Light Sources in 2010

1. Status of UVSOR Accelerators

In the fiscal year 2010, we operated the UVSOR-II accelerators from June ‘10 to March ’11. We had a total of 36 weeks of user operation, 34 weeks of which were in the multi-bunch mode, 1 week in the single-bunch mode, and 1 week in the single-bunch/multi-bunch hybrid mode, which was newly started this year. In the hybrid mode, we basically operate the machine in single-bunch mode during the daytime and multi-bunch mode in the nighttime. We had no week dedicated for machine studies this year, otherwise it was typically a few weeks a year. Because we had a long shutdown period in spring ’10, we gave up the study weeks this year to secure beam time for users as in a usual year. We had a three-month shutdown, starting in March ’10, for reconstruction work on the storage ring and the beam transport line. We had a one-week shutdown in September and a two-week one around New Years Day.

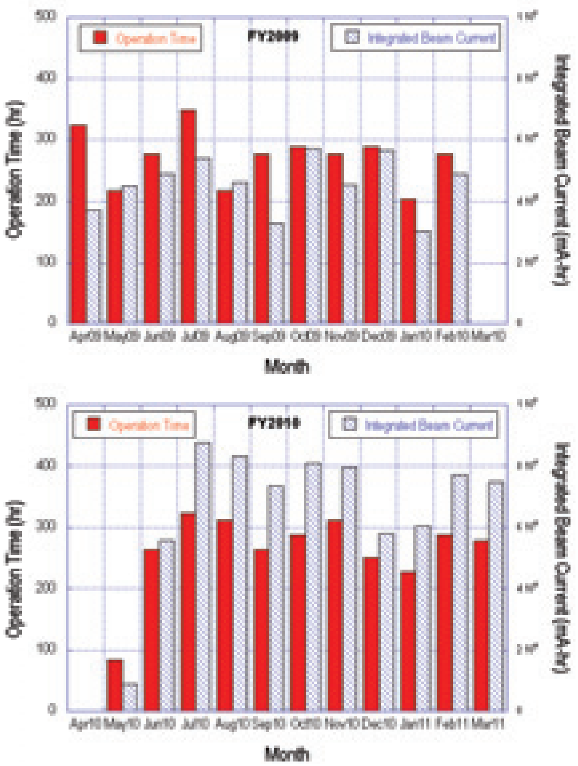


Fig. 1. Monthly statistics in FY2009 (upper) and FY2010 (lower) of the operation time (red bars) and of the integrated beam current (blue dashed bars).

The monthly statistics of the operation time and the integrated beam current are shown in Fig. 1. The operation time per month did not increase compared with last year, but the integrated beam current did. This is because of the start of the full top-up operation, as described later.

The weekly operation schedule is as follows. On Monday, from 9 am to 9 pm, the machine is operated for machine 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. Thus, the user beam time is 60 hours per week. This year, we have started operating the machine in the top-up mode 100% of the user time. The beam current is kept at 300 mA in the multi-bunch mode and 50 mA in the single-bunch mode.

This fiscal year, we had a few troubles regarding the pulse magnet power supplies for beam injection, which may be due to the increase in the operation time of the beam injection system caused by the start of the top-up operation. We had a few troubles with the klystron pulse modulator for the linear accelerator. One switching circuit had difficulties three times in a year. Thus, we are going to improve the circuit in 2011. Fortunately, in all cases, the beam time for users could be secured by extending the operation time.

2. Improvements

Top-up Operation

We introduced the top-up operation for 100% of the users beam time this year in both the multi-bunch mode and the single-bunch mode. Because the orbit movement during the injection is large, we deliver timing signals to the beam lines to stop the data acquisition during the injection if necessary.

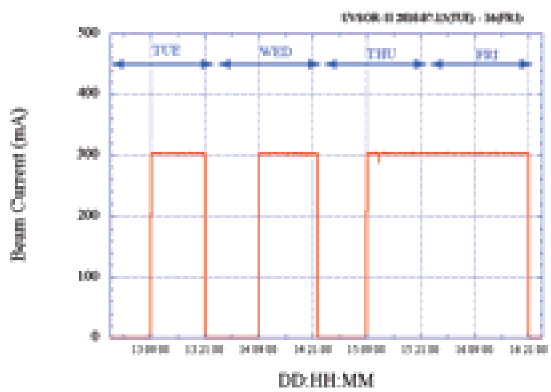


Fig. 2. Typical beam current history in users time from Tuesday to Friday.

Reconstruction of Beam Transport Line

In March 2010, we started the reconstruction of the beam transport line and the storage ring, aiming to produce a 4 m straight section in the ring for a new undulator. We moved the injection point to a short straight section from the 4 m straight section previously used for the injection. The main RF cavity that was installed in the short straight section was moved to another short straight section. The injection septum magnet and the kicker magnets were moved. The beam transport line was extended to the new injection point. All reconstruction works were completed in three months, as shown in Fig. 3. In May, the new beam transport line was successfully commissioned with the same injection efficiency as before.

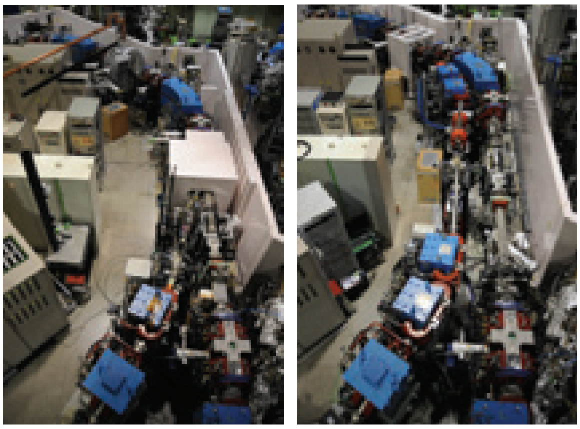


Fig. 3. Beam transport line and injection point of the UVSOR-II storage ring before (left) and after (right) the reconstruction.

Accelerator Technologies

Four undulators are operational at UVSOR-II. They produce various effects on the accelerator performance. One of the undulators, the APPLE-II type one for BL7U, has a significant effect on the beam life time and the injection efficiency. To suppress these effects, we have tested a novel correction method using current wires on the beam duct. By optimizing the electric current on the wires, we could recover the beam lifetime successfully [1]. This method will be introduced to the users beam time soon in the next fiscal year.

3. Research and Development

Coherent Terahertz Synchrotron Radiation

We have been developing technologies to produce coherent synchrotron radiation in the terahertz range by using laser slicing/modulation technologies. By using an external laser source, we can produce various kinds of microdensity structures on the electron bunches. They emit coherent synchrotron radiation in the terahertz range.

This year, we investigated the laser power dependence of the terahertz radiation. We found that the terahertz intensity is proportional to the square of the laser power in the relatively low power range [2].

Coherent Harmonic Generation

Coherent harmonic generation (CHG) is under investigation, aiming to develop a coherent VUV light source and to investigate the basic mechanism of the laser seeding in free electron lasers.

We have succeeded in observing the CHG up to the ninth harmonics in the wide range of the pulse energy of the seed laser. We observed that the CHG power was saturated in the high energy range and oscillates with the laser energy. This was explained by a micro-bunching process in the over-bunching regime [3].

Laser Compton Scattering Gamma-rays

The generation of gamma-rays based on the laser Compton scattering technique has been investigated. This technique is well established and is demonstrated in many accelerator facilities. Usually, the laser and the electron beam collide in a head-on configuration. In contrast, we injected the laser beam into the electron beam in the vertical direction to their orbital plane. With this 90-degree configuration, we have succeeded in producing ultra-short gamma-ray pulses. In addition, we have succeeded in changing the gamma-ray energy continuously by changing the colliding angle around 90 degrees [4].

[1] Y. Kikuchi *et al*., in this report
[2] M. Hosaka *et al*, in this report
[3] T. Tanikawa *et al*., in this report
[4] Y. Taira *et al*., in this report

Masahiro KATOH (UVSOR Facility)

UVSOR Accelerator Complex

Injection Linear Accelerator

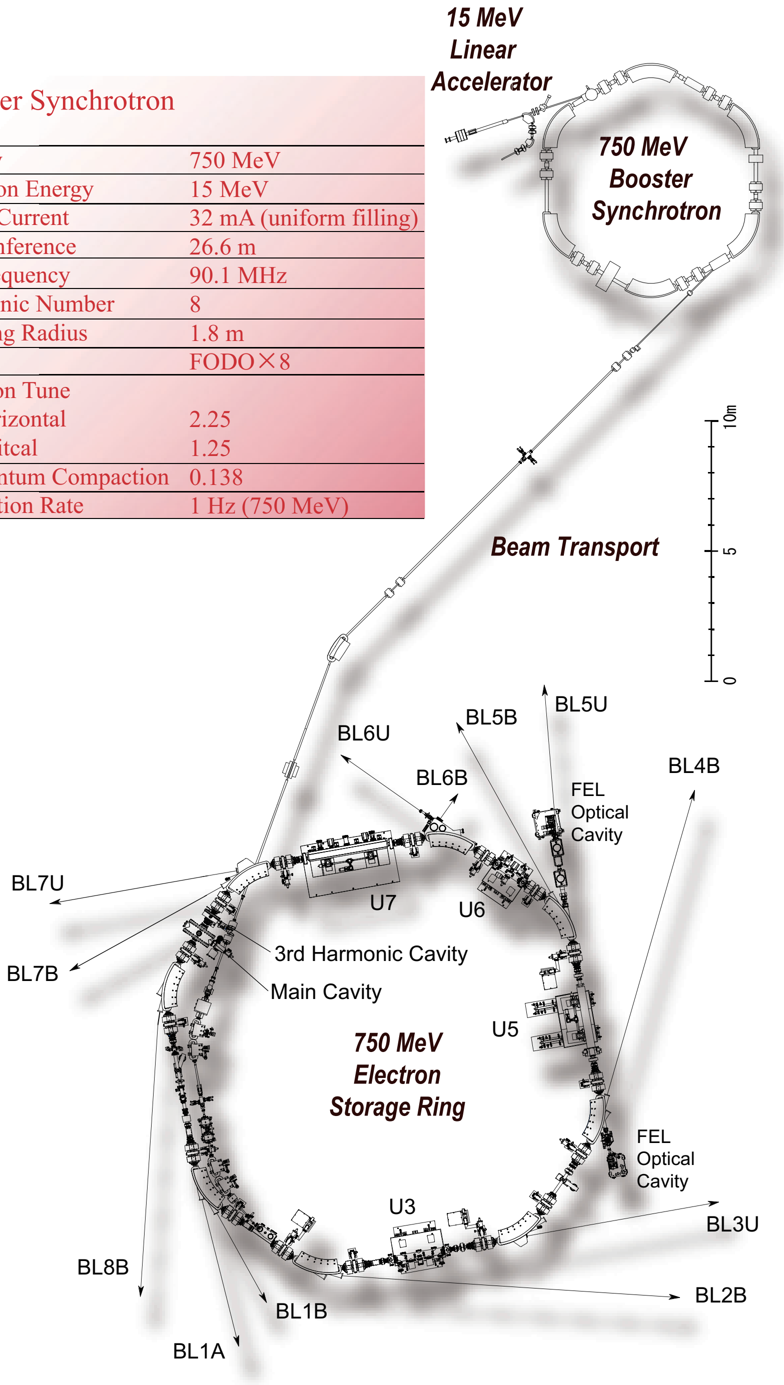
DC Gun	
Electron Source	EIMAC Y-646B
Applied Voltage	75 kV
Accelerator Tube	
Length	2.5 m
Frequency	2856 MHz
Structure	$2\pi/3$ Traveling Wave
Repetition Rate	2.6 Hz
Beam Energy	~15 MeV
Electron Beam Macro-pulse Duration	
Short Pulse Mode	~5 ns
Long Pulse Mode	~1.5 μs
Beam Charge	
Short Pulse Mode	0.8 nC/Macro-pulse
Long Pulse Mode	130 nC/Macro-pulse

Booster Synchrotron

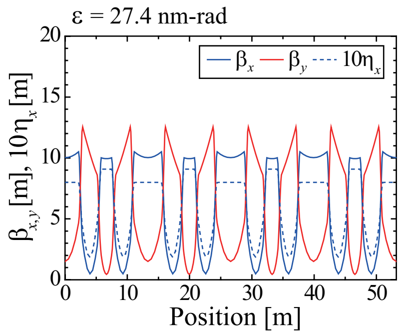
Energy	750 MeV
Injection Energy	15 MeV
Beam Current	32 mA (uniform filling)
Circumference	26.6 m
RF Frequency	90.1 MHz
Harmonic Number	8
Bending Radius	1.8 m
Lattice	FODO×8
Betatron Tune	
Horizontal	2.25
Veritcal	1.25
Momentum Compaction	0.138
Repetition Rate	1 Hz (750 MeV)

UVSOR-II Storage Ring

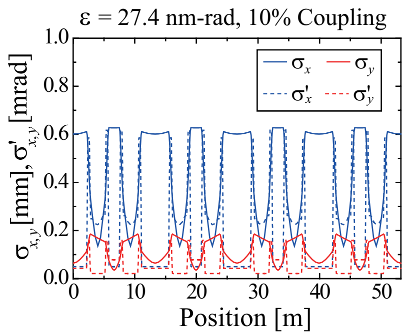
Energy	750 MeV
Injection Energy	750 MeV
Maximum Stored Current	500 mA (multi bunch) 100 mA (single bunch)
Normal Stored Current (Top-up operation)	300 mA (multi bunch) 50 mA (single bunch)
Natural Emittance	27.4 nm-rad
Circumference	53.2 m
RF Frequency	90.1 MHz
Harmonic Number	16
Bending Radius	2.2 m
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



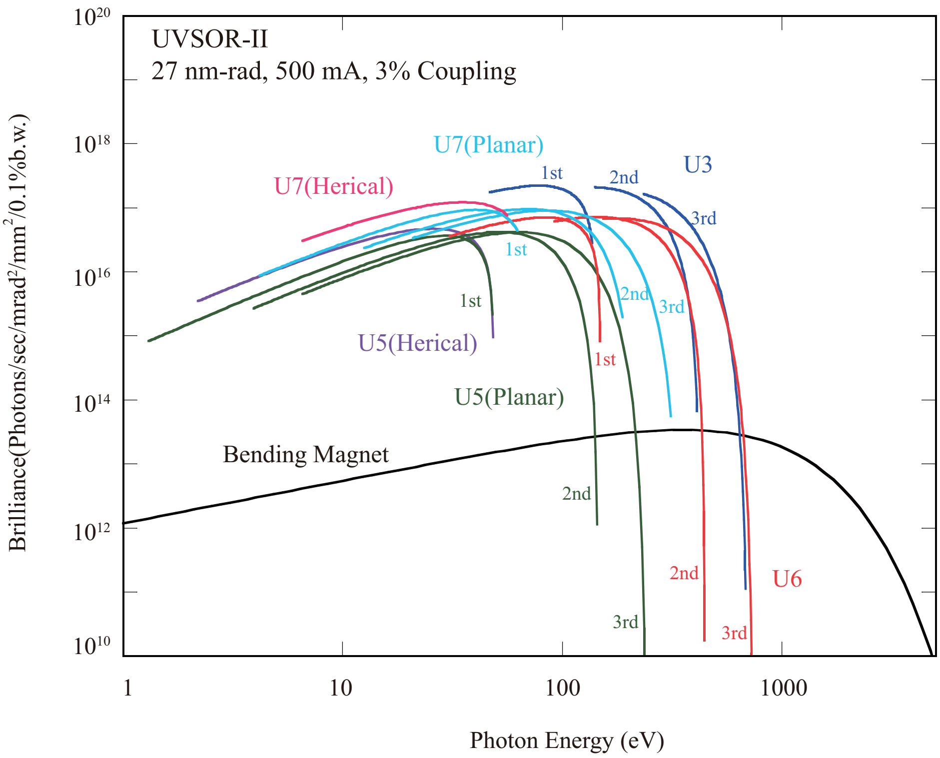
Horizontal / vertical betatron functions and dispersion function



Horizontal / vertical electron beam 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 2010

Eiji SHIGEMASA
UVSOR Facility, Institute for Molecular Science

Following the successful realization of the upgrade project on the UVSOR storage ring (UVSOR-II project), in which the creation of four new straight sections and the achievement of much smaller emittance (27 nm-rad) were planned, the UVSOR facility has become one of the highest brilliance extreme-ultraviolet radiation sources among synchrotron radiation facilities with electron energy of less than 1 GeV. Eight bending magnets and four insertion devices are available for utilizing synchrotron radiation at UVSOR. There has been a total of 12 operational beamlines in 2010, which have been classified into two categories. Nine of them 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 other three beamlines are the so-called "In-house beamlines," and are dedicated to the use by 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 the 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. The experimental activities conducted at BL4A and BL8B1 were terminated in August 2009 and in February 2010, respectively. As a consequence, we have one soft X-ray station equipped with a double-crystal monochromator, seven extreme ultraviolet and soft X-ray stations with a grazing incidence monochromator, three vacuum ultraviolet 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 2010.

"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 Program" conducted by MEXT/JST. In connection, the straight section S1 will be used for generating coherent THz and VUV radiation, where two beamlines will be constructed. In response, BL1A and BL1B must be moved to vacant lots. Because spectroscopic research works on solids have been conducted very actively at these beamlines, it is essential that all users' activities there should segue at new locations. Based upon the result of the discussion 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 on the beamline components, and BL1B will be newly constructed at the place of the previous BL3B, where the Ti:Sa laser system for the machine group occupies. For the monochromator at BL3B, a 2.5-m off-plane Eagle type has been chosen. The practical movement and construction of the related beamlines have just started in the spring of 2011.

A supplementary budget for upgrading the UVSOR facility was approved in the autumn of 2010; it had originally been submitted as one of the estimate budget requests of the National Institutes for Natural Sciences. The supplementary budget includes the cost for constructing a new soft X-ray microscopy beamline at BL4U, where a short undulator with a length of approximately 1 m is available as a light source. The period length chosen for this undulator, U4, is 38 mm, which is the same as that for U3. The spectral region from 60 to 800 eV will be covered with the first and higher harmonic radiation. We have decided to choose the entrance slit-less configuration for the monochromator to keep the monochromator throughput as high as possible, as a result of the successful installations of such a configuration to BL7U and BL6U. In order to cover such a wide photon energy region with one single grating, a variable-included-angle Monk–Gillieson mounting 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 scientist with the design, installation, commissioning, and maintenance of this STXM beamline is now in the selection process. The introduction of photoemission electron microscopy to a branch beamline of BL4U as well as the upgrades of the undulator U5 and the SGM-TRAIN monochromator at BL5U are in the planning stage. Further discussion toward formulating a basic plan on the beamline construction with users will be carried out.

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 page in the summer of 2009), when conducting the actual experimental procedures. Those wishing to use the open and in-house beamlines are recommended to contact the respective beamline master (see next page). For updated information on UVSOR, see http://www.uvsor.ims.ac.jp/.

Beamlines at UVSOR

Beamline	Monochromator / Spectrometer	Energy Range	Targets	Techniques	Contact
BL1A*	Double crystal	600 eV - 4 keV	Solid	Absorption	N. Kondo nkondo@ims.ac.jp
BL1B†	1-m Seya-Namioka	2 - 30 eV	Solid	Reflection Absorption	M. Hasumoto hasumoto@ims.ac.jp
BL2B‡	18-m spherical grating (Dragon)	24 - 205 eV	Gas	Photoionization Photodissociation	K. Mitsuke mitsuke@ims.ac.jp
BL3U‡	Varied-line-spacing plane grating (Monk-Gillieson)	60 - 800 eV	Gas Liquid Solid	Absorption Photoemission Photon-emission	N. Kosugi kosugi@ims.ac.jp
BL4B‡	Varied-line-spacing plane grating (Monk-Gillieson)	25 eV - 1 keV	Gas Solid	Photoionization Photodissociation Photoemission	E. Shigemasa sigemasa@ims.ac.jp
BL5U	Spherical grating (SGM-TRAIN§)	5 - 250 eV	Solid	Photoemission	M. Sakai sakai@ims.ac.jp
BL5B	Plane grating	6 - 600 eV	Solid	Calibration Absorption	M. Hasumoto hasumoto@ims.ac.jp
BL6U‡	Variable-included-angle varied-line-spacing plane grating	30 - 500 eV	Gas Solid	Photoionization Photodissociation Photoemission	E. Shigemasa sigemasa@ims.ac.jp
BL6B	Martin-Puplett FT-FIR, Michelson FT-IR	0.6 meV - 2.5 eV	Solid	Reflection Absorption	S. Kimura kimura@ims.ac.jp
BL7U	10-m normal incidence (modified Wadsworth)	6 - 40 eV	Solid	Photoemission	M. Matsunami matunami@ims.ac.jp
BL7B	3-m normal incidence	1.2 - 25 eV	Solid	Reflection Absorption	M. Hasumoto hasumoto@ims.ac.jp
BL8B	Plane grating	1.9 - 150 eV	Solid	Photoemission	T. Nishi tnishi@ims.ac.jp
FEL	Free electron laser	1.6 - 6.2 eV			M. Katoh mkatoh@ims.ac.jp
CSR	Coherent synchrotron radiation	0.5 - 5 meV			M. Katoh mkatoh@ims.ac.jp

Yellow area: undulator beamline
* This beamline will be moved to BL2A after June 2011.
† This beamline will be moved to BL3B after June 2011.
‡ In-house beamline
§ Spherical grating monochromator with translating and rotating assembly including normal incidence mount

BL1A

Soft X-Ray Beamline for Photoabsorption Spectroscopy

BL1A 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 kinds 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 ($E/\Delta E$) 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 a total electron yield mode, with the use of the EM detector.

This beamline will be moved to BL2A after June 2011.

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

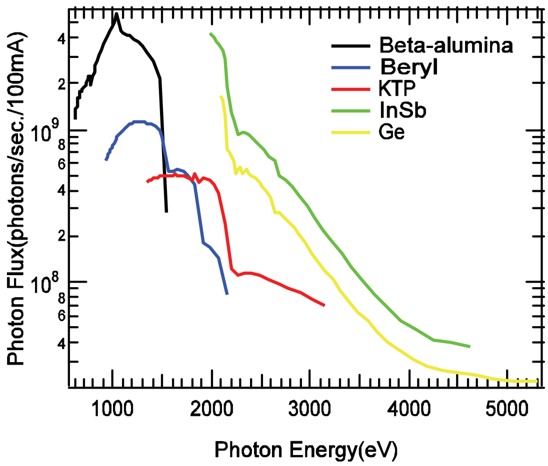


Fig. 1. Throughput spectra of the double crystal monochromator at BL1A.

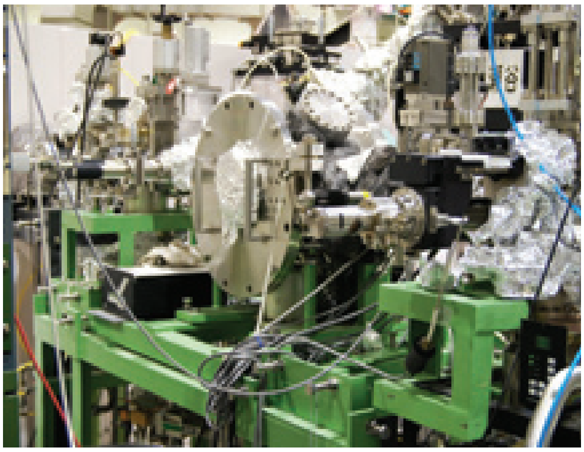


Fig. 2. Side view of BL1A.

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

BL1B

Seya-Namioka Monochromator for General Purposes

BL1B has been constructed to perform various spectroscopic investigations, such as absorption, reflectivity, and luminescence in condensed matters. This beamline consists of a pre-focusing mirror, a 1-m Seya-Namioka-type monochromator, and post-focusing mirrors with different focal lengths. Three gratings of 600, 1200, and 2400 l/mm can cover the wavelength region ranging from 40 to 650 nm ($h\nu$ = 2–30 eV). The post mirror with a longer focal length is usually used with an LiF window to separate the vacuum condition of the monochromator from the main experimental station, which make experiments for liquids and bio-specimens possible; the other is mainly utilized for solid-state spectroscopy. The output flux from this monochromator is approximately 1010 photons/s around 200 nm with 0.1 mm slit openings. The spectral distributions for two gratings measured using a conventional photomultiplier are shown in Fig. 1. A second monochromator (Spex 270M) and a LN-cooled charge-coupled device (CCD) detector (Princeton Inc.) are available for luminescence measurements, together with a liquid helium-flow-type cryostat. To perform time-resolved experiments, a TAC system is also available.

This beamline will be moved to BL3B after June 2011.

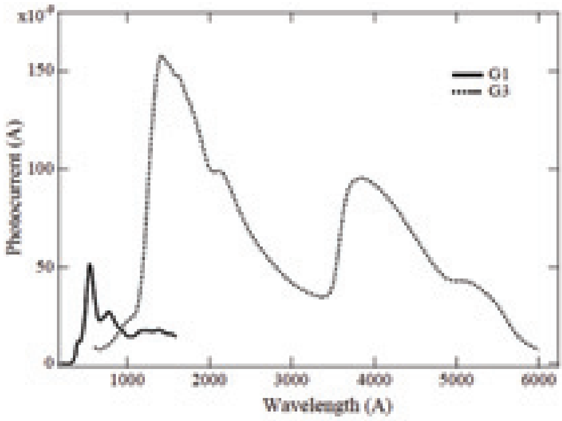


Fig. 1. Photocurrent at the sample position at BL1B.

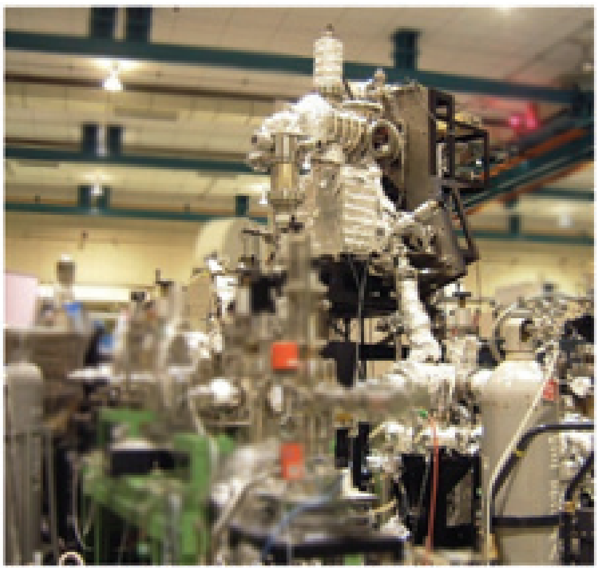


Fig. 2. Photo of BL1B.

Beamline Specifications

Monochromator	1-m Seya-Namioka type
Wavelength Range	40 to 600 nm (2–30 eV)
Resolution	$E/\Delta E$~1000 at 100 nm (10 eV)
Experiments	Absorption, reflection, and luminescence spectroscopy for solids

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.

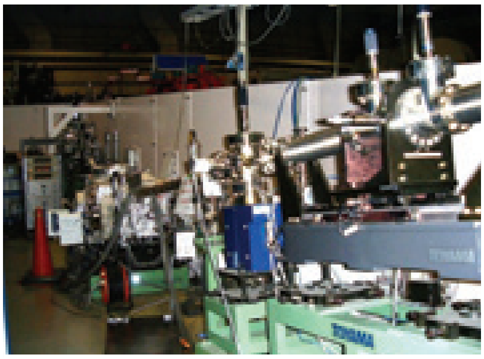


Fig. 1. 18-m spherical grating monochromator at BL2B.

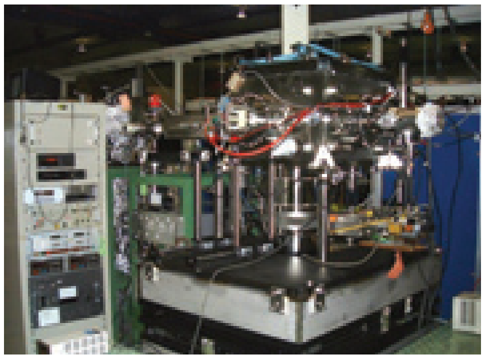


Fig. 2. End station of BL2B for gas phase spectroscopy of refractory materials.

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.

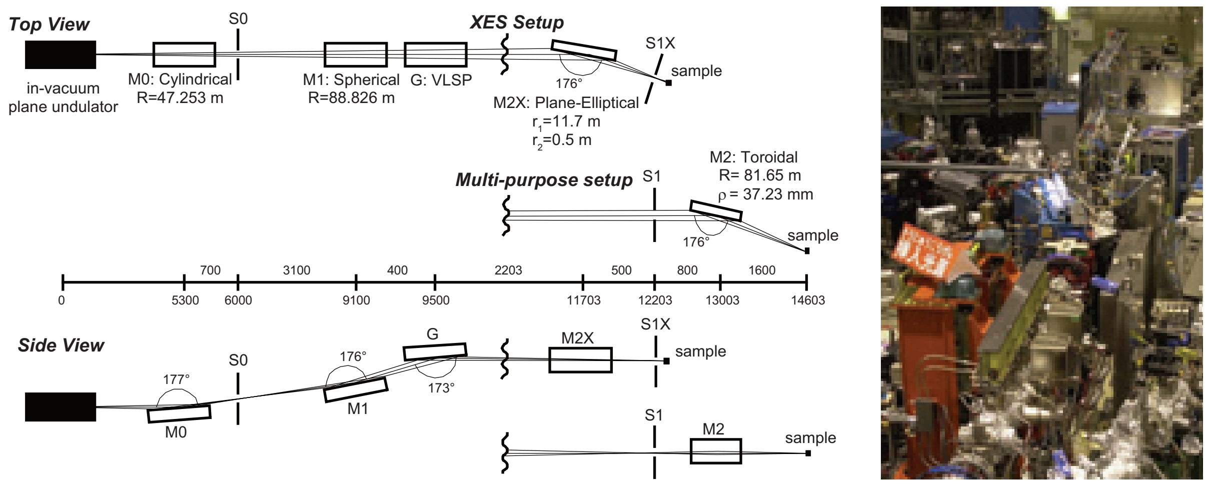


Fig. 1. Schematic layout (left) and the photography (right) of the BL3U. The distances along the beam from the center of the in-vacuum plane undulator are shown in millimeters. S1X and M2X can be replaced with the other exit slit S1 so that experiments can be carried out at either the XES or the multipurpose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

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.

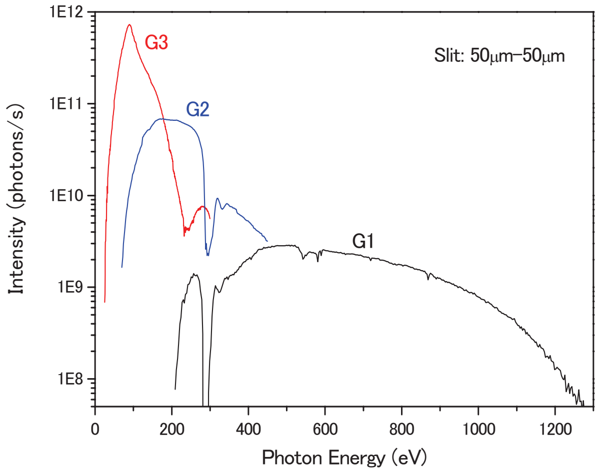


Fig. 1. Throughput from the VLS-PGM monochromator on BL4B.

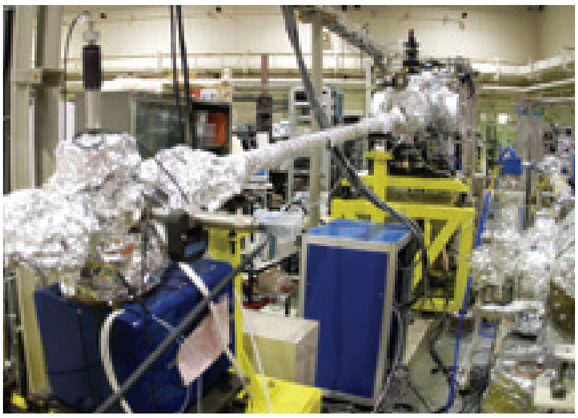


Fig. 2. Photo of BL4B.

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.

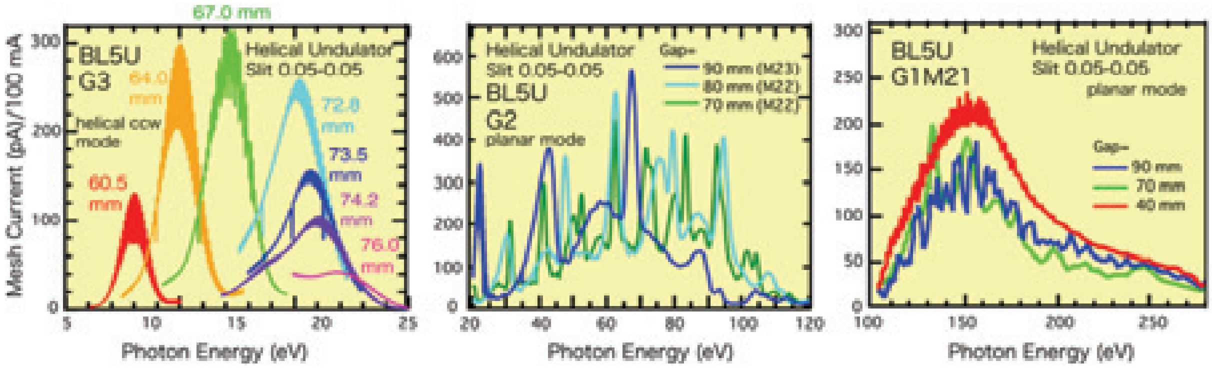


Fig. 1. Throughput spectra from the SGM-TRAIN monochromator at BL5U.

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)

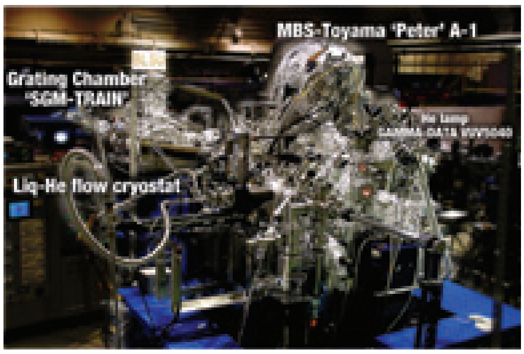


Fig. 2. High-resolution angle-resolved photoemission apparatus at BL5U.

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).

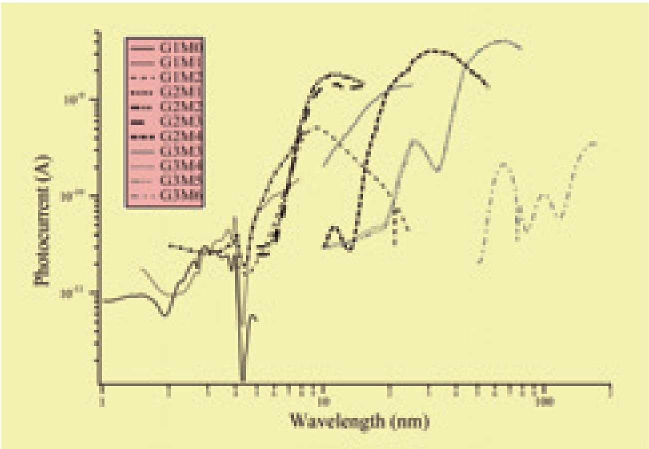


Fig. 1. Throughput spectra for possible combinations of gratings and mirrors at BL5B measured by a gold mesh.

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	$E/\Delta E \sim 500$
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.

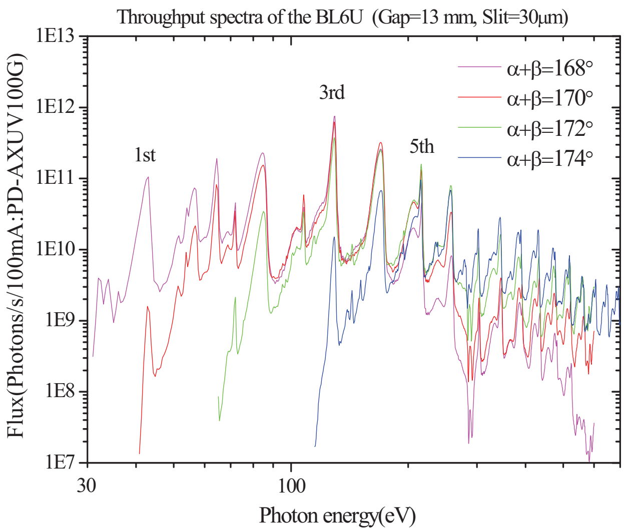


Fig. 1. Throughput spectra of the BL6U monochromator at various included angles.

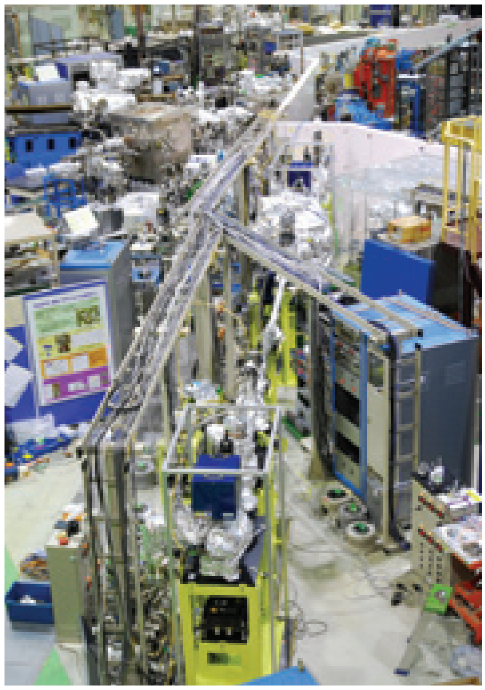


Fig. 2. Photo of BL6U

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 (IR)

Infrared and Terahertz Spectroscopy of Solids

SR has good performance (high brilliance and high flux) not only in the VUV and SX regions but also in the infrared (IR) and terahertz (THz) regions. BL6B covers the IR and THz regions. The previous beamline BL6A1 that was constructed in 1985 was the pioneer of infrared SR research. The beamline was terminated at the end of FY2003 and a new IR/THz beamline, BL6B (IR), was constructed in FY2004. The front-end part, including the bending duct #6, was replaced with a new one with a higher acceptance angle (215 (H) × 80 (V) mrad^2) using a magic mirror, as shown in Fig. 1 [1]. The brilliance and photon flux at the sample were markedly improved.

The beamline is equipped with two interferometers, one is Michelson type (Bruker Vertex 70v) and the other is Martin–Puplett type (JASCO FARIS-1), which cover the wide spectral region from 5 to 30,000 cm^{-1} ($h\nu$ = 0.6 meV–3.7 eV), as shown in Fig. 2. There are two end-stations: one is reflection/absorption spectroscopy for large samples (several millimeters) and the other is IR/THz microscopy for tiny samples (several tens of micrometers).

[1] S. Kimura, E. Nakamura, T. Nishi, Y. Sakurai, K. Hayashi, J. Yamazaki and M. Katoh, Infrared Phys. Tech. **49** (2006) 147.

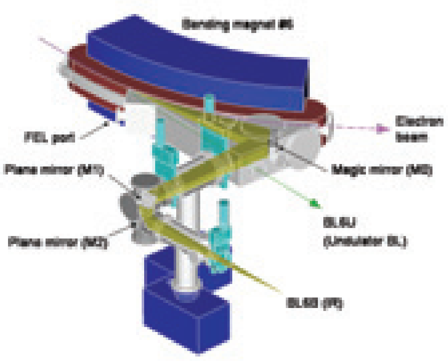


Fig. 1. The design of optics and front end of BL6B.

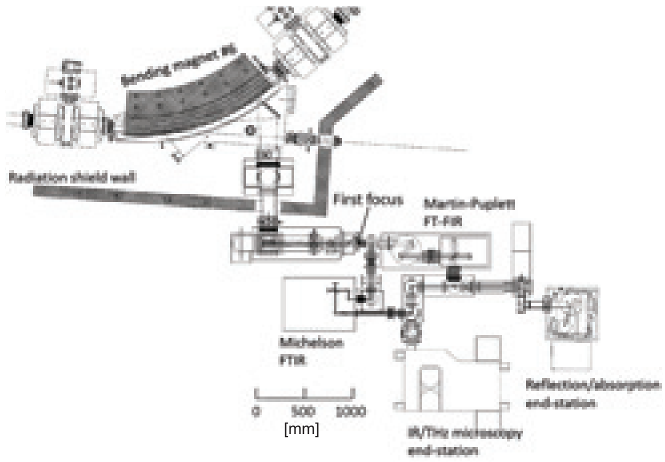


Fig. 2. Schematic figure of top view of BL6B.

Beamline Specifications

Interferometer	Michelson (Bruker Vertex 70v), Martin-Puplett (JASCO FARIS-1)
Wavenumber Range (Energy range)	5–30,000 cm^{-1} (0.6 meV–3.7 eV)
Resolution in cm^{-1}	0.1 cm^{-1} for Vertex 70v 0.25 cm^{-1} for FARIS-1
Experiments	Reflectivity and transmission, microspectroscopy, and magneto-optics
Miscellaneous	User can bring their experimental system in this beamline

BL7U (SAMRAI)

Angle-Resolved Photoemission of Solids in the VUV Region

The beamline BL7U, named Symmetry- And Momentum-Resolved electronic structure Analysis Instrument (SAMRAI) for functional materials, was constructed to provide photon flux with high energy resolution and high flux, mainly for the high-resolution angle-resolved photoemission spectroscopy of solids. An APPLE-II-type variable polarization undulator was equipped for the light source. The undulator can make high-intensity VUV light with horizontal/vertical linear and right/left circular polarization. The undulator light is monochromatized using a modified Wadsworth-type monochromator with three gratings (R = 10 m; 1200, 2400, and 3600 lines/mm optimized at $h\nu$ = 10, 20, and 33 eV). The energy resolution of light ($h\nu/\Delta h\nu$) is more than 10^4 with a photon flux of more than 10^{11} – 10^{12} ph/s on samples in the entire energy region.

The beamline has a photoemission end-station that equips 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 a 6-axes pulse motor control (A-VC Co. Ltd., i-GONIO). The main purpose 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 the physical properties.

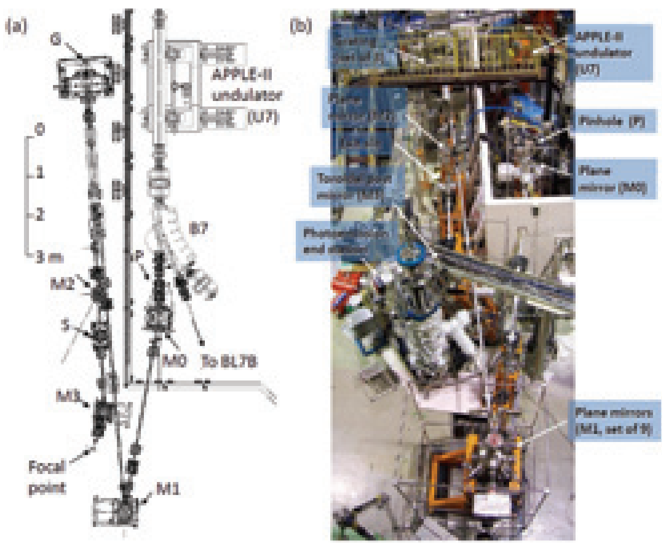


Fig. 1. Layout (a) and photograph (b) of the SAMRAI beamline consisting of the APPLE-II type undulator (U7), the modified Wadsworth-type monochromator (M0 – S), and the high-resolution photoemission analyzer at the focal point. The monochromator has five main optical components: two plane mirrors (M0 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 with a radius of 10 m 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)
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	$\geq 10^{12}$ – 10^{11} ph/s (depends on $h\nu$)
Beam size on sample	200 (H) × 50 (V) μm^2
Experiments	Angle-resolved photoemission of solids (MB Scientific A-1 analyzer)

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.

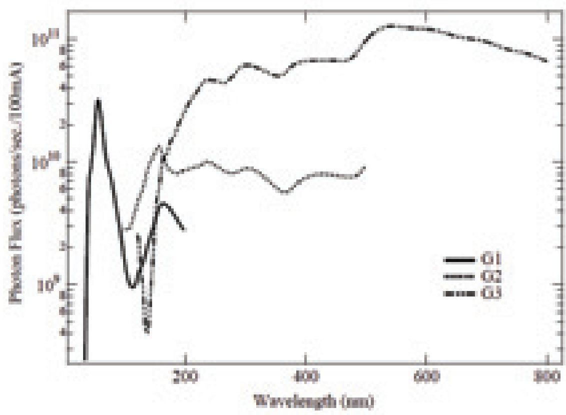


Fig. 1. Throughput spectra of BL7B measured using a silicon photodiode.

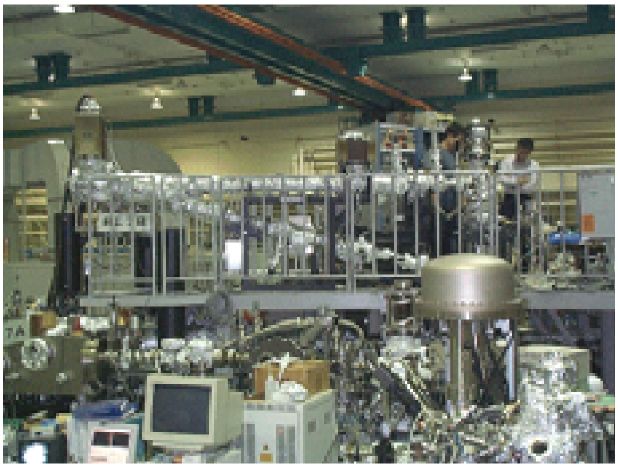


Fig. 2. Photo of BL7B.

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.

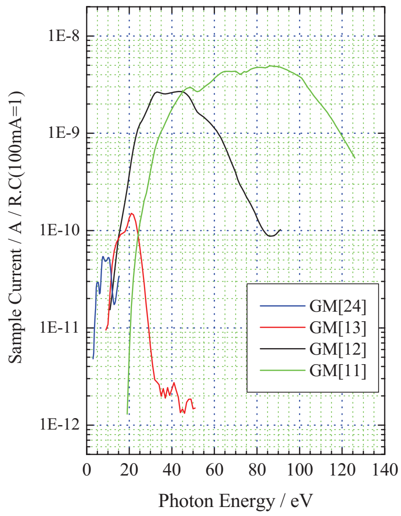


Fig. 1. Throughput spectra of plane-grating monochromator at BL8B2 (slit = 100 µm).

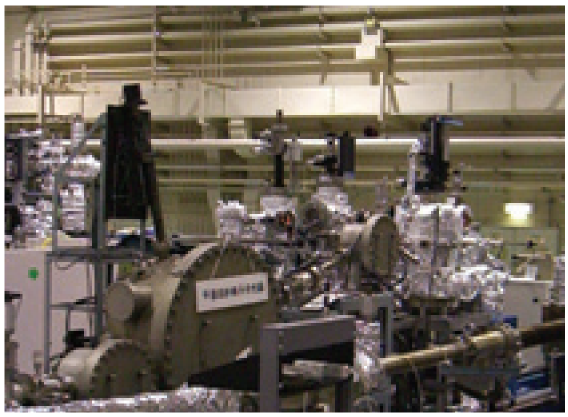


Fig. 2. A photo of BL8B2.

Beamline Specifications

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

FEL

Free Electron Laser

The free electron laser (FEL) at UVSOR-II is parasitically installed at BL5U. The FEL is equipped with a variably polarized optical klystron of 2.35 m in length and an optical cavity of 13.3 m in length. By using various multi-layer mirrors for the cavity, the FEL can provide coherent light in a wide wavelength range from 800 nm to 199 nm. The pulse width is typically several 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 1W was recorded at 230 nm and 570 nm. The FEL can be operated in a 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 beam-lines. The laser beam can be transported to the beam lines by using a mirror system for pump and probe experiments if requested.

The FEL system will be moved to a dedicated long straight section (S1) in fiscal year 2011.

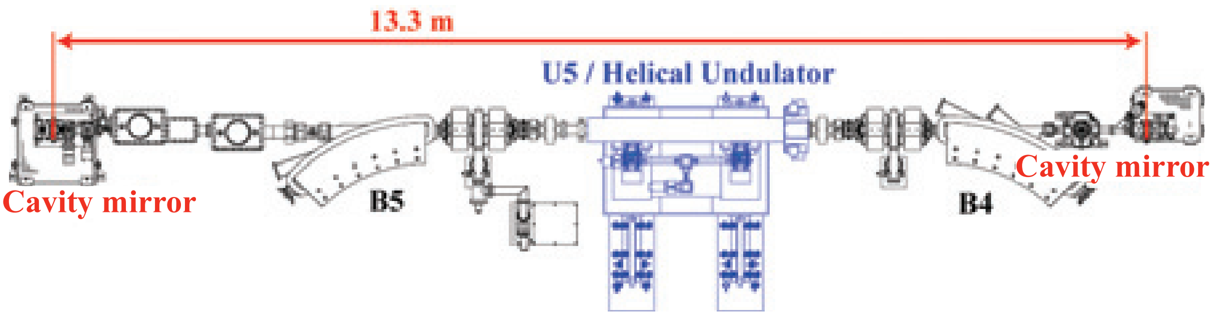


Fig. 1. The schematic of the 13.3-m-long optical cavity.

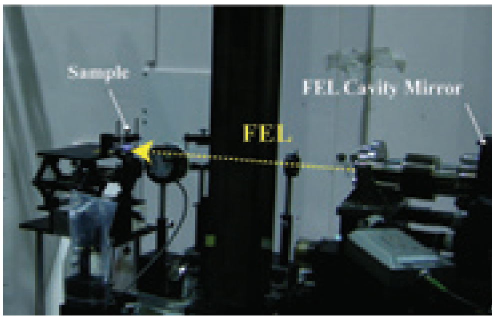


Fig. 2. Left and right circular-polarized FEL is delivered to B4.

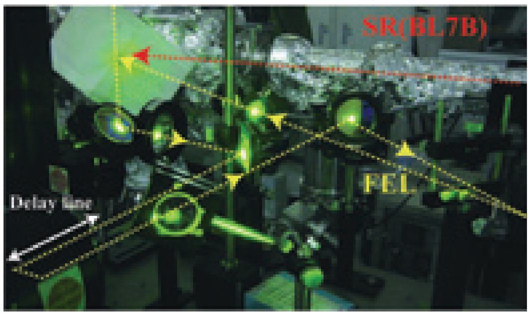


Fig. 3. The FEL is delivered to BL7B. The FEL is irradiated on a target simultaneously with the SR.

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 multi-layer