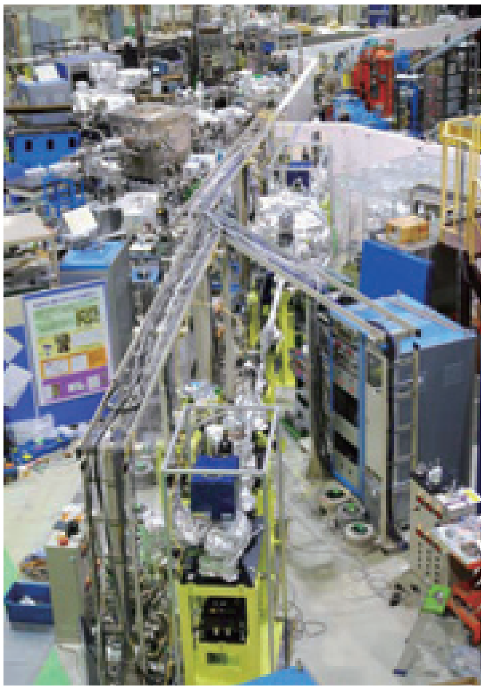


Fig. 2. Photo of BL6U

Beamline Specifications

Monochromator	Variable-included-angle Varied-line-spacing Plane Grating Monochromator
Energy range	40-500 eV
Resolution	$E / \Delta E > 10000$ (at maximum)
Experiments	High-resolution soft X-ray spectroscopy (mainly photoelectron spectroscopy for gaseous and solid targets)

BL6B

Infrared and Terahertz Spectroscopy of Solids

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 [1].

The beamline is equipped with a Michelson type (Bruker Vertex70v) interferometer to cover a wide spectral region from 30 to 20,000 cm^{-1} ($h\nu$ = 4 meV-2.5 eV), as shown in Fig. 2. There are two end-stations; one for reflection/absorption spectroscopy (RAS) of large samples (up to several mm) and the other for IR/THz microscopy (transmission microscopy: TM) of tiny samples (up to several tens of μm). At the RAS end-station, a liquid-helium-flow type cryostat with a minimum temperature of 10 K is installed. At the TM end-station, pressure- and temperature-dependent THz spectroscopy can be performed. A superconducting magnet with a maximum field of 6 T can be installed by the exchange with the TM end-station.

[1] S. Kimura, E. Nakamura, T. Nishi, Y. Sakurai, K. Hayashi, J. Yamazaki, M. Katoh, “Infrared and terahertz spectromicroscopy beam line BL6B(IR) at UVSOR-II,” Infrared Phys. Tech. **49** (2006) 147.

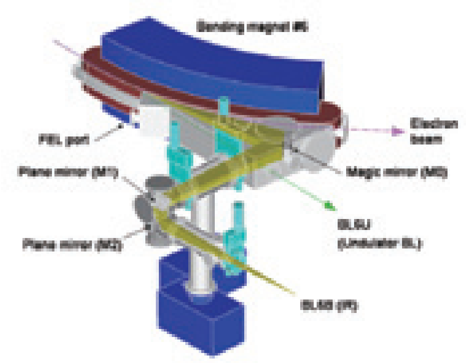


Fig. 1. Design of the optics and front end of BL6B.

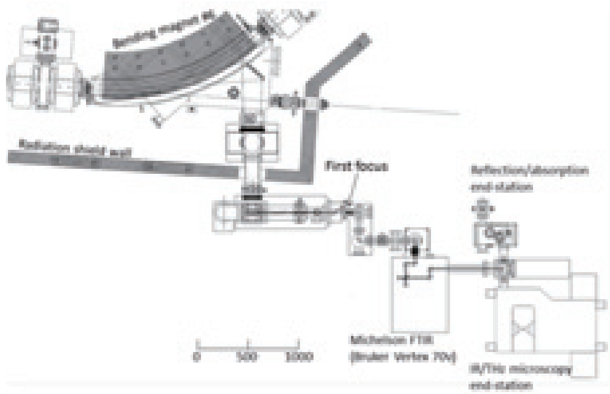


Fig. 2. Schematic top view of BL6B.

Beamline Specifications

Interferometer	Michelson (Bruker Vertex70v)
Wavenumber Range (Energy range)	30-20,000 cm^{-1} (4 meV-2.5 eV)
Resolution in cm^{-1}	0.1cm^{-1}
Experiments	Reflectivity and transmission Microspectroscopy Magneto-optics
Miscellaneous	Users can use their experimental system in this beamline.

BL7U (SAMRAI)

Angle-Resolved Photoemission of Solids in the VUV Region

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 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 (AVC Co., Ltd., i-GONIO). The main function of the beamline is to determine the three-dimensional Fermi surface and electronic structure of solids at low temperatures and their 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, K. Soda, "SAMRAI: A variably polarized angle-resolved photoemission beamline in the VUV region at UVSOR-II," Rev. Sci. Instrum. **81** (2010) 053104.

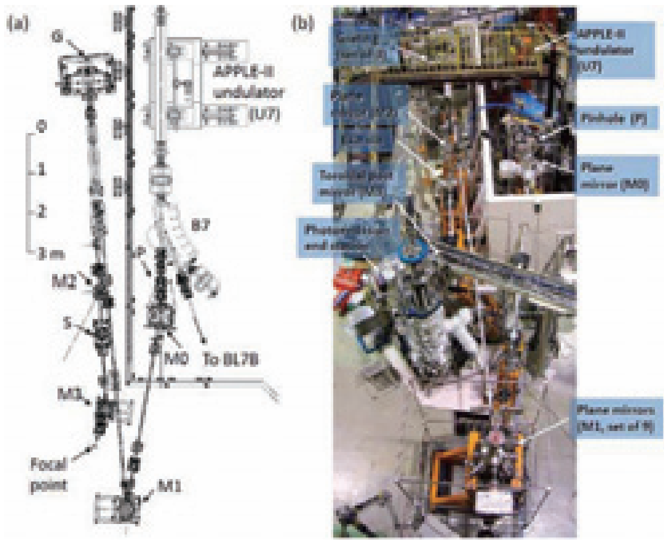


Fig. 1. Layout (a) and photograph (b) of the SAMRAI beamline consisting of an APPLE-II type undulator (U7), a modified Wadsworth type monochromator (M0-S), and a high-resolution photoemission analyzer at the focal point. The monochromator has five major optical components: two plane mirrors (M0 and M1) with water cooling, one set of three spherical gratings (G), an exit slit (S), and one toroidal refocusing mirror (M3). The spherical gratings have a radius of 10 m and are located 22 m from the center of the undulator. There is no entrance slit. S is located 6.47 m from G. A second branch for a VUV microscope end-station is planned to be constructed after the plane mirror (M2) located between G and S.

Beamline Specifications

Light source	APPLE-II type undulator (λ_u = 76 mm, N = 36) vertical/horizontal linear, right/left circular
Monochromator	10 m normal-incidence monochromator (modified Wadsworth type)
Photon energy range	6~40 eV (λ = 30~200 nm)
Resolution ($h\nu/\Delta h\nu$)	1×10^4-5×10^4
Photon flux on sample	≥ 10^{12}-10^{11} ph/s (depending on $h\nu$)
Beam size on sample	200 (H) × 50 (V) μm^2
Experiments	Angle-resolved photoemission of solids (MB Scientific A-1 analyzer, acceptance angle: ± 18 deg)

BL7B

3 m Normal-Incidence Monochromator for Solid-State Spectroscopy

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 40–1000 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. Fig.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.

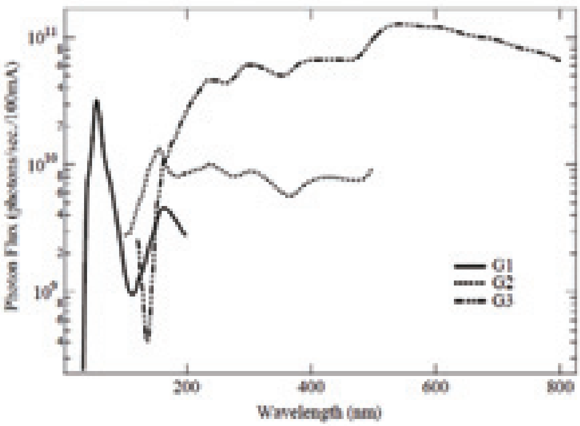


Fig. 1. Throughput spectra of BL7B measured using a silicon photodiode.

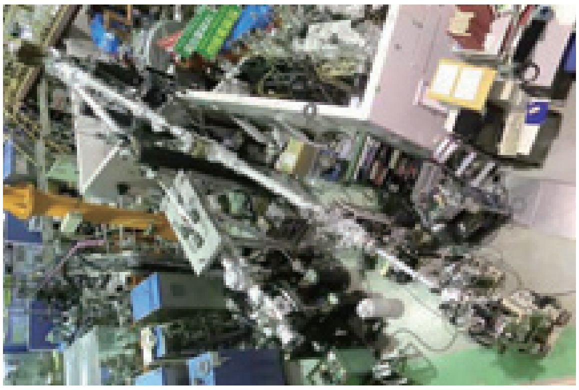


Fig. 2. Photo of BL7B.

Beamline Specifications

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

BL8B

Angle-Resolved Ultraviolet Photoelectron Spectrometer for Solids

BL8B is a beamline for the angle-resolved ultraviolet photoemission spectroscopy (ARUPS) system, which is designed to measure various organic solids such as molecular crystals, organic semiconductors, and conducting polymers. This beamline consists of a plane-grating monochromator (PGM), a sample preparation chamber with a fast-entry load-lock chamber, a measurement chamber (base pressure 1×10^{-10} Torr), a cleaning chamber (base pressure 1×10^{-10} Torr), and a sample evaporation chamber (base pressure 3×10^{-10} Torr). The cleaning chamber is equipped with a back-view LEED/AUGER, an ion gun for Ar^+ sputtering, and an infrared heating unit. The PGM consists of premirrors, a plane grating, focusing mirror, and a post-mirror, with an exit slit. It covers the wide range from 2 to 130 eV with two exchanging gratings (G1: 1200 l/mm, G2: 450 l/mm) and five cylindrical mirrors. The toroidal mirror focuses the divergent radiation onto the sample in the measurement chamber. The spot size of the zeroth-order visible light at the sample surface is approximately 1×1 mm^2. Figure 1 shows the throughput spectra of PGM (slit = 100 µm). The energy resolution at a slit width of 100 µm was found to be $E/\Delta E$ = 1000 in the wavelength range from 2 to 130 eV. A hemispherical electron energy analyzer of 75 mm mean radius with an angular resolution less than 2° can be rotated around the vertical and horizontal axes. The sample mounted on a manipulator (temperature range 14–320 K) can also be rotated around two axes.

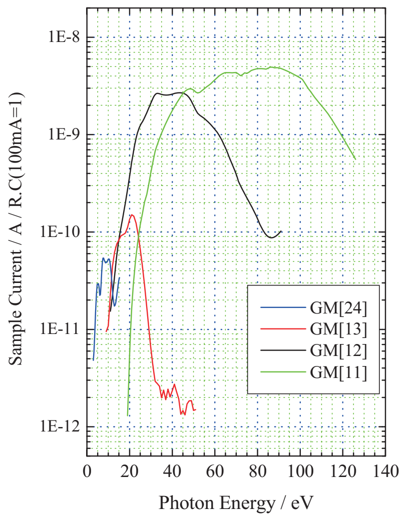


Fig. 1. Throughput spectra of plane-grating monochromator at BL8B (slit = 100 µm).

Fig. 2. A photo of BL8B.

Beamline Specifications

Monochromator	Plane-grating monochromator
Wavelength Range	9-600 nm
Resolution	$E / \Delta E$ = 1000
Experiments	Angle-resolved ultraviolet photoemission spectroscopy