Light Source in 2008

1. Status of UVSOR-II

In the fiscal year 2008, we have operated the UVSOR-II accelerators from April '08 to March '09. We had totally 37 weeks for the users operation, 33 weeks in multi-bunch mode, 2 weeks in single-bunch mode and 2 weeks as bonus runs in multi-bunch mode. We had 6 weeks dedicated for machine studies. We had one month shut-down in August for a construction work of a new undulator beam-line and also for maintenance works on accelerators. We had two 1-week shut-down in May and March, and one 2-week one around the New Years Day.

The monthly statistics of the operation time and the integrated beam current are shown in Fig. 1. The operation time per month has increased by approximately 20% on average since October. This is because of the extended operation for Top-up test runs as described later.

The weekly operation schedule is as follows. On Monday, the machine is operated for machine studies. From Tuesday to Friday, the machine is operated for users, from 9am to 9pm. In case of the multi-bunch mode, the beam injection is made twice a day, at 9am and 3pm. The filling beam current is 350 mA. In case of the single bunch mode, the injection is made three times a day, at 9am, 1pm and 5pm, and the filling current is 100 mA. Normally, it takes about 20 minutes to complete the injection.

Occasionally, we operate the machine after 9pm for beam-line conditionings, free electron laser experiments and so on. Since October, 2008, we operate the machine for 24 hours on every Thursday. After 9pm on these days, the machine is operated to test the Top-up injection scheme.

In this fiscal year, we had one rather serious trouble. In January 2009, the power supply of the bending magnets of the storage ring was malfunctioned. It took about one week to repair. We exchanged a machine study week in February with a users week to secure the beam time. Although we also had a few troubles on the linear accelerator in autumn, fortunately, it was recovered within a few days and the users time could be secured by extending the operation time during the weeks.

2. Improvements

Towards Top-up Operation

In the last two years, we have been preparing for the Top-up operation. The energy upgrade of the booster synchrotron and the beam transport lines were successfully completed. Now, we inject the electron beam at the full energy in the users runs. During the short shut-down period in April, 2008, we installed two beam scrapers and one current transformer (CT) in the beam transport line. The formers are to scrape out the unnecessary electrons in the extracted beam from the booster synchrotron. The latter is to monitor the number of the injected electrons. The signal from the CT is processed and is sent to an interlock module, which stops the injection when the integrated number of electrons reaches to a limiting value. The signal from the DCCT in the ring is also sent to the module. The module controls (starts or stops) the injection to keep the beam current almost constant, as monitoring the stored beam current in the ring.

In October, we have started testing the Top-up operation in users beam time. On every Thursday night, from 9pm to 9am, the ring is operated in the Top-up mode. The users can use synchrotron radiation and check the effects on their experiments. The beam current is kept almost constant at 300mA. The beam is injected for about 10 second every one minute with the repetition rate, 1 Hz. An example of the operational result is shown in Fig. 2. Although it is not shown in this figure, the fluctuation of the stored beam current is less than 1% when the injection efficiency is kept at the normal level.

So far, we have found several problems that have to be solved before starting the Top-up operation in daily user runs. The most serious one is the

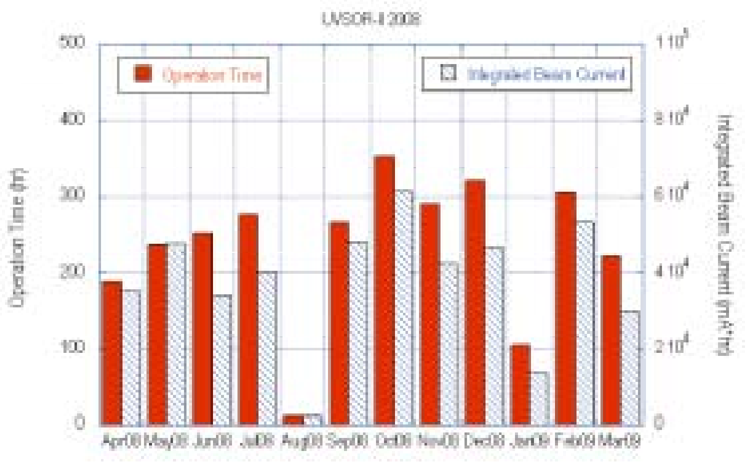


Fig. 1. Monthly statistics of the operation time (red bars) and of the integrated beam current (blue dashed bars).

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. This should be suppressed by precisely adjusting the orbit in near future. In a long term, it has to be solved by introducing some sophisticated injection scheme. As an alternative approach, we are preparing a system to provide injection timing signal for the data acquisition system at the beam-lines to stop the data acquisition during the injection.

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 has found to be significant. Another is the discharge of the electron gun, which takes place roughly once per day. These problems should be improved in near future.

3. Researches and Developments

Coherent Synchrotron Radiation by using an External Laser

Generation of terahertz coherent synchrotron radiation has been intensively studied at UVSOR-II by using laser modulation methods. In these methods, laser pulses from an external source are injected to the storage ring to produce micro-density structures on the electron bunches. When we use sub-picosecond laser pulses, we can produce sub-picosecond dips on the bunches. In this case, broadband coherent THz radiation is emitted in the wavelength range longer than the dip size [1]. When we use amplitude modulated laser pulses, we could produce periodic density structure on the bunches. In this case, the bunches emit quasi-monochromatic coherent THz radiation at the wavelength equal to the density modulation period [2]. We have tried the laser slicing technique in a low alpha operation mode, in which the micro-density structures are kept for a longer time. Some interesting behavior was observed, which was considered to originate from a transverse-longitudinal coupling effect in the storage ring.

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. Coherent 3rd harmonics of a Ti:Sa laser was successfully produced and the properties of the radiation and the mechanisms were investigated [3, 4]. CHG in the full helical configuration was successfully demonstrated for the first time [5].

After the successes of the proof-of-principle experiments on the coherent radiation described above, we have started a new research project under Quantum Beam Technology Program of MEXT. In this five year project, we will reconstruct the beam transport line and move the injection point to produce another new 4m 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.

[1] M. Shimada, M. Katoh, S. Kimura, A. Mochihashi, M. Hosaka, Y. Takashima, T. Hara and T. Takahashi, Jpn. J. Appl. Phys. **46** (2007) 7939.

[2] S. Bielawski, C. Evain, T. Hara, M. Hosaka, M. Katoh, S. Kimura, A. Mochihashi, M. Shimada, C. Szwaj, T. Takahashi and Y. Takashima, Nature Physics **4** (2008) 390.

[3] M. Labat, G. Lambert, M. E. Couprie, M. Shimada, M. Katoh, M. Hosaka, Y. Takashima, T. Hara and A. Mochihashi, Nucl. Instr. Meth. Phys. Res. A **593** (2008) 1.

[4] M. Labat, C. Bruni, G. Lambert, M. Hosaka, M. Shimada, M. Katoh, A. Mochihashi, T. Takashima, T. Hara and M. E. Couprie, Europhys. Lett. **81** (2008) 34004.

[5] M. Labat, M. Hosaka, M. Shimada, M. Katoh and M. E. Couprie, Phys. Rev. Lett. **101** (2008) 164803.

M. Katoh (UVSOR Facility)

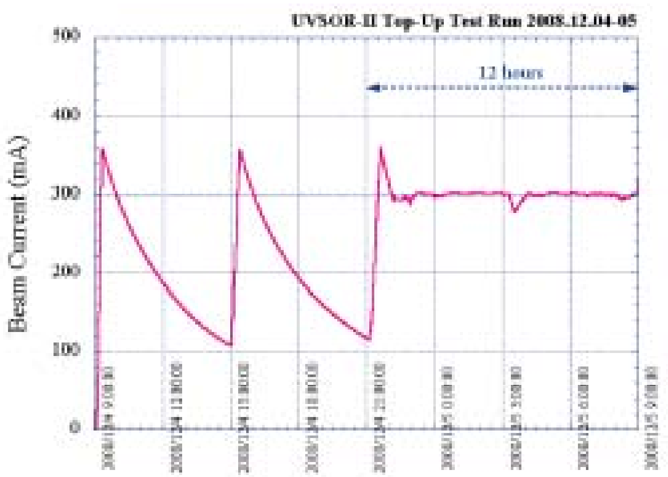


Fig. 2. Top-up Test Operation. After 9pm, the ring was operated in the Top-up mode for about 12 hours.

UVSOR Accelerator Complex

Injection Linear Accelerator

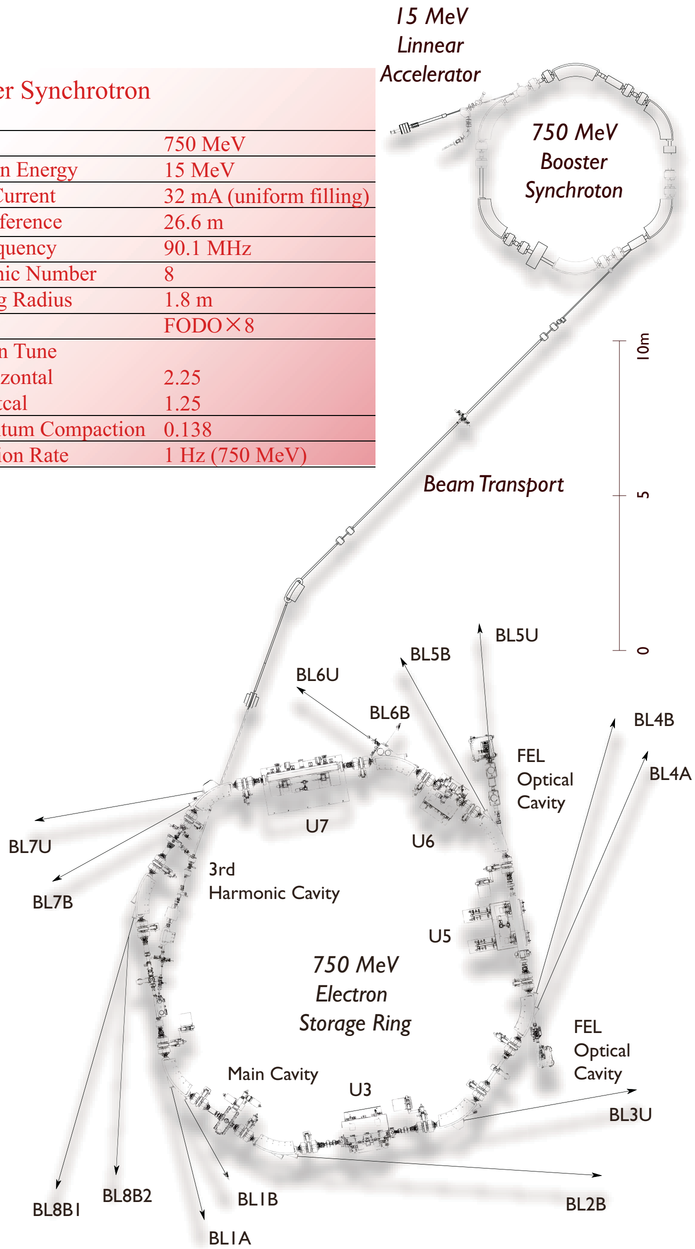
Energy	15 MeV
Length	2.5 m
Frequency	2856 MHz
Accelerating RF Field	$2\pi/3$ Traveling Wave
Klystron Power	1.8 MW
Energy Spread	~1.6 MeV
Repetition Rate	2.6 Hz

Booster Synchrotron

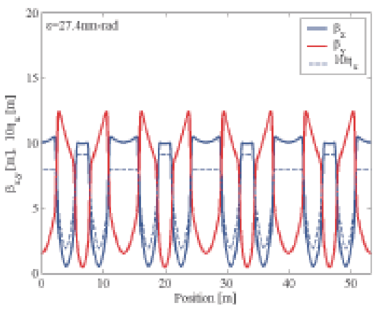
Energy	750 MeV
Injection Energy	15 MeV
Beam Current	32 mA (uniform filling)
Circumference	26.6 m
RF Frequency	90.1 MHz
Harmonic Number	8
Bending Radius	1.8 m
Lattice	FODO×8
Betatron Tune	
Horizontal	2.25
Veritcal	1.25
Momentum Compaction	0.138
Repetition Rate	1 Hz (750 MeV)

UVSOR-II Storage Ring

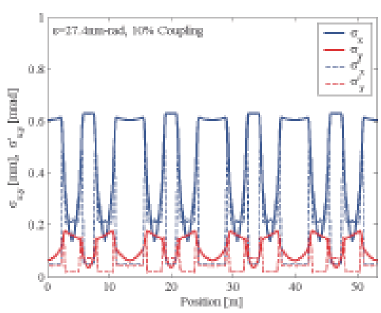
Energy	750 MeV
Injection Energy	750 MeV
Maximum Stored Current	500 mA (multi bunch) 100 mA (single bunch)
Natural Emittance	27.4 nm-rad
Circumference	53.2 m
RF Frequency	90.1 MHz
Harmonic Number	16
Bending Radius	2.2 m
Lattice	Extended DBA×4
Straight Section	(4 m×4)+(1.5 m×4)
RF Voltage	100 kV
Betatron 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



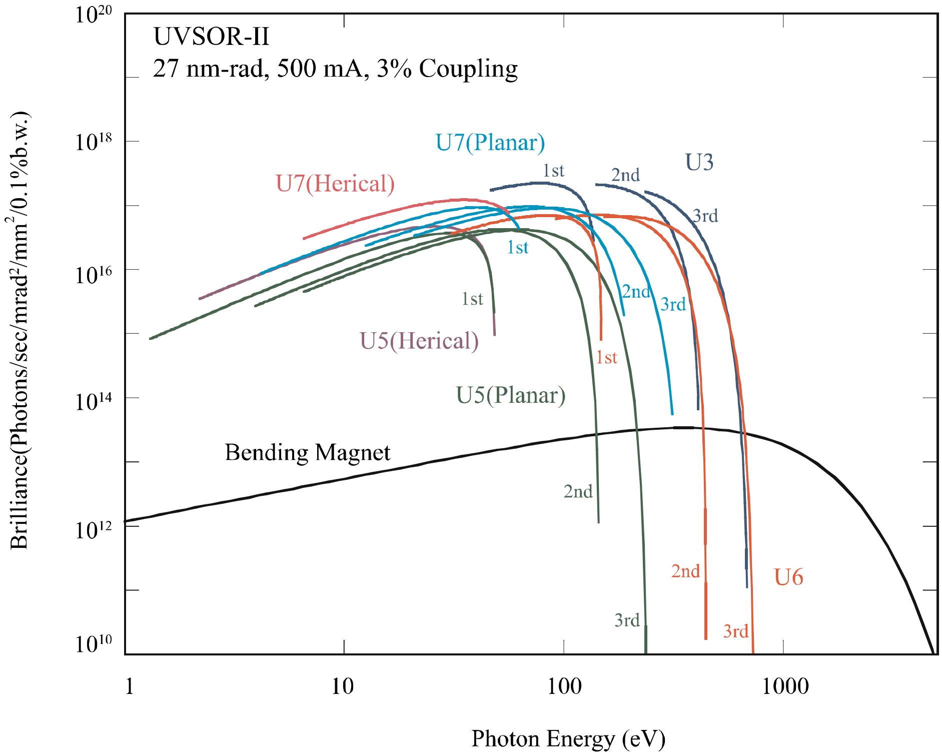
Horizontal /vertical betatron functions and dispersion function



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 2009

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, 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. Eight bending magnets and four insertion devices are available for utilizing synchrotron radiation at UVSOR. There is a total of thirteen operational beamlines (BL6U has been under construction) in 2008, 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 four beamlines are so-called "In-house beamlines", and are dedicated to the use of research groups within IMS. We have one soft X-rays station equipped with a double-crystal monochromator, seven extreme ultraviolet and soft X-rays stations with a grazing incidence monochromator, three vacuum ultraviolet stations with a normal incidence monochromator, one infrared (IR) station equipped with Fourier-Transform interferometers, one station with a multi-layer monochromator, as shown in the appended table (next page) for all available beamlines at UVSOR.

Keeping pace with the upgrade project, 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. Concerning the utilization of the first in-vacuum type undulator, which has been relocated from the long straight section U7 to the short one between B05 and B06, a new project for constructing the undulator beamline BL6U has been initiated. BL6U will be initially prepared as an in-house beamline. The 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. The first light has been observed and short performance tests have been carried out in December 2008. After the beamline commissioning of BL6U, BL4B will be allocated to an open beamline, and all users' activities continued at BL8B1 will be accepted at BL4B. The experimental activities conducted at BL4A will be terminated in August 2009. All the beamline components at BL4A will be removed later on, and the space thus created will be utilized for constructing a new undulator beamline.

As a research program in "Quantum Beam Technology Project" conducted by MEXT/JST, "Development and Application of Light Source Technology Based on Electron Storage Ring and Laser" proposed by the UVSOR machine group was accepted in 2008. In connection, the straight section U1 will be used for generating coherent THz and VUV radiation, where two beamlines will be constructed. Accordingly 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. In order to discuss near future plans for BL1A and BL1B, the users' meetings have been organized separately by the UVSOR User's Union. As a result, it has been decided that BL1A will be moved to the location of the previous BL2A, and BL1B will be newly constructed at the place of the previous BL3B. The practical movement and construction will start from the spring of 2011. Further serious 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 will be 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/.

E. 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
4A*	Multi-Layered-Mirror	50 eV – 95 eV	Irradiation	T. Urisu urisu@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)	S. Kimura kimura@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
8B1	15m Constant Deviation Grazing Incidence	30 eV – 800 eV	Solid (Absorption)	E. Nakamura eiken@ims.ac.jp
8B2	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 586 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] A. Hiraya *et al.*, Rev. Sci. Instrum. **63** (1992) 1264.

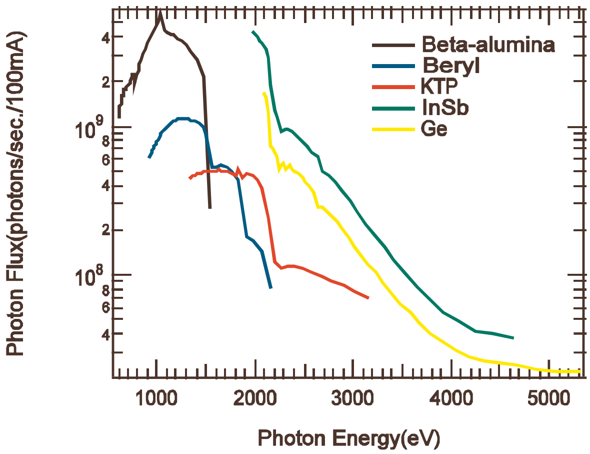


Fig. 1. Throughput spectra of the double crystal monochromator at BL1A.

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, 586-1535 eV), beryl (15.965 Å, 827-2167 eV), KTP (10.95 Å, 1205-3158 eV), quartz (8.512 Å, 1550-4000 eV), InSb (7.481 Å, 1764-4000 eV), Ge (6.532 Å, 2020-4000 eV)
Resolution	E/ΔE = 1500 for beryl and InSb
Experiment	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 10^{10} 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.

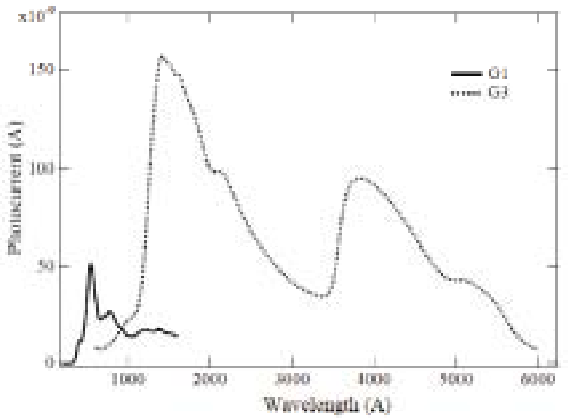


Fig. 1. Photocurrent at the sample position at BL1B.

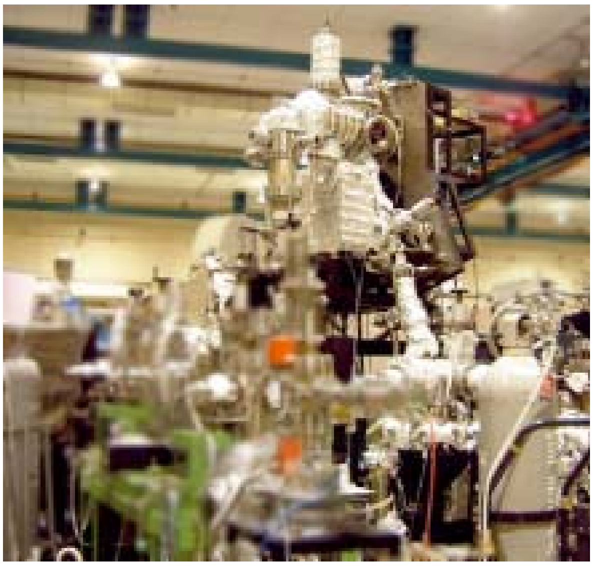


Fig. 2. Photo of BL1B.

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)
Experiment	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** (2001) 577.

[2] H. Yoshida and K. Mitsuke, J. Synchrotron Radiat. **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.

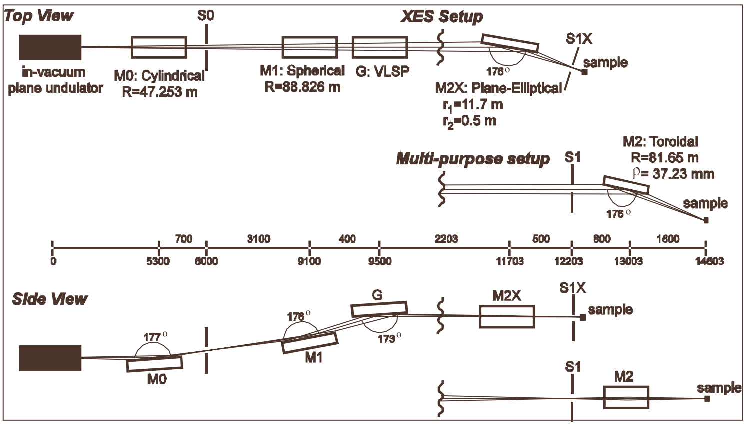
Beamline Specifications

Monochromator	18-m spherical grating Dragon-type
Wavelength Range	6-55 nm; 24-205 eV
Resolution	2000 - 8000 depending on the gratings
Experiment	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 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.



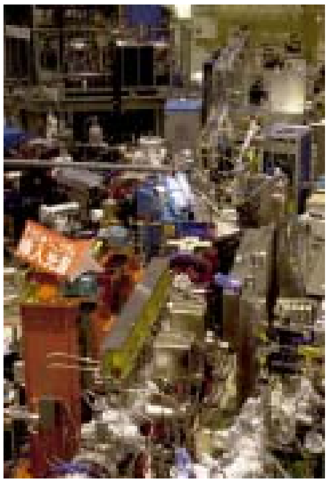


Fig. 1. Schematic layout (left) and the photography (right) of the BL3U. The distances along the beam from the center of the in-vacuum plane undulator are shown in mm. S1X and M2X can be replaced with the other exit slit S1 so that experiments can be carried out at either the XES or multi-purpose endstation. 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/ΔE > 10000
Experiment	Soft X-ray spectroscopy (XPS, XES, XAS)
Beam Size (XES Endstation)	Gaussian shape Vertical 5-20 μm; Horizontal 41 μm (FWHM)

BL4A

Multilayered Mirror Monochromator for Photochemistry

BL4A has been constructed to perform the synchrotron radiation induced etching of Si and SiO_2 using XeF_2 as an etching gas. This beam-line is composed of a multilayered mirror (MLM) monochromator, a beam condenser system, and a differential pump system. The XeF_2 pressure during the etching will reach to 0.5 Torr, so a differential pump apparatus is installed in the vacuum system and the etching chamber as shown in Fig. 1. The etching chamber is evacuated independently and is designed to achieve high pressure (0.5 Torr) keeping other vacuum system at low pressure (< 10^{-5} Torr) by an aperture flange and a sequence of pressure stages. The condenser mirror focuses the divergent radiation onto the sample surface in the etching chamber, and obtains an extreme higher photon flux can be obtained.

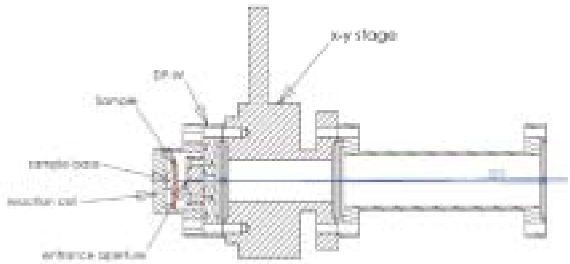


Fig. 1. Section view of differential pump apparatus installed in the etching chamber (reaction cell) and the entrance of beam.

Fig. 2. A side view of the end-station at BL4A.

Beamline Specifications

Monochromator	Multilayered mirror monochromator
Wavelength Range	13.3-22.5 nm; 55-93 eV
Resolution	5-9 eV (FWHM)
Experiment	Irradiation

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.

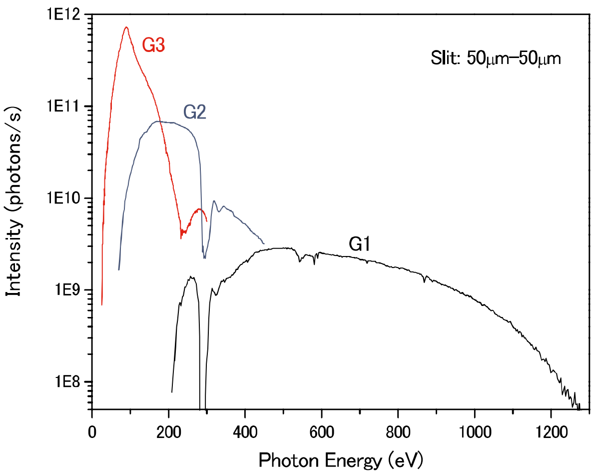


Fig. 1. Throughput from the VLS-PGM monochromator on BL4B.

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)
Experiment	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.

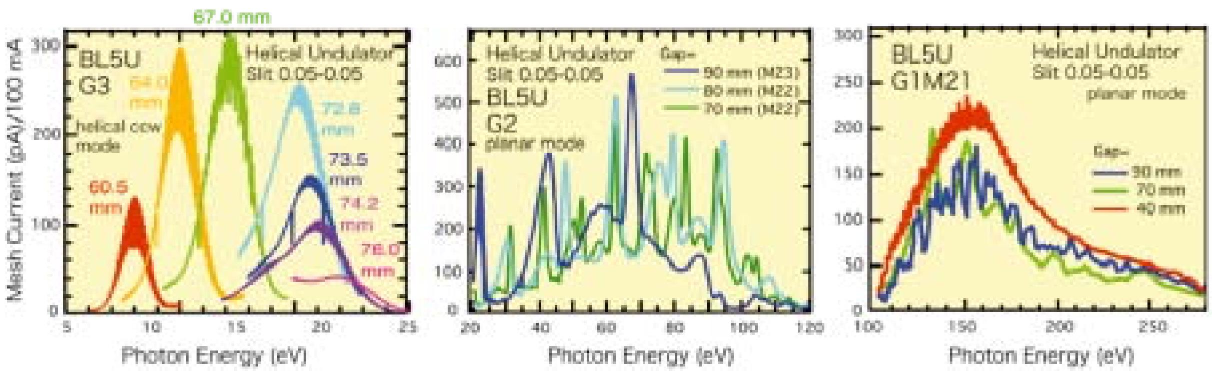


Fig. 1. Throughput spectra from the SGM-TRAIN monochromator at BL5U.

Beamline Specifications

Monochromator	SGM-TRAIN
Energy Range	5-250 eV
Resolution	hν/ΔE >2000 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)

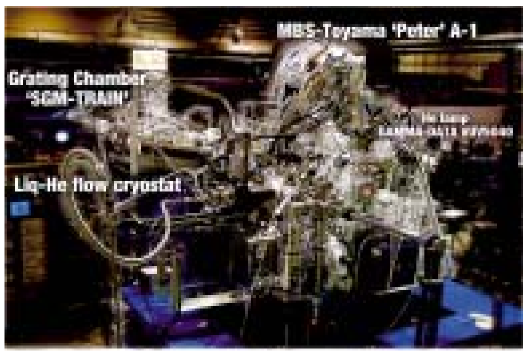


Fig. 2. High-resolution angle-resolved photoemission apparatus at BL5U.

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).

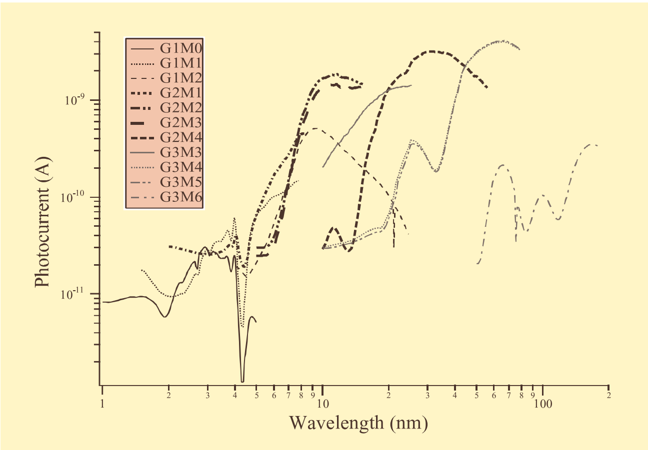


Fig. 1. Throughput spectra for possible combinations of gratings and mirrors at BL5B measured by a gold mesh.

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 throughputs estimated from photocurrent measurements using a Au plate, with the exit-slit opening set at 30 µm, which corresponds to the theoretical resolving power of 10000 at 80 eV.

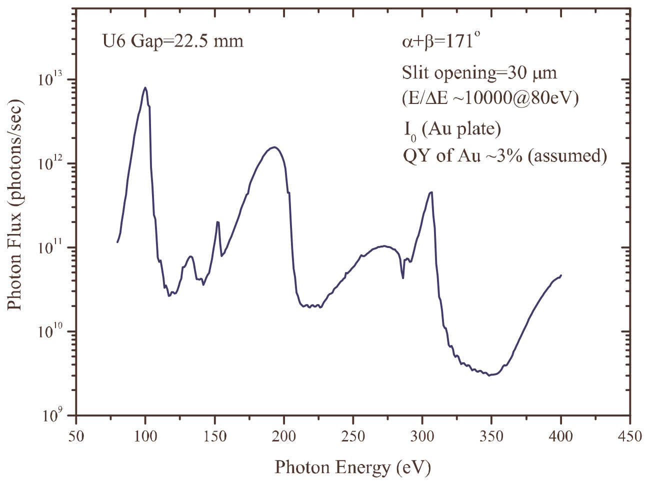


Fig. 1. Throughput from the BL6U monochromator at a given condition.

Fig. 2. Photo of BL6U.

Beamline Specifications

Monochromator	Variable-included-angle varied-line-spacing plane grating monochromator
Energy range	30-500 eV
Resolution	E/ΔE > 10000 (at maximum)
Experiment	High-resolution soft X-ray spectroscopy (mainly, photoelectron spectroscopy for gaseous and solid targets)

BL6B

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 beamline is equipped with two interferometers, one is Michelson-type (Bruker IFS-66v) and the other Martin-Puplett-type (JASCO FARIS-1), to cover the wide spectral region from several to 20,000 cm^{-1} ($h\nu$ = several 100 μeV – 2.5 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.

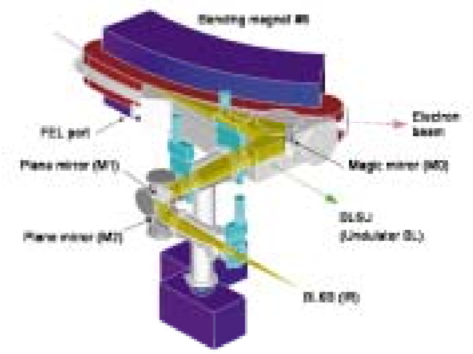


Fig. 1. The design of optics and front end of BL6B.

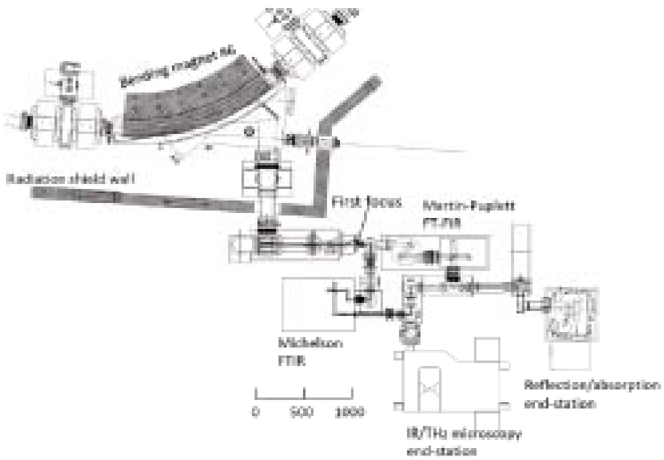


Fig. 2. Schematic figure of top view of BL6B.

Beamline Specifications

Interferometer	Michelson (Bruker IFS66v), Martin-Puplett (JASCO FARIS-1)
Wavenumber Range (Energy range)	several – 20,000 cm^{-1} (several 100 μeV – 2.5 eV)
Resolution in cm^{-1}	0.1cm^{-1} for IFS66v, 0.25cm^{-1} for FARIS-1
Experiments	Reflectivity and transmission, microspectroscopy, and magneto-optics
Miscellaneous	Users can bring their experimental system in this beamline.

BL7U

Angle-Resolved Photoemission of Solids in the VUV Region

The beamline 7U is 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.

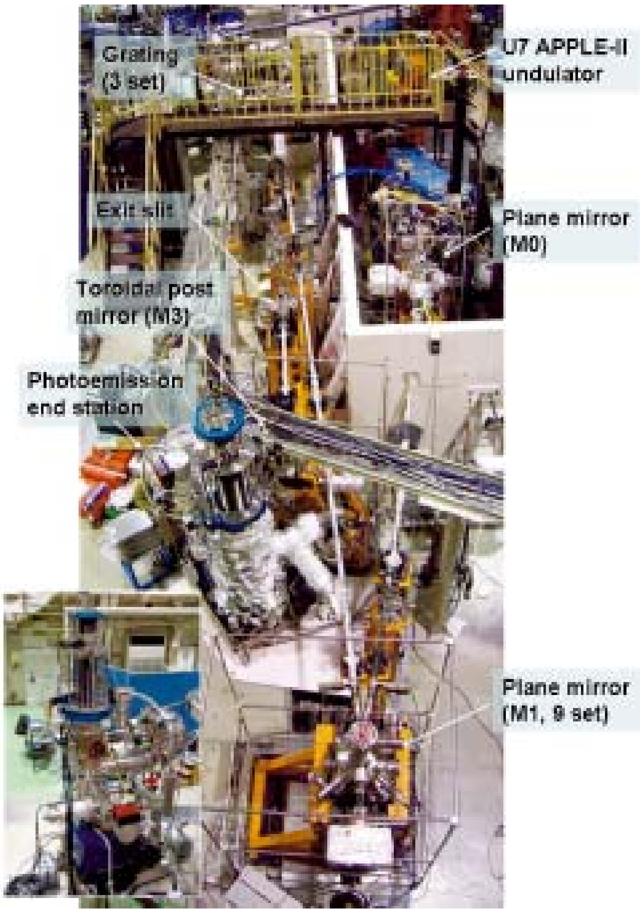


Fig.1. Top-view of BL7U.

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	$\geq10^{12}$ - 10^{11} ph/s (depend on $h\nu$)
Beam size on sample	200(H)×50(V) μm^2
Experiment	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.

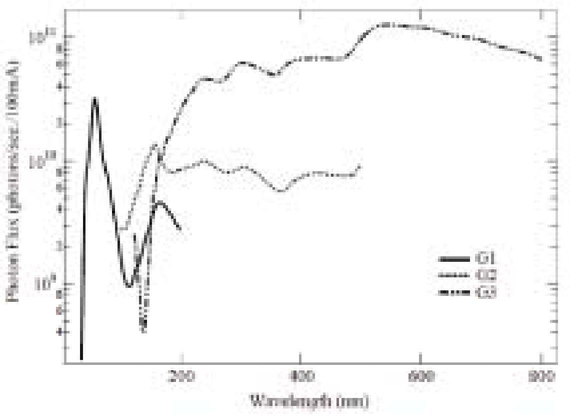


Fig. 1. Throughput spectra of BL7B measured by a silicon photodiode.

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
Experiment	Absorption, reflection, fluorescence spectroscopy, mainly for solids

BL8B1

Spherical Grating Monochromator for Soft X-Ray Spectroscopic Studies on Solids and Surfaces

The beamline BL8B1 equipped with a constant-deviation constant-length spherical grating monochromator [1] provides soft X-ray photons in the energy range 30-800 eV with medium energy resolution. The photon energy range is covered by using three gratings (R=15 m; 1080 l/mm, R=15 m; 540l/m, and R=7.5m; 360 l/mm) which are interchangeable in vacuum. Figure 1 shows a throughput spectrum measured with the entrance- and exit-slit openings of 10 µm. Under this condition, the achievable resolving power is about 4000 at 400 eV and 3000 at 245 eV, respectively.

An experimental chamber is equipped for conventional measurements of electron yield spectra, or pseudo-photoabsorption spectra, under a ~1×10^{-6} Torr vacuum condition.

[1] A. Hiraya *et al*., Rev. Sci. Instrum. **66** (1995) 2104.

Fig. 1. Photo of BL8B1.

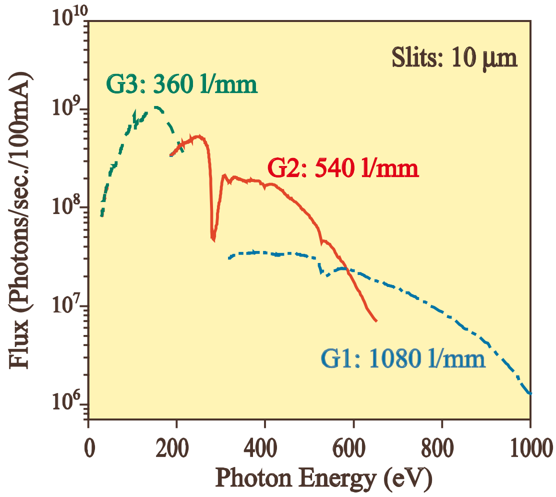


Fig. 2. Throughput of the monochromator at BL8B1.

Beamline Specifications

Monochromator	Constant-deviation constant-length spherical grating type
Energy range	30-800 eV
Resolution	E/ΔE = 4000 at 400 eV and 3000 at 245 eV
Experiment	Photoabsorption spectroscopy, electron spectroscopy and electron-ion coincidence spectroscopy for solids and surfaces

BL8B2

Angle-Resolved Ultraviolet Photoelectron Spectrometer for Solids

BL8B2 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 130 eV with exchanging two 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 about 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/ΔE = 1000 in the wavelength range from 2 to 130 eV. A hemi-spherical electron energy analyzer of 75 mm 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.

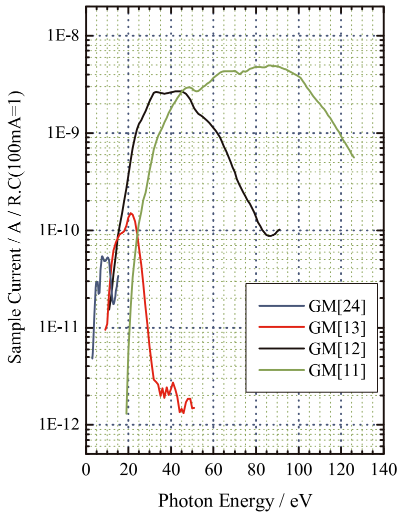


Fig. 1. Throughput spectra of plane-grating monochromator at BL8B2 (slit=100 μm).

Fig. 2. A photo of BL8B2.

Beamline Specifications

Monochromator	Plane-grating monochromator
Wavelength Range	9-600 nm (1.9-150 eV)
Resolution	E/ΔE = 1000
Experiment	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 1 W was recorded at 230 nm and 570 nm. 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.

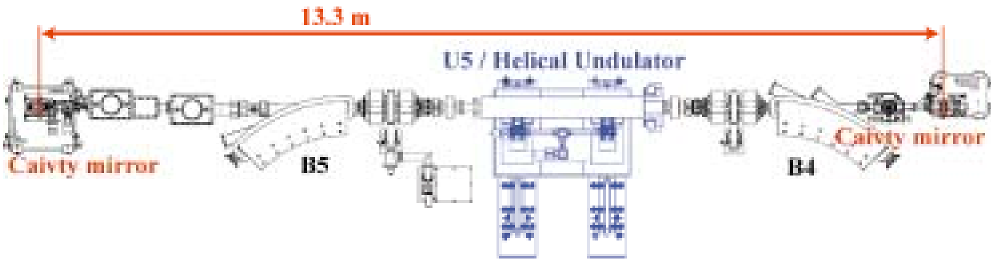


Fig. 1. The schematic of the 13.3-m long optical cavity.

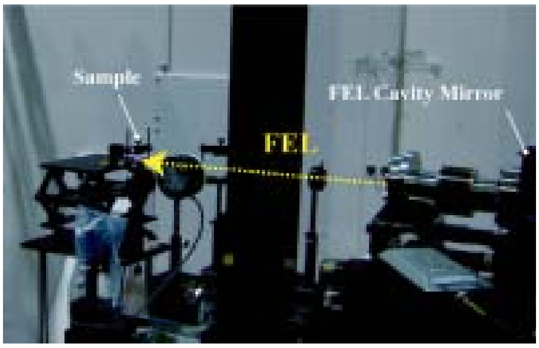


Fig. 2. Left and right circular polarized FEL is delivered to B4.

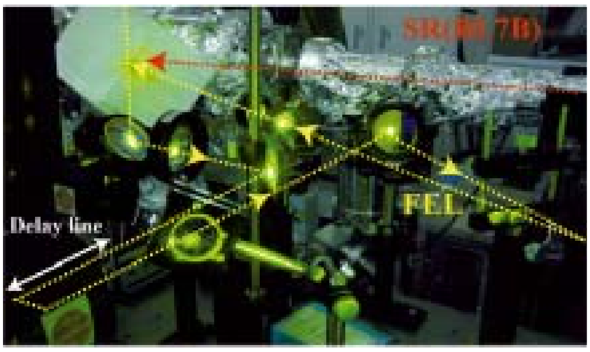


Fig. 3. The FEL is delivered to BL7B. The FEL is irradiated on a target simultaneously with the SR.

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