Light Sources in 2009

1. Status of UVSOR-II

In the fiscal year 2009, we have operated the UVSOR-II accelerators from April '09 to February '10. We had totally 37 weeks for the users operation, 35 weeks of which are in the multi-bunch mode, 2 weeks in the single-bunch mode. We had 6 weeks dedicated for machine studies. We have three month shut-down, starting from March '10 for a re-construction work on the storage ring and the beam transport line. We had 2 one week shut-down in May, August and September and 1 two week one around the New Years Day.

The monthly statistics of the operation time and the integrated beam current are shown in FIGURE 1. In these two years, the operation time per month has increased by approximately 20% on average. This is because of the extended operations for the top-up test runs as described later.

The weekly operation schedule is as follows. On Monday, from 0 am to 9 pm, the machine is operated for machine studies. From Tuesday to Friday, from 9am to 9pm, the machine is operated for users. The beam injection is made twice a day, at 9am and 3pm, with the filling beam current is 350 mA. On Thursday and Friday, the machine is operated in the top-up mode with the beam current, 300 mA. In 2009, we have been increasing the top-up operation time, step by step, as shown in FIGURE 2. In case of the single bunch mode, the machine is fully operated in the top-up mode with the beam current, 50 mA [1].

In this fiscal year, we had a few troubles on the injector. One is on the cooling water system of the linear accelerator. Others are on the pulse magnet power supplies. Fortunately, the users time could be secured by extending the operation time during the weeks.

2. Improvements

Top-up Operation

We have operated UVSOR-II in the top-up mode for users for one year and a half as shown in the previous section. So far, we have found several problems that have to be solved. The most serious one is the instantaneous orbit movement at injection. Some beam-lines are located inside of the injection bump. Thus, the effect is inevitable. However, even in the other beam-lines, they observe the effect because of the leakage of the bump orbit. We have prepared a system to provide injection timing signal for the data acquisition system at the beam-lines to stop the data acquisition during the injection. It was successfully demonstrated in a few beam-lines to eliminate the effect of the injection on their data.

There are a few other practical problems. One is the stability of the injection efficiency. In particular, the drift of the injection efficiency from the linac to the booster synchrotron was significant. It was found that the origin of the drift mainly arises from the drift of the excitation voltage of the injection septum at the booster synchrotron. A drift of the RF power in the linac was also noticeable. Some feedback systems have been constructed by using digital oscilloscopes and PCs. The injection efficiency was drastically stabilized by using them [2].

Quantum Beam Technology Program

After the successes of the proof-of-principle experiments on the new light source technologies using lasers and a storage ring, we have started a new research project under Quantum Beam Technology Program of MEXT. This is a five year project started in 2008. In this program, we will reconstruct the beam transport line and move the injection point to produce another new 4 m long straight section in the ring. We will upgrade the laser system and install new undulators, which are dedicated to the coherent radiation production. We will also construct two new beam-lines which are also dedicated to applications of the coherent radiation in the THz and VUV ranges.

In FY2008 and FY2009, we have constructed an undulator, magnets and power supplies for new beam transport lines and new laser amplifiers. In March, 2010, we have started the reconstruction on the beam transport line and the storage ring.

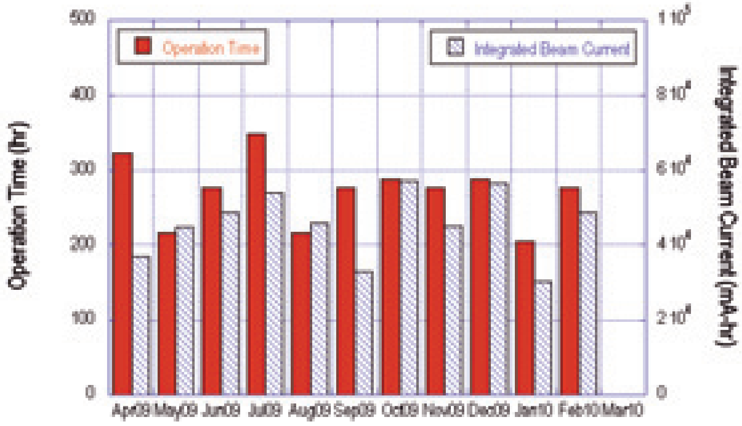

Fig. 1. Monthly statistics of the operation time (red bars) and of the integrated beam current (blue dashed bars).

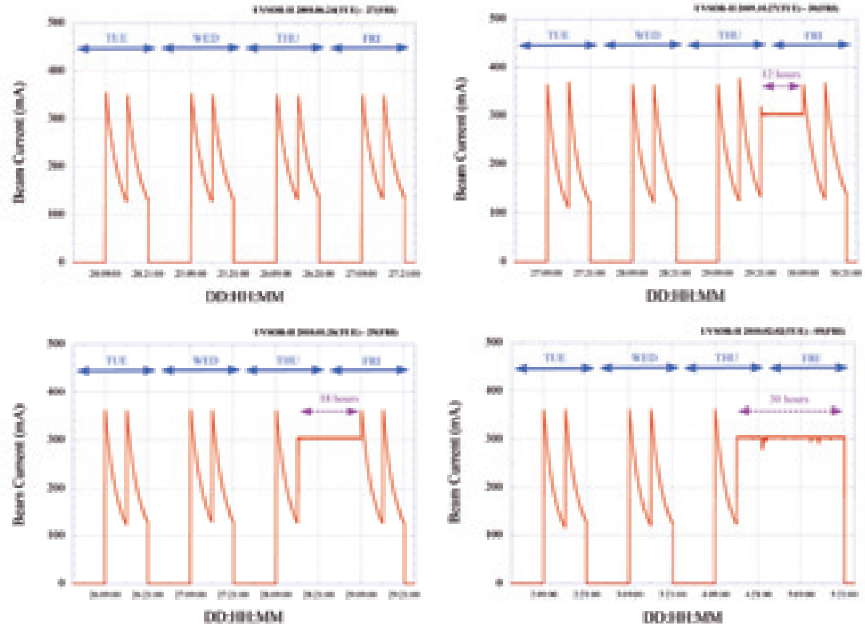

Fig. 2. Top-up Test Operation. Beam current histories in four days for users runs are shown. From 2008 to 2010, we have gradually increased the top-up operation time.

Accelerator Technologies

A single pass beam position monitor has been developed, which utilizes the existing BPM heads in the ring. The signals from the BPM heads are recorded by a digital oscilloscope and are analyzed off line [3]. It was successfully demonstrated that the injection bump orbit and the injection orbit could be measured. The beam orbit executing a betatron oscillation produced by the RFKO system was also successfully measured [4]. The result indicates that non-linear effect produced by the sextupole magnets strongly suppresses the amplitude of the betatron oscillation.

3. Researches and Developments

Free Electron Laser

The top-up injection is not only useful for the SR users experiments but also for the free electron laser (FEL) and other new light sources. In case of the FEL, since the ring is operated in single bunch mode, the beam lifetime is short. The rapid change in the beam current causes a rapid change in the FEL power, a part of which is due to the change in the gain and another part is due to the thermal deformation on the optical cavity mirror.

We have tried a FEL operation in the top-up mode [3]. It was found that the output power is quite stable. We carried out a users experiment in the top-up mode and found that, since there is no interruption by the injection, the effective beam time for the FEL users increased much.

Coherent Harmonic Generation by using an External Laser

To get coherent radiation in the VUV range, which is hard to reach with the resonator type free electron laser, coherent harmonic generation (CHG) is under investigation. After the successful observations on the coherent 3rd harmonics of a Ti:Sa laser[4, 5], we prepared a spectrometer for the VUV range. By using this, we have succeeded in observing the CHG up to 9th harmonics [6]

[1] H. Zen *et al.*, in this report
[2] H. Zen *et al.*, in this report
[3] A. Nagatani *et al.*, in this report
[4] Y. Furui *et al.*, in this report
[3] H. Zen *et al.*, in this report
[4] M. Labat, C. Bruni, G. Lambert, M. Hosaka, M. Shimada, M. Katoh, A. Mochihashi, T. Takashima, T. Hara, M. E. Couprie, Europhys. Lett., 81 (2008) 34004
[5] M. Labat, M. Hosaka, M. Shimada, M. Katoh, M. E. Couprie, Phys. Rev. Lett. 101, 164803 (2008)
[6] T. Tanikawa *et al.*, in this report

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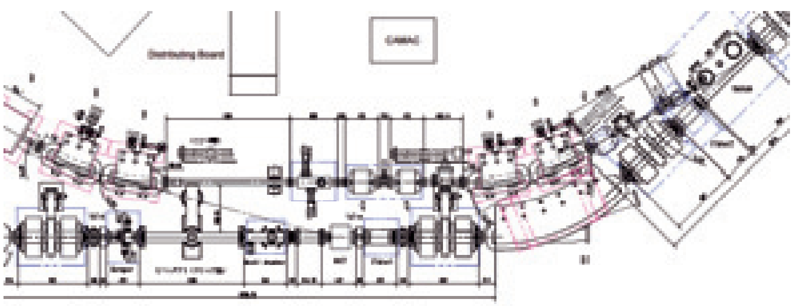


Fig. 3. New configuration of the beam transport line

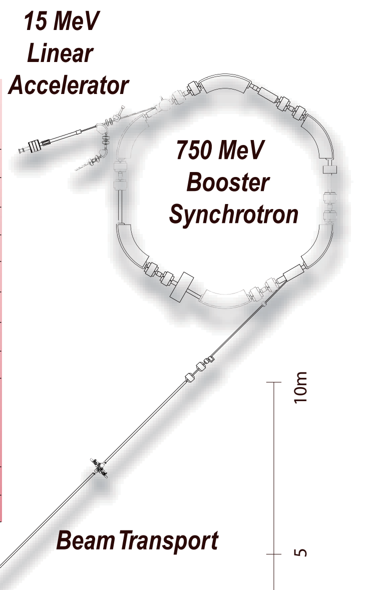
UVSOR Accelerator Complex

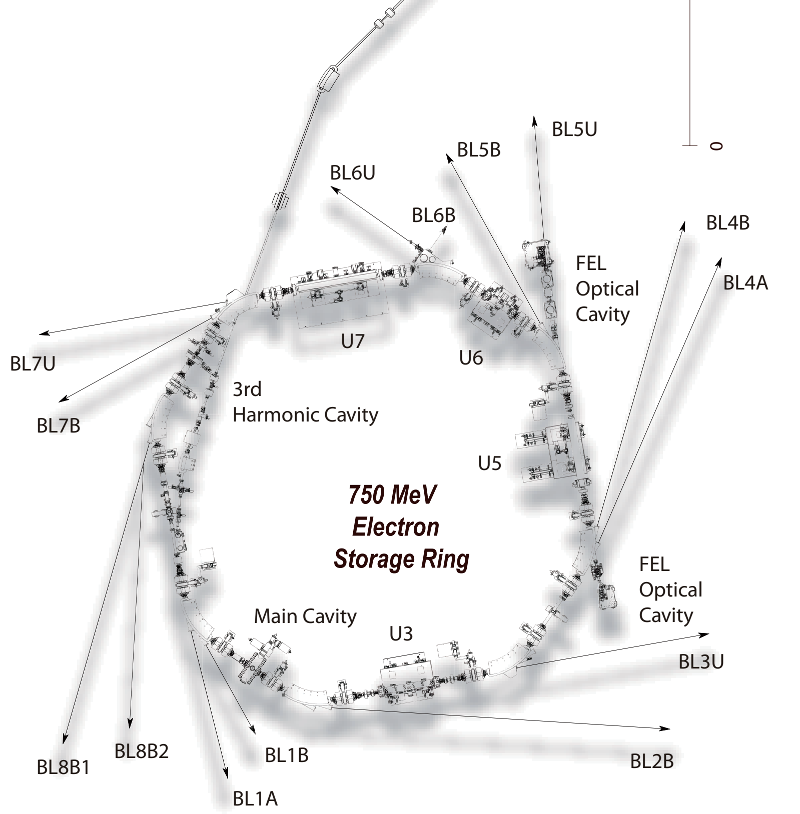
Injection Linear Accelerator

DC Gun	
Electron Source	EIMAC Y-646B
Applied Voltage	75 kV
Accelerator Tube	
Length	2.5 m
Frequency	2856 MHz
Structure	2π/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)

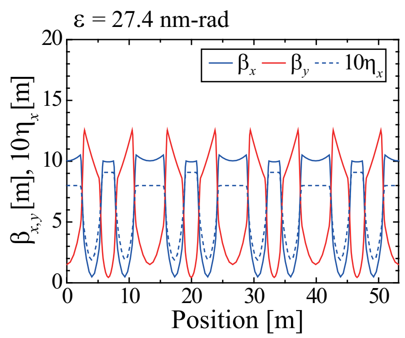




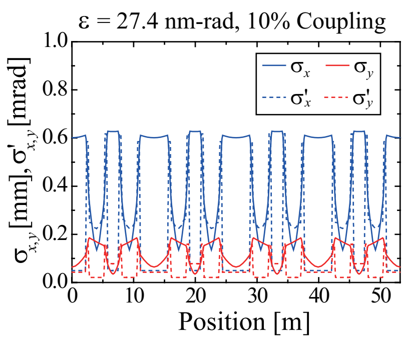
UVSOR-II Storage Ring

Energy	750 MeV
Injection Energy	750 MeV
Maximum Stored Current	500 mA (multi bunch)
	100 mA (single bunch)
Normal Stored Current	300 mA (multi bunch)
(Top-up operation)	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



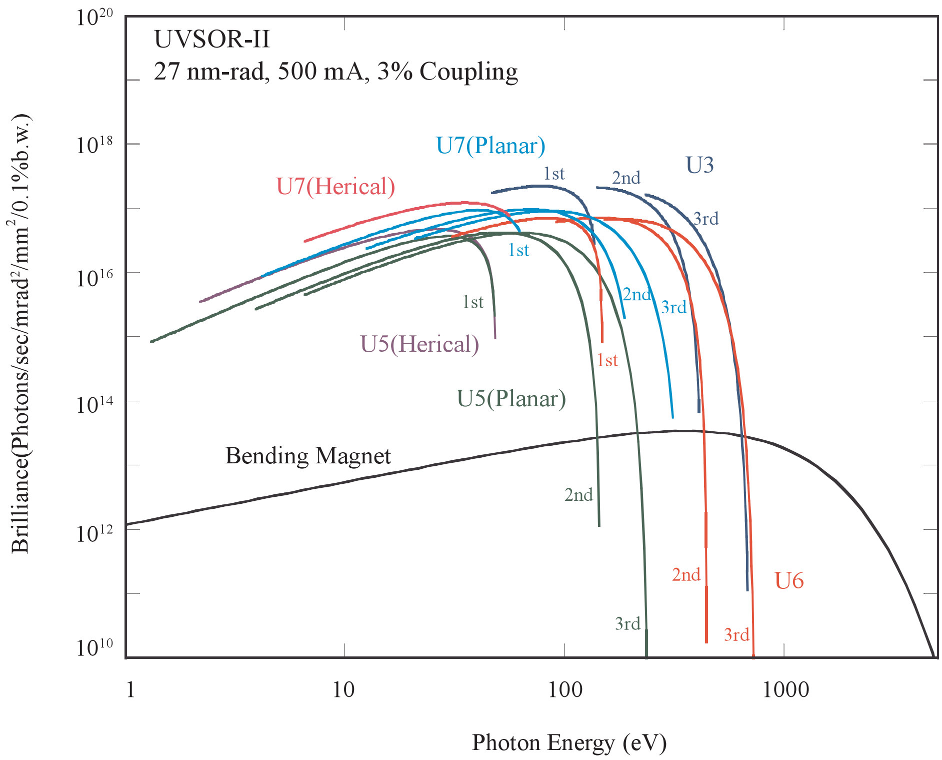
Horizontal / vertical betatron functions and dispersion function



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 2009

The UVSOR facility has become one of the highest brilliance extreme-ultraviolet radiation sources among synchrotron radiation facilities with electron energy less than 1 GeV, since the successful accomplishment 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. Eight bending magnets and four insertion devices are available for utilizing synchrotron radiation at UVSOR. There is a total of fourteen operational beamlines in 2009, which are 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 rest of the five beamlines are so-called "In-house beamlines", and 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. Newly constructed (BL3U and BL7U) as well as the upgraded (BL5U and BL6B) beamlines synchronized with the UVSOR-II project have been routinely operated, and a number of outcome has emerged through the utilization of these beamlines. The in-vacuum type undulator U6, which has been relocated from the long straight section S7 to the short one S6, has 26 magnetic periods and the period length is 36 mm. The spectral region from 50 eV to 140 eV was covered with the first harmonic radiation. There was an inherent energy gap between the highest and lowest photon energies, covered by the first and third harmonics, respectively. The photon energy range from 30 to 500 eV can be covered by odd harmonics of U6 up to seventh without any energy gap. Then a new project for constructing the undulator beamline BL6U has been initiated.

The BL6U monochromator designed covers the photon energy ranging from 30 to 500 eV, with the resolving power higher than 10000 and the photon flux more than 10^{10} photons/sec. The practical construction of BL6U has begun from the summer shutdown in 2008, and the first light has been observed in December 2008. After the fine tuning of the monochromator, it has been confirmed that the photon energy ranging from 40 to 400 eV, with the resolving power higher than 5000 and the photon flux more than 10^{11} photons/sec, can be covered, when the storage ring is operated in the top-up mode. Accordingly, BL4B will be allocated to an open beamline from fiscal year 2010. 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, 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 “Quantum Beam Technology Project” conducted by MEXT/JST. In connection, the straight section U1 will be used for generating coherent THz and VUV radiation, where two beamlines will be constructed. In response to this, BL1A and BL1B must be moved to vacant lots. Since spectroscopic research works on solids have been conducted very actively at these beamlines, it is essential that all the 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. A design study for the new beamline optics has been started. For the monochromator at BL3B, a 2.5-m off-plane Eagle type has been chosen. The practical movement and construction will start from the spring of 2011. Further discussion toward utilizing the available straight sections most effectively and formulating a basic plan on the beamline construction, will be continued.

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

Eiji SHIGEMASA (UVSOR Facility)

Beamlines at UVSOR

Beam-line	Monochromator, Spectrometer	Energy Region (eV)	Experiments	Beamline master
1A	Double-Crystal	600 eV – 4 kev	Solid (Absorption)	N. Kondo nkondo@ims.ac.jp
1B	1m Seya-Namioka	2 eV – 30 eV	Solid (Reflection, Absorption)	M. Hasumoto hasumoto@ims.ac.jp
2B*	18m Spherical Grating (Dragon)	24 eV – 205 eV	Gas (Photoionization, Photodissociation)	K. Mitsuke mitsuke@ims.ac.jp
3U*	Varied-Line-Spacing Plane Grating (Monk-Gillieson)	60 eV – 800 eV	Gas, Liquid, Solid (Absorption, Photoemission, Photon Emission)	N. Kosugi kosugi@ims.ac.jp
4B*	Varied-Line-Spacing Plane Grating (Monk-Gillieson)	25 eV – 1 keV	Gas (Photoionization, Photodissociation) Solid (Photoemission)	E. Shigemasa sigemasa@ims.ac.jp
5U	Spherical Grating (SGM-TRAIN*)	5 eV – 250 eV	Solid (Photoemission)	M. Sakai sakai@ims.ac.jp
5B	Plane Grating	6 eV – 600 eV	Calibration Solid (Absorption)	M. Hasumoto hasumoto@ims.ac.jp
6U*	Variable-Included-Angle Varied-Line-Spacing Plane Grating	30 eV – 500 eV	Gas (Photoionization, Photodissociation) Solid (Photoemission)	E. Shigemasa sigemasa@ims.ac.jp
6B	Martin-Puplett FT-FIR Michelson FT-IR	0.1 meV – 2.5 eV	Solid (Reflection, Absorption)	S. Kimura kimura@ims.ac.jp
7U	10m Normal Incidence (Modified Wadsworth)	6 eV – 40 eV	Solid (Photoemission)	S. Kimura kimura@ims.ac.jp
7B	3m Normal Incidence	1.2 eV – 25 eV	Solid (Reflection, Absorption)	M. Hasumoto hasumoto@ims.ac.jp
8B	Plane Grating	1.9 eV – 150 eV	Solid (Photoemission)	T. Nishi nishi@ims.ac.jp
FEL	Free Electron Laser	1.6 eV – 6.2 eV		M. Katoh mkatoh@ims.ac.jp
CSR	Coherent Synchrotoron Radiation	0.5 meV – 5 meV		M. Katoh mkatoh@ims.ac.jp

* 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 by using several kinds of single crystals such as β-Al_2O_3, beryl, KTP ($KTiOPO_4$), quartz, InSb, and Ge. The throughput spectra measured by a Si photodiode (AXUV-100, IRD Inc.) are shown in Fig. 1. Typical energy resolution (E/ΔE) of the monochromator is about 1500 for beryl and InSb. There are no experimental setups specific of 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.

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

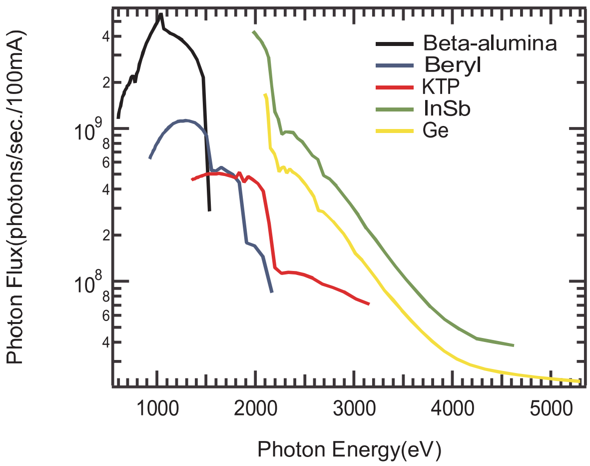


Fig. 1. Throughput spectra of the double crystal monochromator at BL1A.

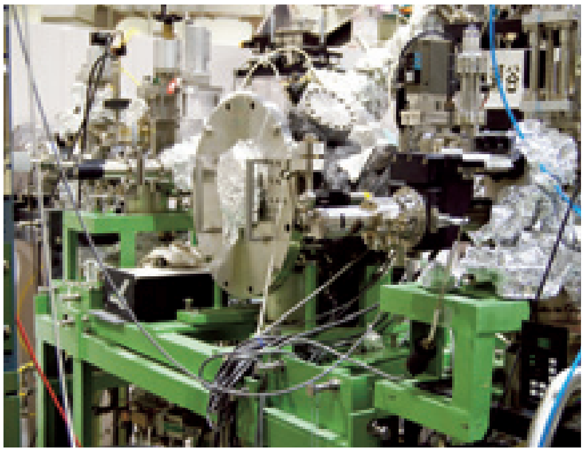


Fig. 2. Side view of BL1A.

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/ΔE = 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 a main experimental station, which make experiments for liquids and bio-specimens possible, while the other is mainly utilized for solid-state spectroscopy. The output flux from this monochromator is about 1010 photons/sec. around 200 nm with 0.1 mm slit openings. The spectral distributions for two gratings measured by a conventional photomultiplyer are shown in Fig. 1. A second monochromator (Spex 270M) and a LN-cooled 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.

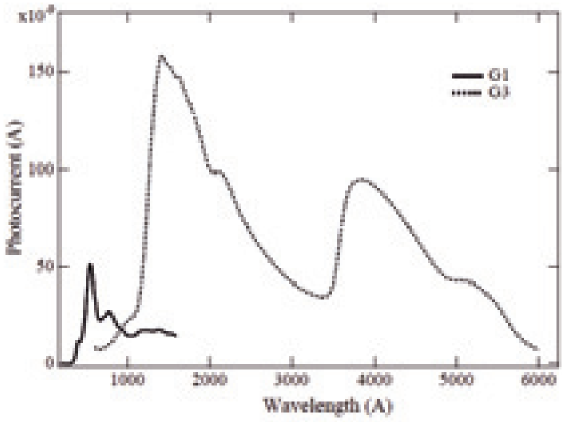


Fig. 1. Photocurrent at the sample position at BL1B.

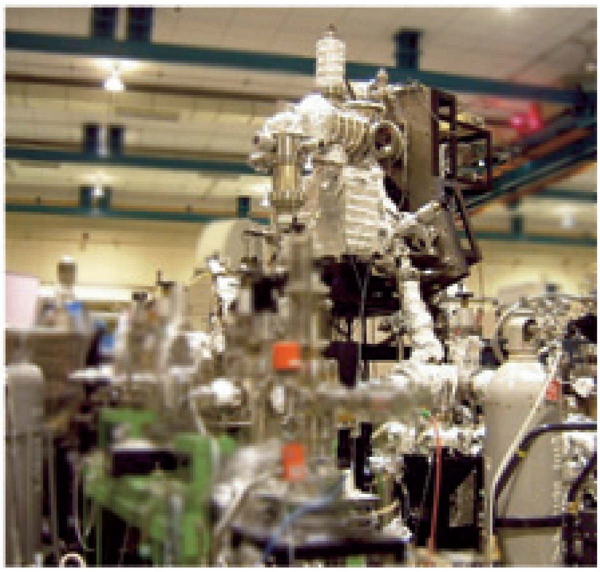


Fig. 2. Photo of BL1B..

Beamline Specifications

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

BL2B

Beamline for Gas Phase Photoionization and Reaction Dynamics

This beamline has been developed for the purpose of studying 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 prefocusing 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 taking 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 enough amount of sample. This situation has been rapidly changed since the start of this century, because the techniques of syntheses, isolation, and purification have been advanced so rapidly that appreciable amount of fullerenes can be readily obtained.

[1] M. Ono, H. Yoshida, H. Hattori and K. Mitsuke, Nucl. Instrum. Meth. Phys. Res. A **467-468**, 577 (2001).
[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.

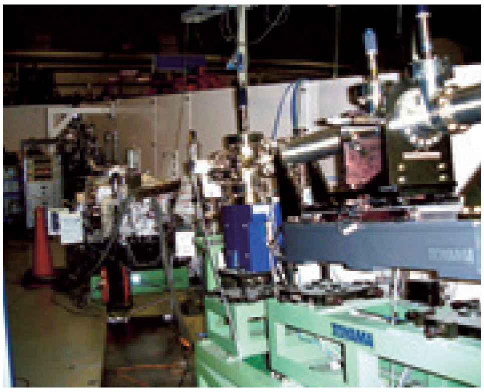


Fig. 1. 18-m spherical grating monochromator at BL2B.

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-vaccum 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 eV 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 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.

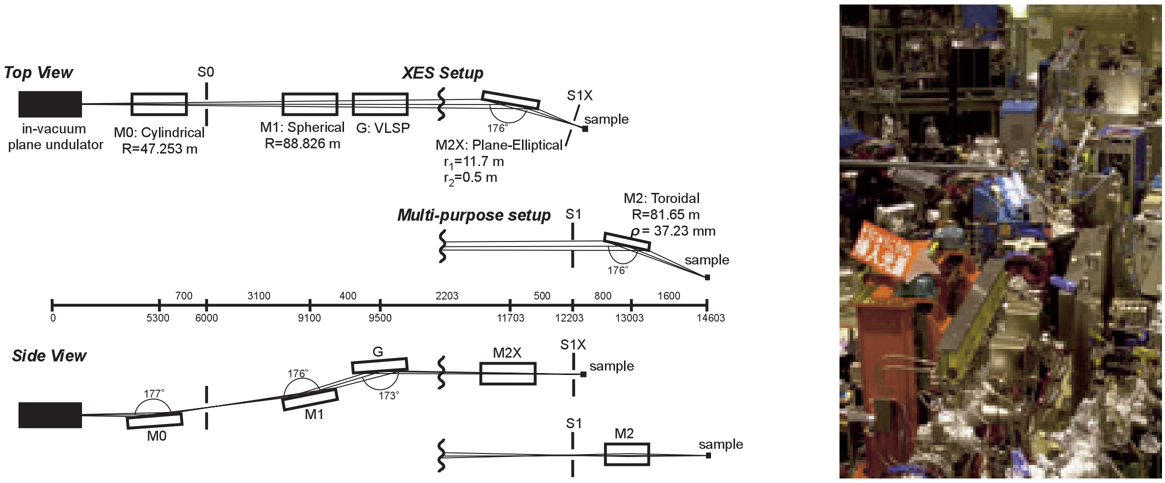


Fig. 1. Schematic layout (left) and the photography (right) of the BL3U. The distances along the beam from the center of the in-vacuum plane undulator are shown in mm. S1X and M2X can be replaced with the other exit slit S1 so that experiments can be carried out at either the XES or multi-purpose endstation. In the XES setup, the sample is placed at 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 eV to 800 eV. The gratings with the 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 by a Si photodiode (IRD Inc.), with the entrance- and exit-slit openings set at 50 and 50 μm, respectively. The maximum resolving power (E/ΔE) achieved for each grating is more than 5000.

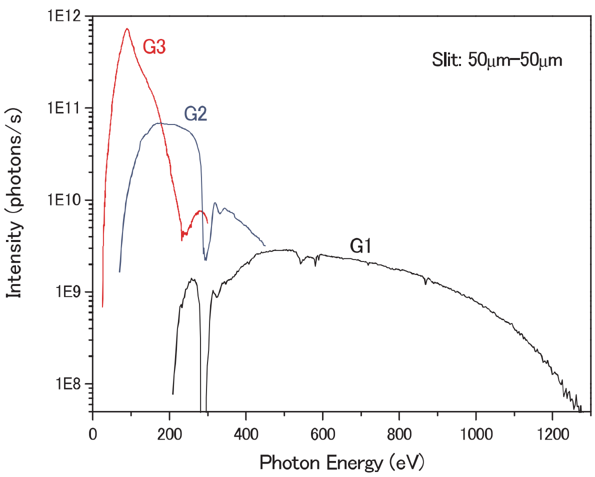


Fig. 1. Throughput from the VLS-PGM monochromator on BL4B.

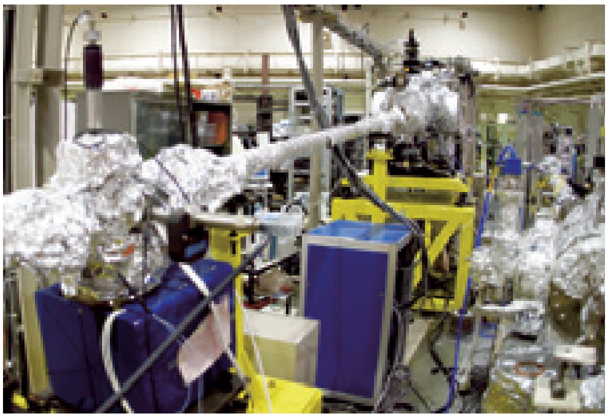


Fig. 2. Photo of BL4B.

Beamline Specifications

Monochromator	Varied-line-spacing Plane Grating Monochromator
Energy range	25-1000 eV
Resolution	E/ΔE > 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 a high-resolution angle-resolved photoemission study on 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 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 to aim 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 by using laminar profile gratings and combinations of mirrors and gratings.

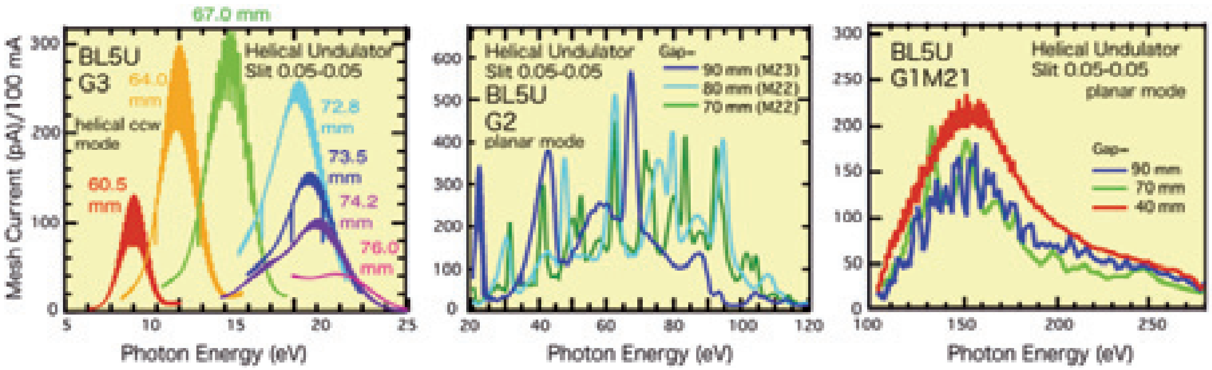


Fig. 1. Throughput spectra from the SGM-TRAIN monochromator at BL5U.

Beamline Specifications

Monochromator	SGM-TRAIN
Energy Range	5-250 eV
Resolution	hν/ΔE >2,000 for < 40μm slits
Experiment	ARPES, AIPES, XAS
Flux	$<10^{11}$ photons/s for < 40μm slits (at 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)

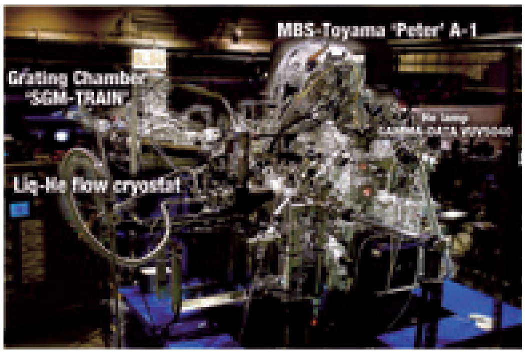


Fig. 2. High-resolution angle-resolved photoemission apparatus at BL5U.

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 end stations in tandem. The most upstream station is used for 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-degree-of-freedom; X-Y translation of a sample, and interchange of samples and filters. These are driven by pulse motors in vacuum. Since the polarization of synchrotron radiation is essential for such measurements, the rotation axis can be made in either horizontal or vertical direction (s- or p-polarization).

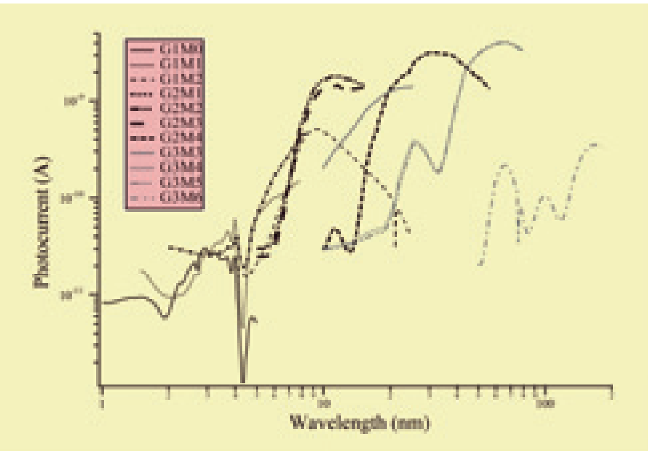


Fig. 1. Throughput spectra for possible combinations of gratings and mirrors at BL5B measured by a gold mesh.

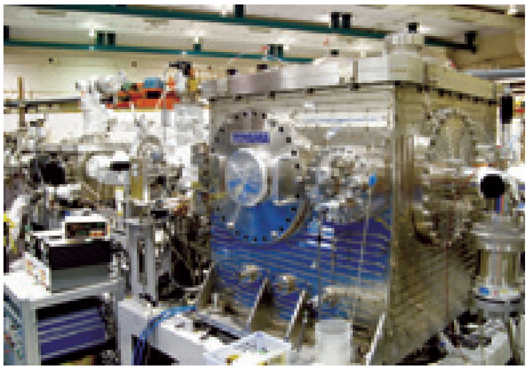


Fig. 2. A side view of the experimental chamber for calibration measurements.

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. By a combination of undulator radiation and the sophisticated monochromator design (entrance slit-less configuration and variable-included-angle mechanism), with using one single grating, the monochromator can cover the photon energy ranging from 30 to 500 eV, with the resolving power higher than 10000 and the photon flux more than 10^{10} photons/sec. Figure 1 shows an example of the monochromator throughput spectra measured by 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.

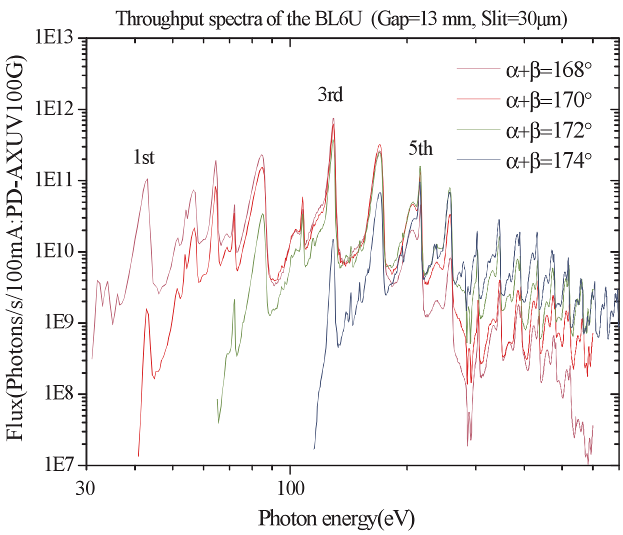


Fig. 1. Throughput spectra of the BL6U monochromator at various included angles.

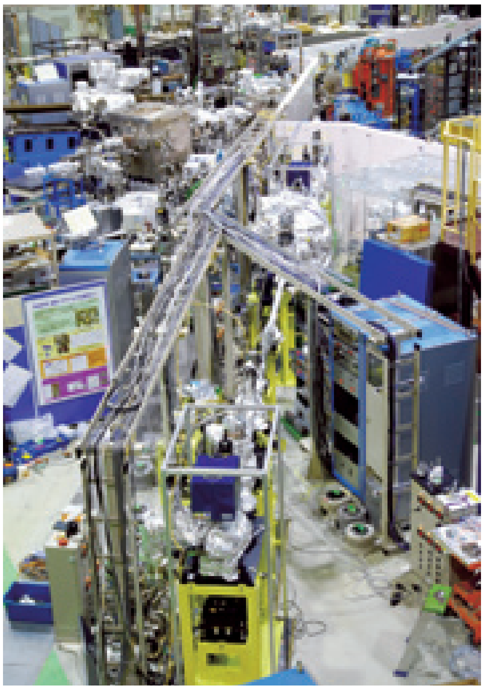


Fig. 2. Photo of BL6U

Beamline Specifications

Monochromator	Variable-Included-Angle Varied-line-spacing Plane Grating Monochromator
Energy range	40-500 eV
Resolution	E/ΔE > 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 a 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 in the IR and THz regions. The previous beamline BL6A1 that has been constructed in 1985 is the pioneer of the infrared SR research. The beamline was quitted 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 to a new one with 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 highly improved.

The beamline is equipped with two interferometers, one is Michelson-type (Bruker Vertex 70v) and the other Martin-Puplett-type (JASCO FARIS-1), to 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 mm) and the other IR/THz microscopy for tiny samples (~ several ten μm).

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

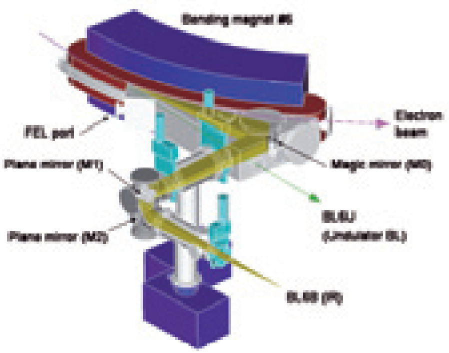


Fig. 1. The design of optics and front end of BL6B.

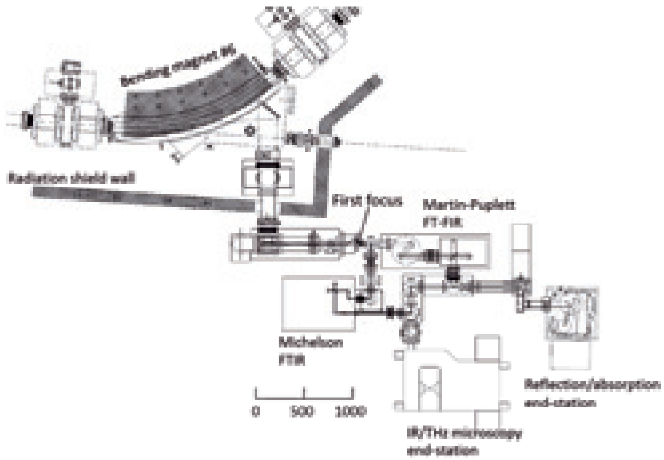


Fig. 2. Schematic figure of top view of BL6B.

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 IFS66v 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 7U, named Symmetry And Momentum Resolved electronic structure Analysis Instrument (SAMRAI) for functional materials, was constructed to provide the photon flux with high energy resolution and high flux mainly for high-resolution angle-resolved photoemission spectroscopy of solids. An APPLE-II-type variable polarization undulator is equipped for the light source. The undulator can make high intense VUV light with horizontal/vertical linear and right/left circular polarization. The undulator light is monochromatized by the 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 the photon flux of more than $10^{11} - 10^{12}$ ph/s on samples in the whole energy region.

The beamline has a photoemission end-station which 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 to reveal the origin of the physical properties.

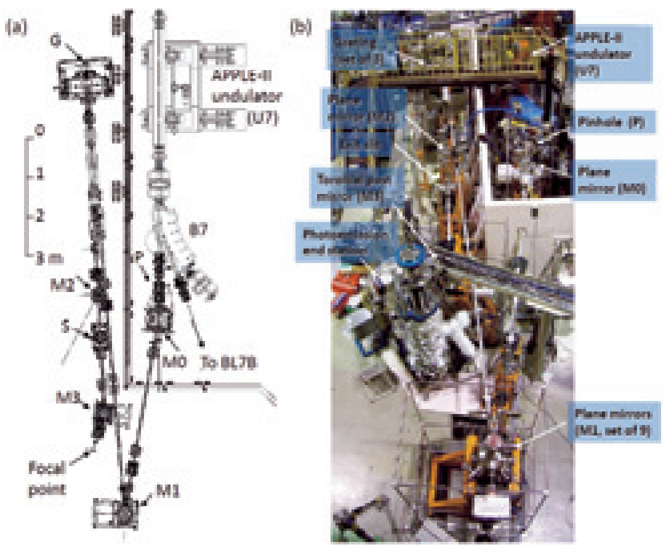


Fig. 1. Layout (a) and photograph (b) of the SAMRAI beamline consisting of the APPLE-II type undulator (U7), the modified Wadsworth type monochromator (M0 – S), and the high-resolution photoemission analyzer at the focal point. The monochromator, mainly has five optical components: two plane mirrors (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 = 76mm, 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	$\geq10^{12} - 10^{11}$ ph/s (depend 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, enough intensity for luminescence measurements, a wide wavelength coverage for Kramers-Kronig analyses, and the minimum deformation to the polarization characteristic of the 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 in between the end valve of the beamline and the focusing position. Figure 1 shows 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 for measuring the photon intensity and the absolute photon flux was estimated, taking the quantum efficiency of the photodiode into account.

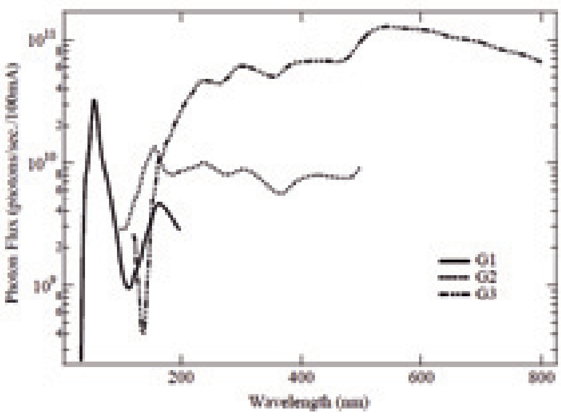


Fig. 1. Throughput spectra of BL7B measured by a silicon photodiode.

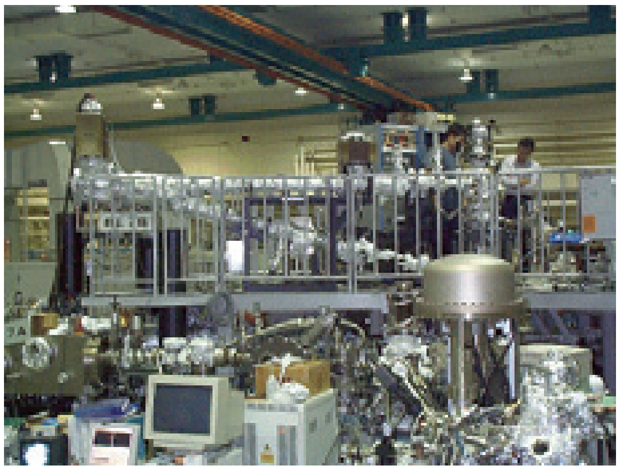


Fig. 2. Photo of BL7B.

Beamline Specifications

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

BL8B

Angle-Resolved Ultraviolet Photoelectron Spectrometer for Solids

BL8B is a beamline for angle-resolved ultraviolet photoemission spectroscopy (ARUPS) system which is designed for measuring 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 with an accurate for temperature dependence (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 130eV with exchanging two gratings (G1: 1200l/mm, G2: 450l/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 about $1\times1mm^2$. Figure 1 shows the throughput spectra of PGM (slit=100μm). The energy resolution at a slit width of 100μm was found to be E/ΔE = 1000 in the wavelength range from 2 to 130eV. A hemi-spherical electron energy analyzer of 75mm mean radius with an angular resolution less than 2° can be rotated around vertical and horizontal axes. The sample mounted on a manipulator can be also rotated around two axes.

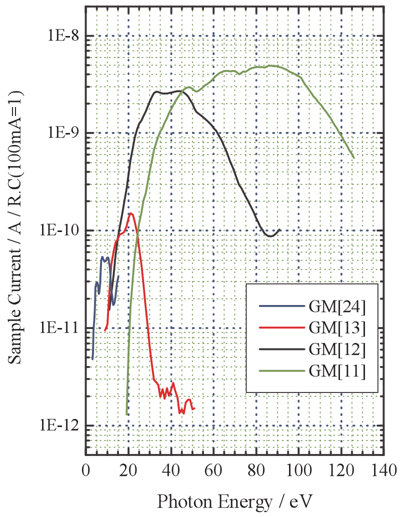


Fig. 1. Throughput spectra of plane-grating monochromator at BL8B2 (slit=100μm).

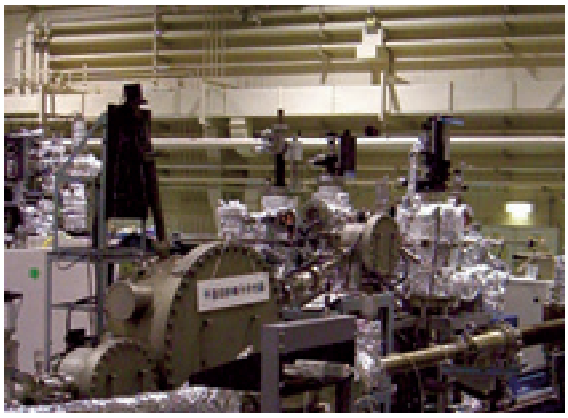


Fig. 2. A photo of BL8B2.

Beamline Specifications

Monochromator	Plane-grating monochromator
Wavelength Range	9- 600 nm
Resolution	E/ΔE = 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 long and an optical cavity of 13.3 m long. 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 about 11 MHz. The average output power depends on the wavelength but its typical value is several 100 mA. The output power higher than 1W was recorded at 230 nm and 570 nm. The FEL can be operated with the top-up injection mode. The users can use the FEL for several hours with quasi constant output power. The laser pulses are naturally synchronized with the synchrotron radiation pulses which 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.

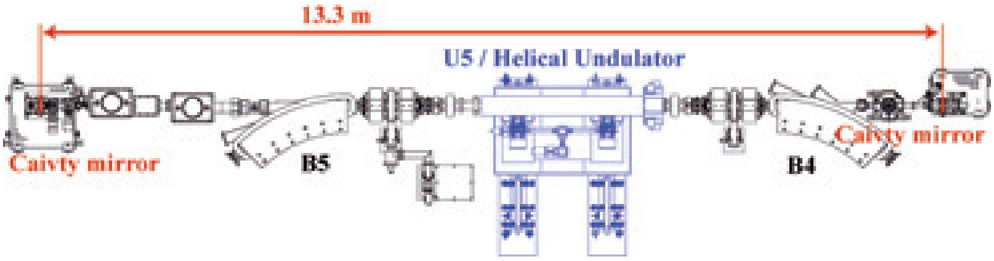


Fig. 1. The schematic of the 13.3-m long optical cavity.

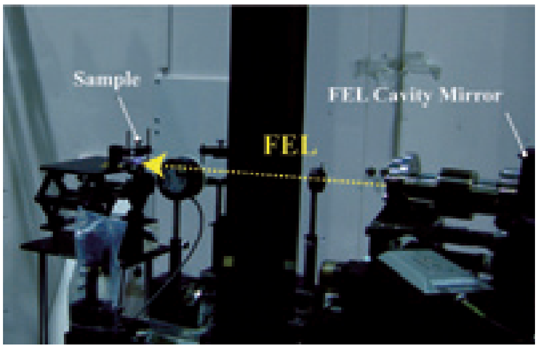


Fig. 2. Left and right circular polarized FEL is delivered to B4.

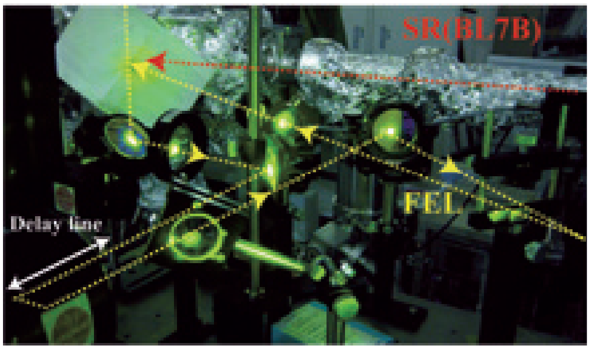


Fig. 3. The FEL is delivered to BL7B. The FEL is irradiated on a target simultaneously with the SR.

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