Light Source in 2003

Masahiro KATOH

UVSOR Facility, Institute for Molecular Science

1. Construction and Commissioning of UVSOR-II

The original UVSOR (UVSOR-I) had been operated for about 20 years as a national VUV light source in Japan. About 20 beam-lines, including a few infrared ones, were utilized for performing various kinds of experiments in the research field for molecular science. After the 20 years, the accelerator components had become less reliable. With the relatively large emittance (160 nm-rad) and only two undulators, it seemed difficult for the facility to survive in the next decade as a national light source, and thus, became our proposal for an upgrade plan in 2000 [1]. The magnetic lattice of the storage ring would be modified to have small emittance of 27 nm-rad. The ring would have eight straight sections, six of which would be available for insertion devices. The circumference would be kept same, and modification of the existing beam-lines would be unnecessary. The super-conducting wiggler and one of two undulators, both old and partly malfunctioned, would be replaced with two short period undulators of in-vacuum type. New beam-lines would be constructed for these undulators. Some components of the injector would be replaced.

The configuration of the upgraded storage ring, UVSOR-II, is illustrated in Figure 1. The quadrupole triplets between the bending magnets are replaced with two quadrupole doublets and a short straight section 1.5 m long. To save space, sextupole magnets are integrated in the quadrupole magnets. The doublets on the both sides of the longer straight sections are also replaced. As a result, the lengths of the sections are increased from 3 m to 4 m.

The optical functions of UVSOR-I and II are compared in Figure 2. The horizontal betatron function and the dispersion function of UVSOR-II have their minima in the bending magnets, and thus a small emittance of 27 nm-rad is realized. The vertical betatron function is small at all the straight sections, which enables insertion devices with narrow pole gaps to be installed. The lattice has a large dynamic aperture in a wide range of the betatron tunes. The parameters of UVSOR-II are summarized in Table 1.

Fortunately, in the fiscal year 2002, the project was funded and all the necessary accelerator components were constructed, such as 32 multi-pole magnets, 16 vertical steering magnets, their power supplies, their girders, their beam ducts, vacuum pumps, an in-vacuum undulator, an electron gun, a klystron pulse modulator and so on. The control systems for the magnets and the undulator were also constructed.

In the end of March 2003, the operation of UVSOR-I was terminated and the reconstruction work was begun. After the old components were removed, the new magnets and their girders were installed. Then, the beam ducts and the vacuum pumps were installed. The magnet power supplies, the new undulator and the new components for the injector were also installed in parallel. All the installations were completed at the end of June. All the vacuum components of the storage ring were baked in the first week of July.

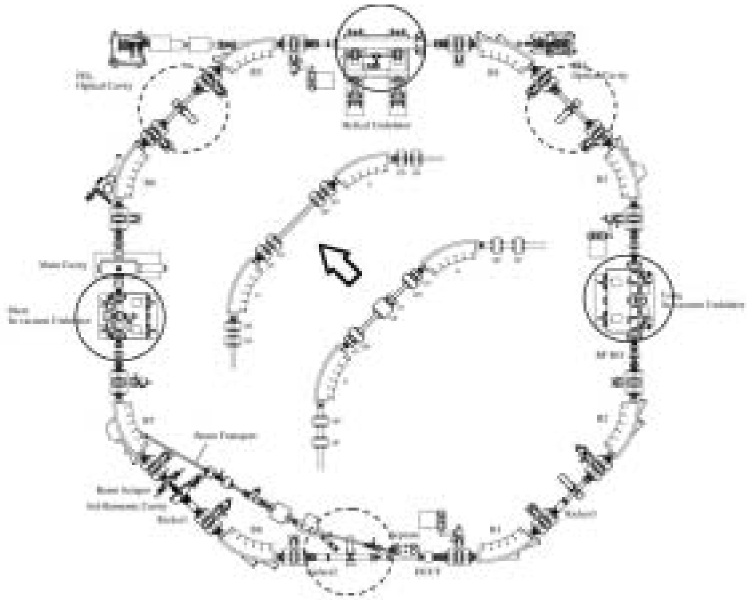


FIGURE 1. Configuration of UVSOR-II Storage Ring. Three undulators indicated by solid circles are in operation. Three short straight sections indicated by dashed circles are reserved for future insertion devices.

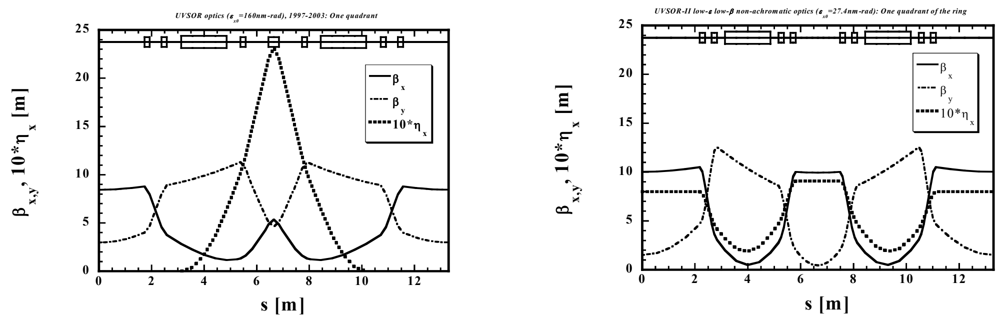


FIGURE 2. Electron Beam Optics of UVSOR-I (left) and II (right). One quadrant of the ring is shown.

TABLE 1. Parameters of UVSOR-I and II

	UVSOR-I	UVSOR-II
Electron Energy	750 MeV	750 MeV
Circumference	53.2 m	53.2 m
Number of Super-periods	4	4
Straight Sections	3 m x 4	4 m x 4, 1.5 m x 4
Emittance	165 nm-rad	27.4 nm-rad
Energy Spread	$4.2\text{x}10^{-4}$	$4.2\text{x}10^{-4}$
Betatron Tunes (ν_x, ν_y)	(3.16, 1.44)	(3.75, 3.20)
Natural Chromaticity (ξ_x, ξ_y)	(-3.4, -2.5)	(-8.1, -7.3)
Momentum Compaction Factor	0.026	0.028
XY Coupling (presumed)	10%	10%

FIGURE 3. UVSOR just after removing old accelerator components

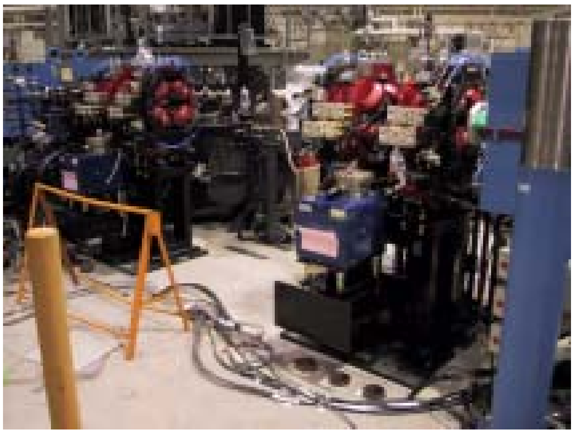


FIGURE 4. New multi-pole magnets and their girders just after the installation

FIGURE 5. Installation of the beam duct for the bending magnet B07

FIGURE 6. Installation of the beam duct for the multi-pole magnets

FIGURE 7. Alignment of the accelerator components

FIGURE 8. New In-vacuum undulator being transported in the storage ring room

FIGURE 9. A part of the storage ring (between B02 and B04) just after finishing the installation. New in-vacuum undulator between B02 and B03, and a short free space reserved for future undulator can be seen.

FIGURE 10. New control system for the magnets

FIGURE 11. New controllers and power supplies for vacuum pumps and gauges

FIGURE 12. New magnet power supplies

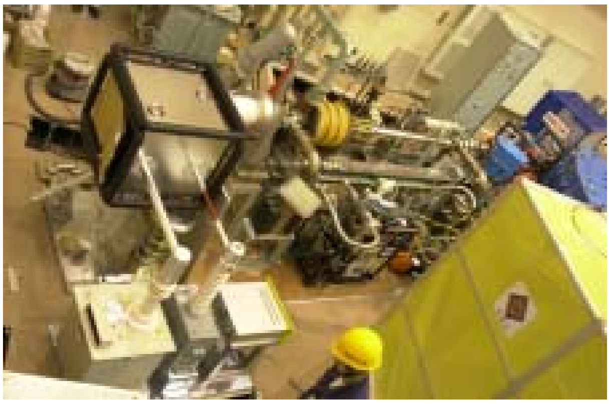


FIGURE 13. Installation of the new electron gun for the injection linac

FIGURE 14. UVSOR-II just after finishing the installation

We started the commissioning of the injector during the first week of July. Within two days, we were able to accelerate the electron beam up to 600 MeV, the normal injection energy into the storage ring. The injection efficiency into the booster-synchrotron from the linac was much improved. The beam intensity at the exit of the synchrotron was larger by a factor of 2 than before the upgrade.

In the second week of July, we started to inject the beam into the storage ring. We started the commissioning using the same betatron tunes and nearly the same optical functions as we had prior to the upgrade. On 14th July, we succeeded in storing the beam in the storage ring. One week later, the maximum beam current reached 500 mA. On 30th July, we succeeded in operating the ring in the low emittance mode of 27 nm-rad. There was no difficulty in injection and storage. Preliminary measurements on the optical functions and the beam sizes suggested that the design goal of 27 nm-rad was likely achieved. The beam profile in the low emittance mode (27nm-rad) and the high emittance mode (190nm-rad) are compared in Fig. 15. More precise measurement is under preparation.

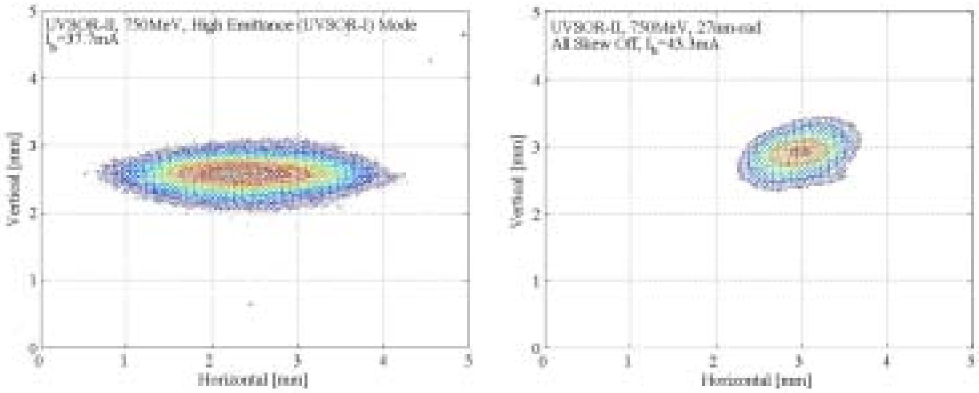


FIGURE 15. Beam Profile observed at the bending B03 in the high emittance (190nm-rad) mode (left) and the low emittance (27nm-rad) mode (right).

In August, the machine tuning and the vacuum conditioning were continued in parallel with the conditioning of the beam-lines. Since almost two thirds of the beam ducts in the storage ring were replaced, the pressure rise due to the irradiation of synchrotron radiation was very large. However, as the integrated beam current increased, the beam lifetime recovered as shown in Figure 16.

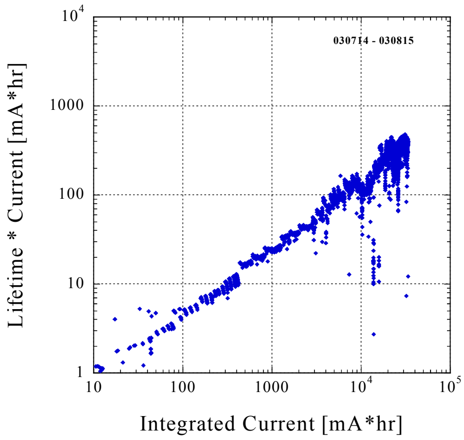


FIGURE 16. Recovery of the beam lifetime during the first one month. The lifetime multiplied by the beam current is illustrated versus time-integrated beam current. The normal lifetime of UVSOR-I was about 1000-1500 mA

2. Operation of UVSOR-II

After the conditionings of the machine and the beam-lines in July and August, the operation for the users was re-started in the first week of September. A moderately small emittance of 60 nm-rad was chosen for the initial stage of the users operation as considering the short Touschek lifetime. After the RF cavity is reinforced, users operation with the smaller emittance of 27 nm-rad will be started.

From the first week of September to the last week of March, 2004, the machine has been operated for users. The operation was stopped only for two weeks around the New Years Day. Normally, from Tuesday to Friday, the machine is operated for users. The injection is twice a day, at 9:00 and 15:00. The initial beam current of each run is 350 mA in multi-bunch condition and about 100 mA in single bunch condition. There was no serious trouble on the machine in the first 7 month operation of UVSOR-II. The monthly statistics of the operation time and the integrated beam current are shown in Figures 17 and 18.

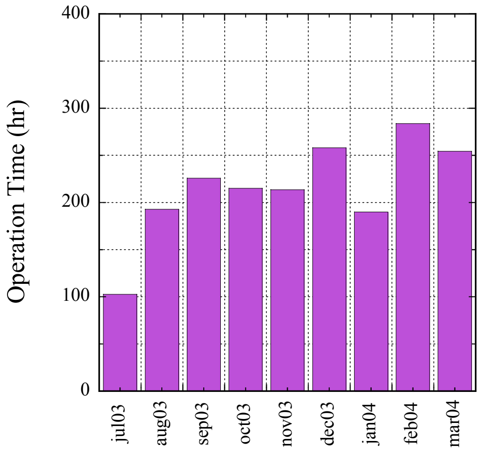


FIGURE 17. Monthly statistics of the operation time

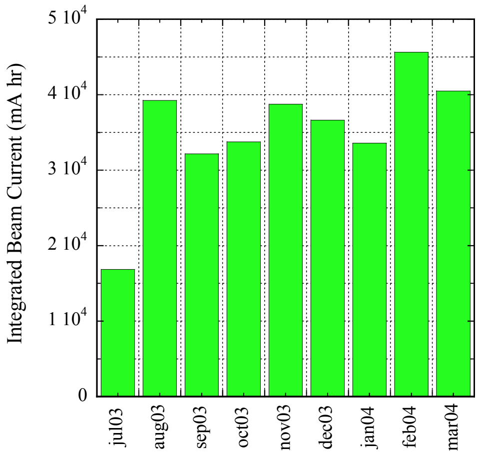


FIGURE 18. Monthly statistics of the integrated beam current

3. Improvements

Second In-vacuum Undulator for BL3U

In parallel with the reconstruction of the storage ring, an in-vacuum undulator was installed at a straight section between the bending magnet B02 and B03, as shown in Figure 19. This undulator provides intense VUV radiation to the BL3U, which was also newly constructed during the reconstruction of the ring. The main parameters of the undulator are shown in the Table 2. The period length is 38 mm and the number of the periods is 50.

The minimum pole gap is 15 mm for the beam optics shown in Figure 2. The minimum gap is a very important parameter which limited the tunability. We made a measurement on the pole gap and the beam lifetime and got an unexpected result. A reduction of the beam lifetime was observed for the pole gap smaller than 20 mm, which was larger than expected. We made various measurements and were convinced that the undulator had some problem. Later, in April 2004, we opened the vacuum chamber and found that a small bolt of a few mm was on the lower pole that came out of the upper pole. After removing the bolt, we could confirm that the pole gap of 15 mm did not affect the lifetime.

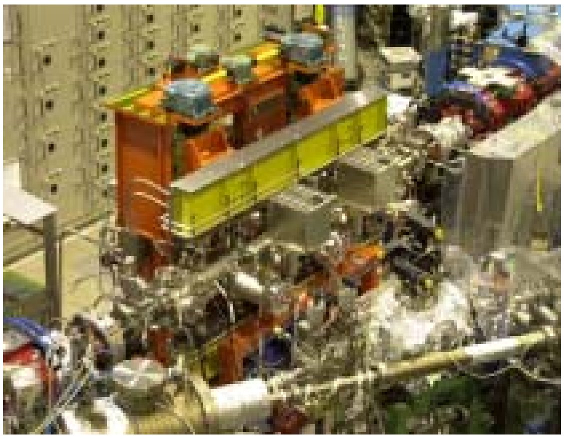


FIGURE 19. In-vacuum undulator for BL3U

TABLE 2. Parameters of Undulator for BL3U

Type	in-vacuum
Polarity	linear
Number of Periods	50
Period Length	38 mm
Pole Length	1.9 m
Max. K Parameter	2.0

New Optical Station for Beam Diagnostics

At the bending magnet B03 and B07, there are SR ports for beam diagnostics. New optical station was constructed near B03, inside of the ring. Visible light from B03 is introduced to the station. The beam profile can be monitored by a CCD camera. The beam sizes can be measured precisely by an interferometer. Purity of the RF bucket can be monitored by a PM tube.

4. Researches and Developments

Free Electron Laser

The smaller emittance of UVSOR-II has a great advantage on the free electron laser, especially to oscillate in the shorter wave length region [2]. In November, we re-started the FEL experiment with the re-alignment of the optical cavity. In December 1st, we could oscillate in the visible region. A preliminarily measurement on the FEL gain indicated an increase of the gain due to the smaller emittance.

Design of the new RF cavity

In the fiscal year 2004, the new RF cavity will be constructed. As the result of the design study, main parameters of the new cavity was decided to be as shown in Table 3. With the present RF power source whose maximum output power is 20 kW, the new cavity will produce 150 kV accelerating voltage for the beam current of 500 mA. This will greatly improve the Touschek lifetime as shown in Figure 20. The new cavity will be installed in the ring in April 2005.

TABLE 3. Basic specification of present/planned RF cavity.

	Present Cavity	Planned Cavity
Frequency	90.1 MHz	90.1 MHz
Cavity voltage	55 kV	150 kV
Shunt impedance	0.5 MΩ	2.2 MΩ
Material	SUS + Cu	Cu (OFHC)
Cells	Re-entrant×1	Re-entrant×1
Coupler	Air-cooled	Water-cooled
Tuner	Plunger×1	Plunger×2

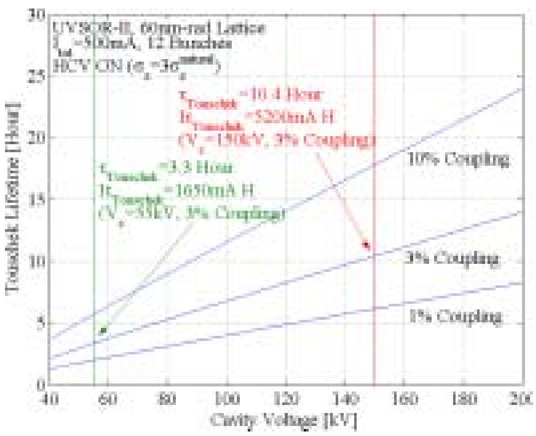


FIGURE 20. Change in Touschek lifetime on the caviti voltage. Green and red lines correspond to the present and planned cavity voltage, respectively.

[1] M. Katoh et al., Nuclear Instruments and Methods in Physics Research A, 467-468 (2001), 68-71

[2] M. Hosaka et al., presented at the 2003 FEL Conference (Tsukuba, 2003)

UVSOR Accelerator Complex 2003

Parameters of UVSOR-II Storage Ring (Upgraded UVSOR)

Energy	750 MeV
Injection Energy	600 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	(4m × 4) + (1.5m × 4)
RF Voltage	55 kV
Betatron Tune Horizontal Vertical	 3.75 3.20
Momentum Compaction	0.028
Natural Chromaticity Horizontal Vertical	 -8.1 -7.3
Energy Spread	4.2×10^{-4}
Natural Bunch Length	160 ps

Parameters of Injector

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	600 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
Vertical	1.25
Momentum Compaction	0.138
Repetition Rate	2.6 Hz

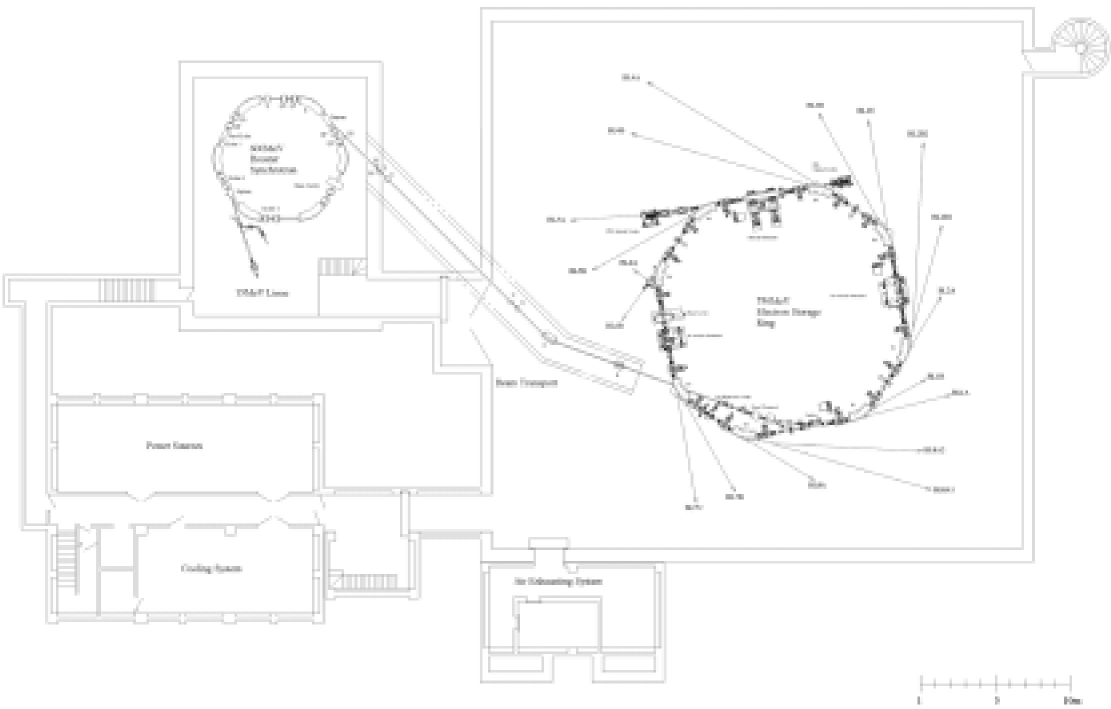


Fig. 1 Accelerator complex in the UVSOR facility.

Electron Beam Optics of UVSOR-II Storage Ring

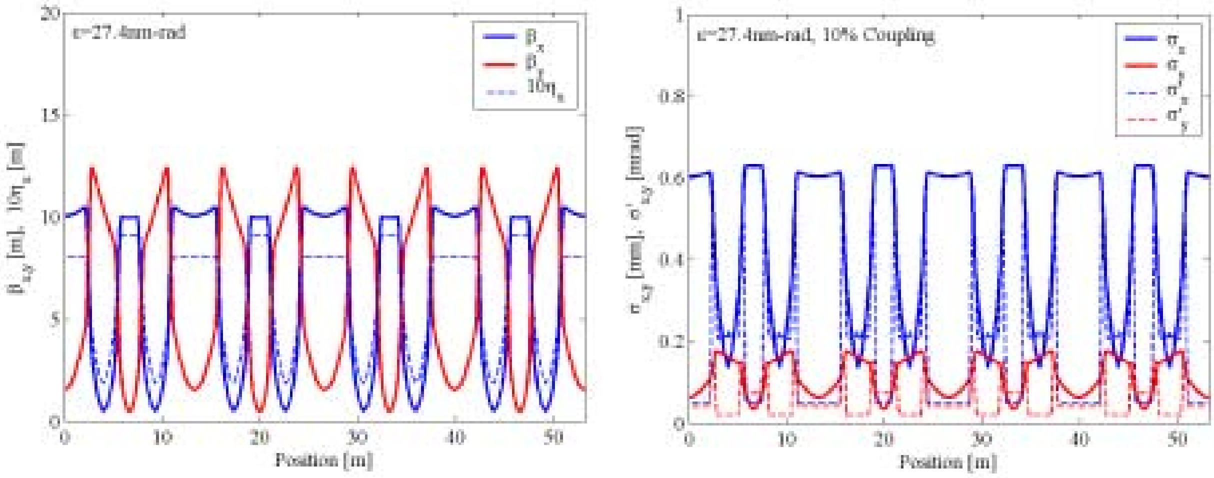


Fig. 2. (Left)Horizontal/vertical betatron functions and dispersion function, and (right) horizontal/vertical electron beam sizes and beam divergences of the UVSOR-II electron storage ring.

Synchrotron Radiation Spectra & Light Source Parameters

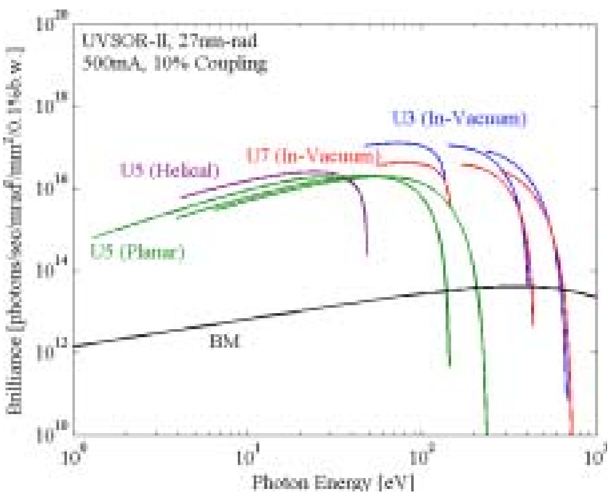


Fig. 3. Brilliances of light sources in UVSOR-II electron storage ring.

Bending Magnets

Bending Radius	**2.2 m**
Critical Energy	**425 eV**

BL3U In-vacuum Undulator

Number of Periods	**50**
Period Length	**38mm**
Pole Length	**1.9 m**
Pole Gap	**15~40mm**
Deflection Parameter	**2.0~0.24**

BL5U Helical Undulator / Optical Klystron

Number of Periods	**21 / 9+9(Opt. Kly.)**
Period Length	**110mm**
Pole Length	**23.5mm**
Pole Gap	**30~150mm**
Deflection Parameter	**4.6~0.07(Helical) 8.5~0.15(Linear)**

BL7U In-vacuum Undulator

Number of Periods	**26**
Period Length	**36mm**
Pole Length	**0.94m**
Pole Gap	**15~40mm**
Deflection Parameter	**2.0~0.19**

Beamlines in 2003

Eiji SHIGEMASA

UVSOR Facility, Institute for Molecular Science

Eight bending magnets and three insertion devices are available for utilizing Synchrotron Radiation at UVSOR. There is a total of sixteen operational beamlines, which are classified into two categories. Eight 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 eight 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, and three non-monochromatized stations for irradiation of white-light, as shown in the appended table for all available beamlines at UVSOR.

Discussion with users, concerning the improvements and upgrades of the beamlines at UVSOR, has been continuously held as series of UVSOR workshops. Recently, discussion for the reconstruction and rearrangement of several old beamlines has been initiated, on the basis of the review and evaluation report on the present status of UVSOR in 2000. The upgrade project of the UVSOR storage ring, in which the creation of four new straight sections and the achievement of much smaller emittance (27 nm-rad) were planned, has been approved in the fiscal year of 2002. Keeping pace with this project, a new in-vacuum undulator and monochromator for BL3 and a new high-resolution photoelectron energy analyzer for the end station at BL5U have successfully been installed. Correspondingly, in order to achieve effective utilizations of the straight sections, the operations of two old beamlines, BL2A and BL2B1, have been terminated and all the beamline components and end stations of these beamlines have been completely removed till the end of FY 2003. Parallel to the UVSOR upgrade project, the renewal of the vacuum duct at BL6 was initially scheduled in the spring of 2003, but has been postponed until the regular shutdown in the spring of 2004. In coincidence with this, a so-called magic mirror will be installed as the first mirror for BL6B, to realize the highest intensity in the wavelength range from sub-milli to near IR region all over the world. The front-end part of BL6B will be renewed to make place for BL6A. As a result, we have two vacant lots at BL2A and BL6A to construct novel beamlines. The short straight section between B01 and B02 is planned to utilize for a new RF cavity; BL2A will be a bending-magnet beamline while BL6A is to be an undulator one. Accordingly, the long straight section between B06 and B07, where the in-vacuum undulator of 1-m long for BL7U and the present RF cavity lie, will be available for a new undulator with the length more than 2 m. Further serious discussion toward utilizing the available straight sections most effectively and formulating a basic plan on the beamline construction, will be made in the near future.

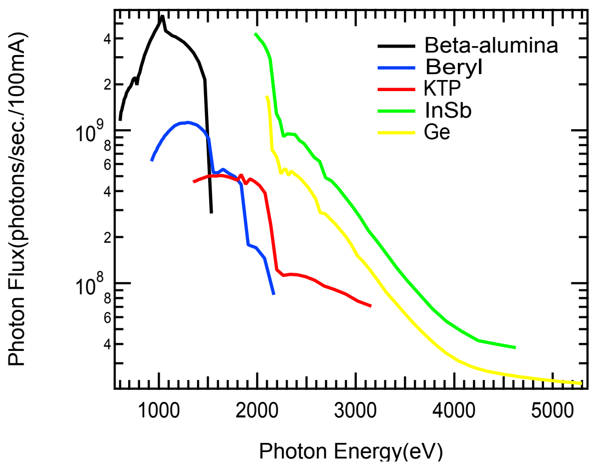
All users are required to refer to the beamline manuals and the UVSOR guidebook (latest revision in 1999), on the occasion of conducting the actual experimental procedures. Those wishing to use the open and in-house beamlines are recommended to contact the stationmaster/supervisor and the representative, respectively. For updated information of UVSOR, http://www.uvsor.ims.ac.jp/.

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, 1264 (1992).



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 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.

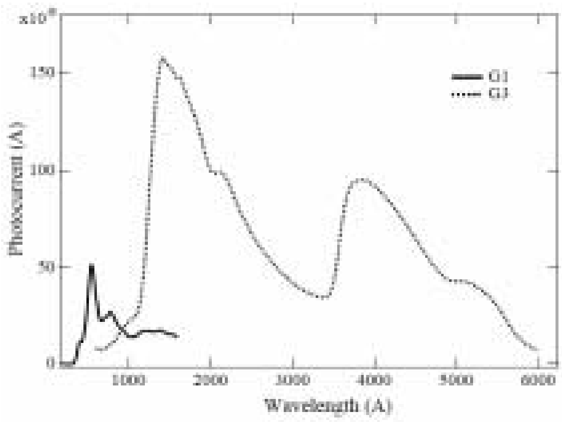


Fig. 1. Photocurrent at the sample position at BL1B.

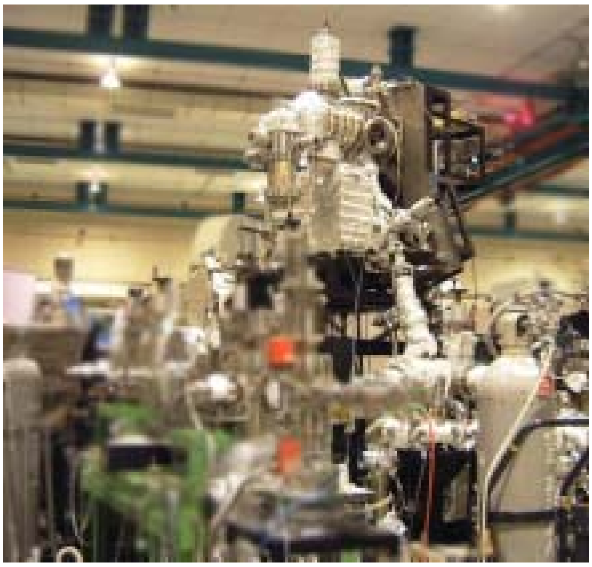


Fig. 2. Photo of BL1B.

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

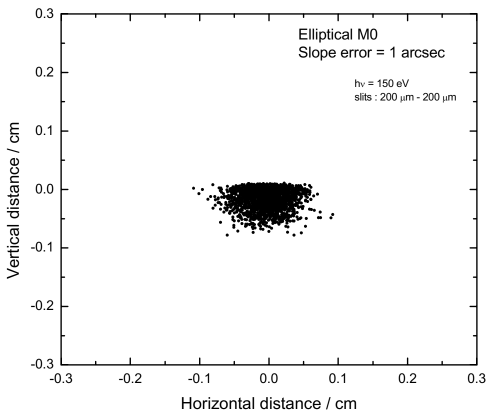
Beamline for Gas Phase Photoionization and Reaction Dynamics

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]. A second-order light of 7 % is contained at a photon energy of 45.6 eV (G3). 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.

We have been taking photoion yield curves of various fullerenes. 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 is very limited in the extreme UV region, which has been probably due to difficulties in acquiring enough amount of sample. This situation has been rapidly changed in these few years, since the techniques of syntheses, isolation, and purification have been advanced so rapidly that appreciable amount of fullerenes can be readily obtained.

[1] M. Ono *et al.*, *Nucl. Instrum. Meth. Phys. Res. A* **467-468**, 577 (2001).

[2] H. Yoshida and K. Mitsuke, *J. Synchrotron Radiat.* **5,** 774 (1998).



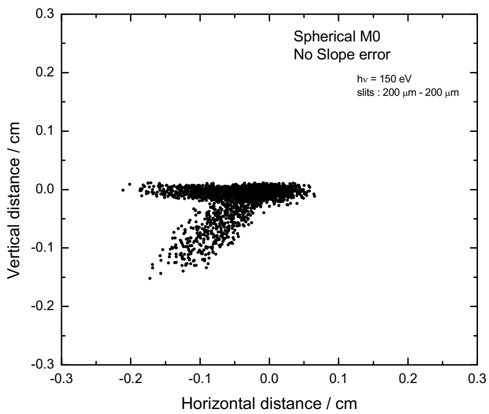


Figure 1. Spot profiles at the sample point. (Left) employing meridional elliptical M0 prefocusing mirror with a slope error of 1 arcsec RMS. (Right) employing spherical M0 mirror without slope error.

Beamline Specifications

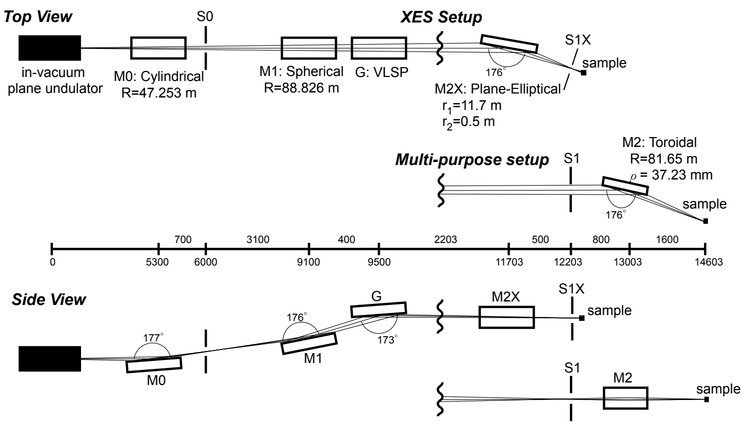
Monochromator	18-m spherical grating Dragon-type
Wavelength Range	6 – 55 nm
Resolution	2000-8000
Experiment	Mass spectrom.; Photoelectron spectrosc.

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 on the exit slit by plane-elliptical mirror in order to produce beam size less than 50 micron. 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.



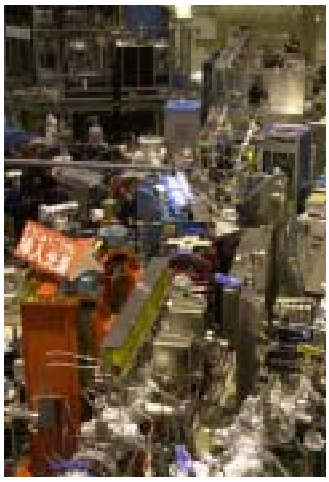


Fig. 1. Schematic layout (left) and the photography (right) of the BL3U. The distances along the beam from the center of the in-vacuum plane undulator are shown in mm. S1X and M2X can be replaced with the other exit slit S1 so that experiments can be carried out at either the XES or multi-purpose endstation. 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 > 7000
Experiment	Soft X-ray spectroscopy (XPS, XES, XAS)

BL3B

Beamline for Gas Phase Photoelectron Spectroscopy

This beam line is devoted to studies of elementary atomic and molecular processes induced by excitation of valence electrons. A monochromator is a vertically dispersed normal incidence type with 3m focal length and 10° angle between the incident and diffracted photon beams. The maximum wavelength resolution of 0.007nm is narrow enough to separate vibrational levels of excited states for various molecules. A main component in an experimental chamber is a spherical sector electrostatic energy analyzer which has been designed and setup for photoelectron spectroscopy. One can perform two-dimensional photoelectron spectroscopy with good resolution (≤ 30meV) in which the photoelectron yield is measured as a function of both photon energy and electron kinetic energy (binding energy). A two-dimensional spectrum, usually represented as a contour plot, contains rich information on photoionization dynamics and properties of superexcited states. A great variety of interesting high-lying states involved in autoionization have been studied (please see the references).

[1] K. Mitsuke *et al.*, *J. Electron Spectrosc. Rel. Phenom.* **79**, 395 (1996).
[2] H. Hattori and K. Mitsuke, *ibid.* **80**, 1 (1996); H. Hattori *et al.*, *J. Chem. Phys.* **106**, 4902 (1997).
[3] Y. Hikosaka *et al.*, *J. Chem. Phys.* **105**, 6367 (1996); *ibid.* **107**, 2950 (1997); *ibid.* **110**, 335 (1999).
[4] K. Mitsuke *et al.*, *J. Electron Spectrosc. Rel. Phenom.* **112**, 137 (2000).
[5] Y. Hikosaka and K. Mitsuke, *J. Phys. Chem.* **105**, 8130 (2001); *J. Chem. Phys.* **121**, xxxx (2004).

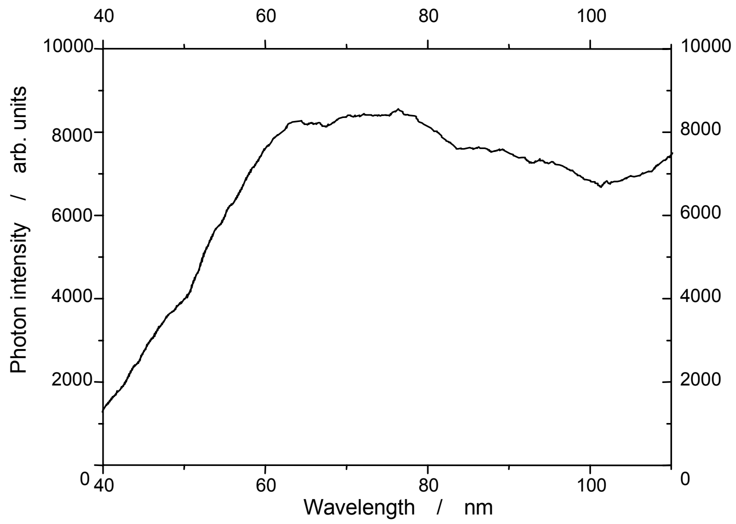


Fig. 1. Relative photon intensity at the sample point of BL3B.

Beamline Specifications

Monochromator	3-m normal incidence
Wavelength Range	30 – 200 nm
Resolution	14000 at 100 nm
Experiment	Photoelectron Spectroscopy

BL4A2

SR-CVD beam line

This beam line is used for synchrotron radiation chemical vapor deposition (SR-CVD) and photo-etching experiments. The beam line has no monochromator for high photon flux to irradiate and consists of only two mirrors. One is for focusing and the other is for branching. At the beam line, the gas supply and extinction system is equipped for using legally controlled high pressure gasses such as SiH_4, Si_2H_6 and GeH_4. They are commonly used to CVD of semiconductor crystals.

The SR-CVD and photo-etching chambers are connected to the beam line as shown in Fig. 1. In those chambers, infrared reflection absorption spectroscopy (IRRAS) system is installed to study the surface photochemistry on Si surfaces modified with various kinds of molecules.

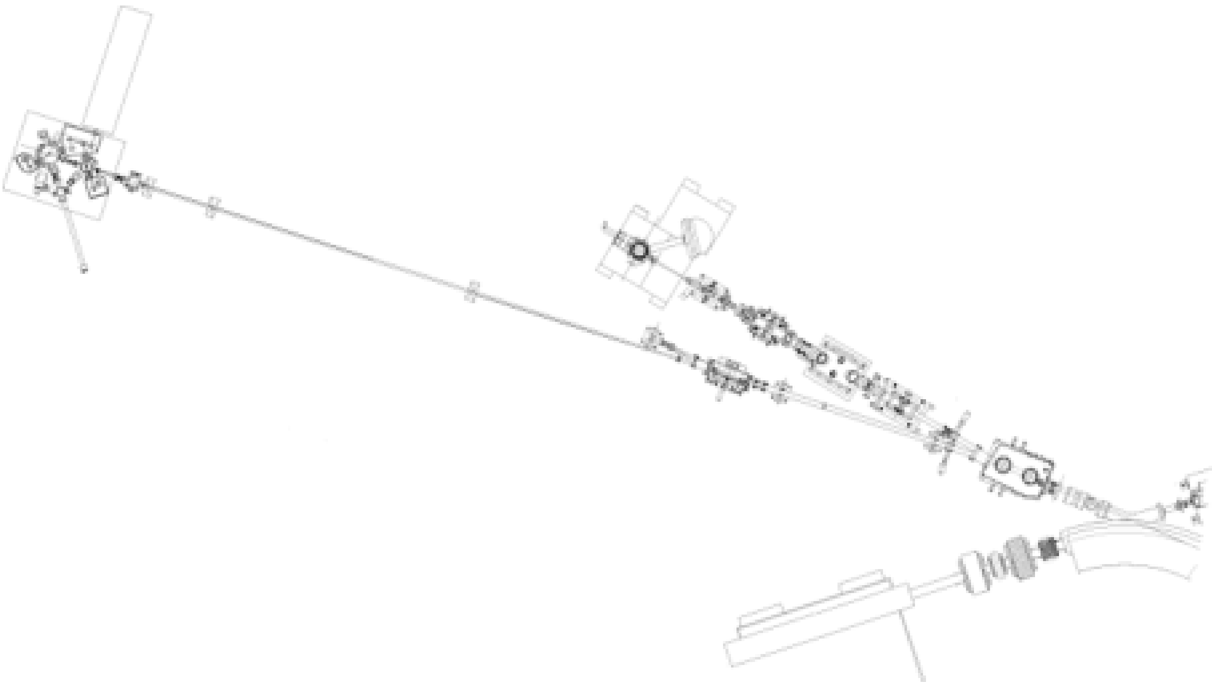


Figure 1 Top view of BL4A2

Specifications

Spectral range: whole range of synchrotron radiation from UVSOR

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. Two holographically ruled laminar profile plane gratings with SiO_2 substrates are designed to cover the photon energy range from 80 eV to 800 eV. The gratings with the groove densities of 267 and 800 l/mm cover the spectral ranges of 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 25 and 10 μm, respectively. Under this condition, the corresponding resolving power (E/ΔE) for the 800 l/mm grating is expected to be more than 8000 at 400 eV.

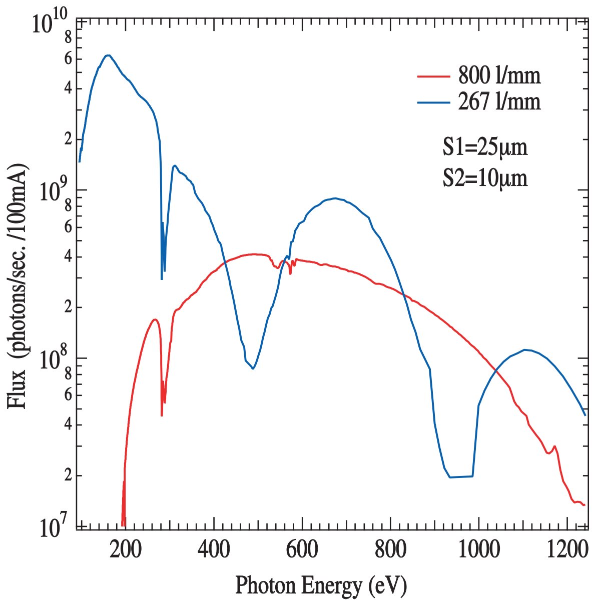


Fig. 1 Throughput from the VLS-PGM monochromator on BL4B.

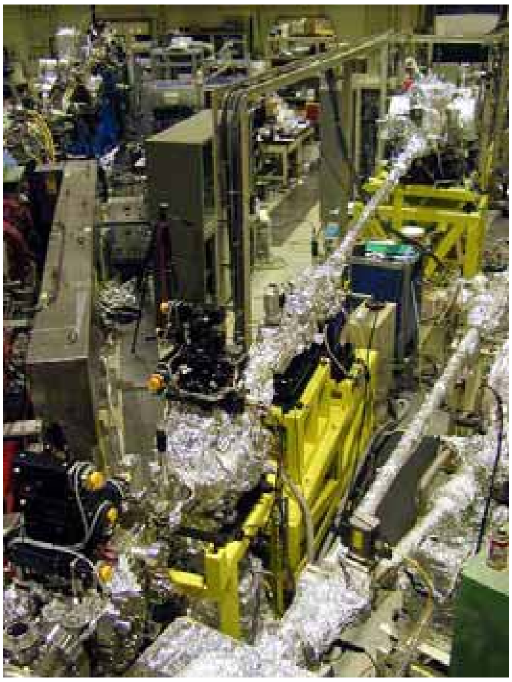


Fig. 2 A photo of BL4B taken from the upper platform of BL3B.

Beamline Specifications

Monochromator	Varied-line-spacing Plane Grating Monochromator
Energy range	60-1000 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

Photoelectron Spectrometer for Solids and Surfaces

This beamline is designed for high-resolution angle-resolved photoemission study for solids and surfaces with the linearly and circularly 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) wide energy range of 5-250 eV, (2) high resolving power, (3) use of linearly and circularly polarized light, (4) reduction of second-order light, and (5) two driving modes by a computer control. The second-order light is well suppressed by using laminar profile gratings and combinations of mirrors and gratings.

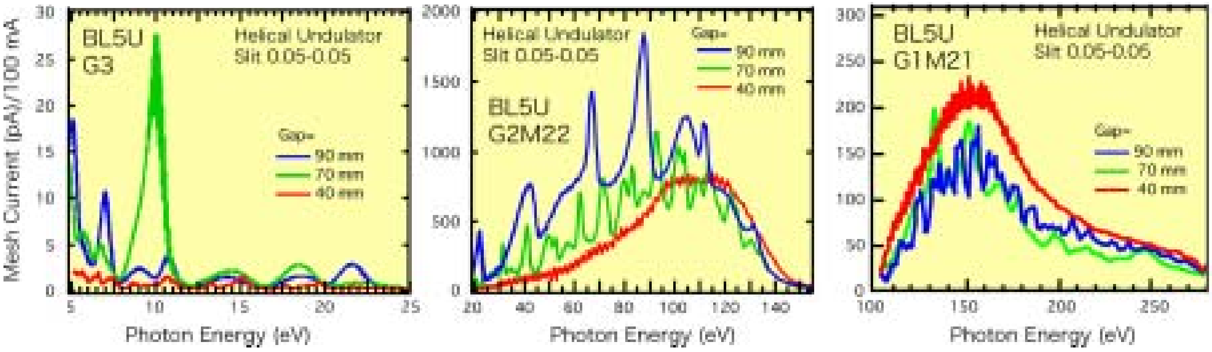


Fig. 1. Throughput from the SGM-TRAIN monochromator on BL5U.

Beamline Specifications

Monochromator	SGM-TRAIN
Energy Range	5-250 eV
Resolution	0.5-80 meV (with slits width of 0.01 mm)
Experiment	ARPES, AIPES, XAS
Flux	1x 10^{12} photons/s for undulator radiation in MPW mode
Main Instruments	Hemispherical photoelectron analyzer (MBS-Toyama, A-1), LEED of reverse type (OMICRON), Liq-He flow qryostat (5 – 400 K)

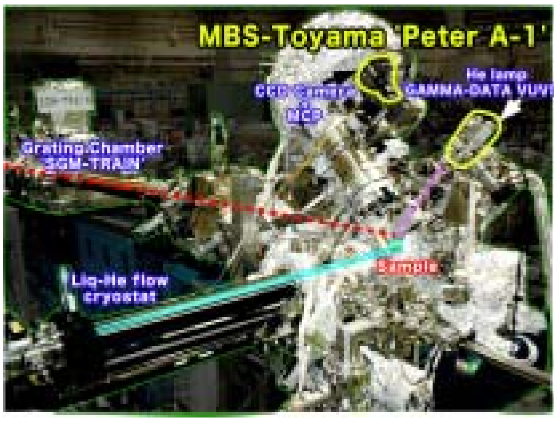


Fig. 2. High-resolution angle-resolved photoemission apparatus for BL5U

BL6B (IR)

Infrared and terahertz spectroscopy of solids

SR has a good performance (high brilliance and high flux) not only in VUV and SX regions but also in IR and terahertz regions. This beamline covers in the IR and terahertz regions. The previous beamline BL6A1 that has been constructed in 1985 is the pioneer of the infrared SR research. The beamline was upgraded in the spring of 2004 and the name was changed to be BL6B (IR). The front-end part including the bending duct #6 was replaced to a new one with higher acceptance angle using a magic mirror as shown in Fig. 1.

The beamline is equipped with two interferometers, one is Michelson-type (Bruker IFS-66v) and the other Martin-Puplett-type (JASCO FARIS-1), for the wide spectral region from several to 20,000 cm^{-1} ($h\nu$ = several 100 μeV – 2.5 eV) as shown in Fig. 2. The experimental chamber in which users bring can be equipped at the free port. In the near future, an IR microscope covering down to terahertz region will be set up.

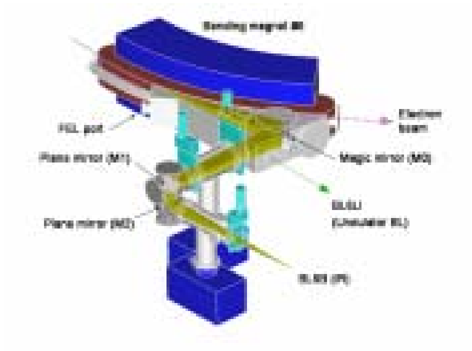


Fig. 1. The design of optics and front end of BL6B.

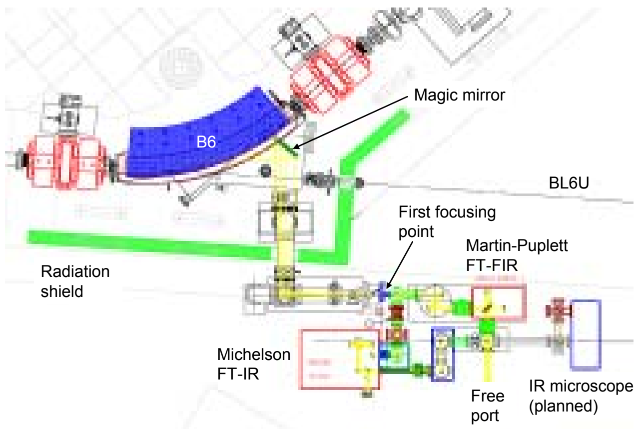


Fig. 2. Schematic figure of top view of BL6B.

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 Magneto-optics (Microspectroscopy)
Miscellaneous	Users can bring their experimental system in this beamline.

BL7U

Undulator Irradiation Beamline for STM Observation

This beamline has been constructed for STM observation of surface photochemical reactions stimulated by undulator irradiation. The schematic drawing of the BL7U is shown in Fig. 1. The undulator is in-vacuum type, of which the period is 36 mm and the number of the period is 26. The 1st harmonic is tuned from 70 eV to 140 eV [4]. Two Pt-coated cylindrical mirrors are used for the vertical and horizontal focusing. These two mirrors also suppress the higher harmonics of the undulator radiation into ~10% with respect to the first harmonic. The focus point is set at the point of 9100 mm downstream from the middle of the undulator. The spot size on the sample surface was 1.0 mm (H) x 0.4 mm (V) and the estimated photon flux density was 10^{18} photons (cm^2 sec 100 mA)$^{-1}$.

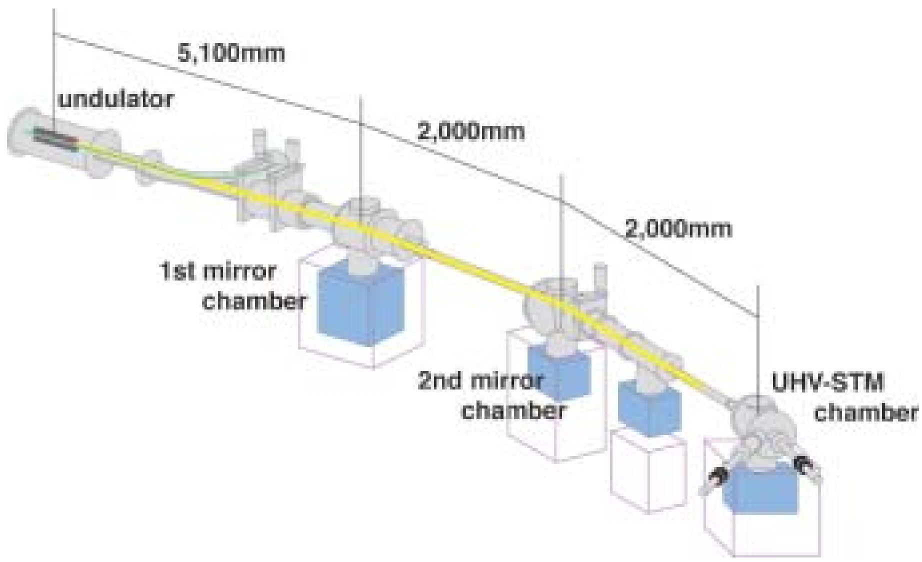


Fig. 1.Schematic drawing of BL7U

Beamline Specifications

Monochromator	None
Wavelength Range	70 – 140 eV (1st harmonic)
Resolution	~10 -
Experiment	Undulator Irradiation and STM Observation
Miscellaneous	

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 MgF2 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.

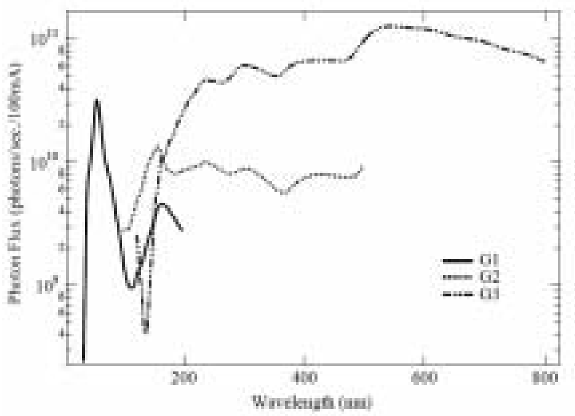


Fig. 1. Throughput spectra of BL7B measured by a silicon photodiode.

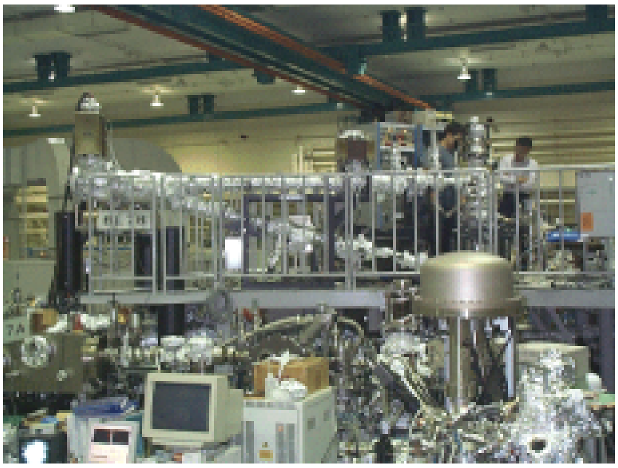


Fig. 2. Photo of BL7B.

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

BL8A

Irradiation Beamline for Studies of Photochemical Reaction on Solids

The beamline BL8A was constructed for providing synchrotron radiation without monochromatizaion. The white synchrotron radiation is focused into a 3.5 mm × 2.5 mm size by use of a toroidal mirror. The focusing mirror can be removed for obtaining a bigger irradiation area. A differential pumping system with three stages is introduced, which enables users to perform experiments under a very low vacuum condition (<0.5 Torr). The intense white light available at this beamline is suitable for studies on photochemical reaction, chemical vapor deposition, photo-etching and irradiation damage effects. No standing experimental stations are placed at the beamline; users may install their own experimental chambers, while some standard chambers are arranged by UVSOR.

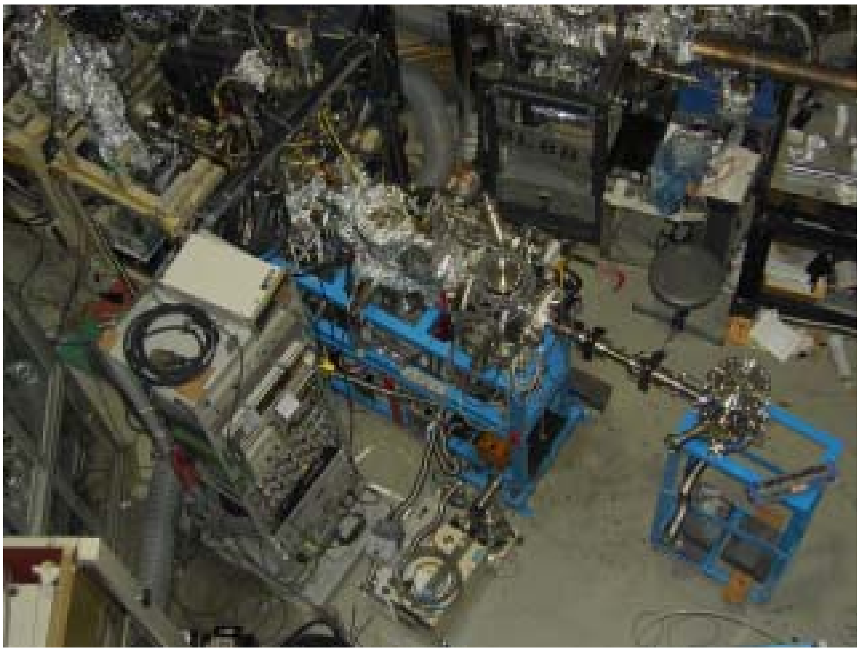


Fig. 1. A top-view photo of the beamline.

Beamline Specifications

Monochromator	None
Energy Range	The whole energy range of the synchrotron radiation
Resolution	—
Experiments	Photochemical reaction, chemical vapor deposition and photo-etching experiments
Miscellaneous	Beam spot size: (H)3.5 mm × (V)2.5 mm

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.

Two experimental chambers are arranged for users. One of them has recently been placed at BL8B1, which used to be at BL2B1 for a long time. This chamber is equipped with an electron-ion coincidence spectrometer, a double-pass cylindrical mirror analyzer, a LEED of reverse type, a quadrupole mass spectrometer, an ion-gun for sputtering, and a liquid helium cryostat. Photoelectron and Auger spectroscopies for solids and surfaces are feasible under ultra-high vacuum ($\sim 1\times10^{-10}$ Torr). The other experimental chamber is for conventional measurements of electron yield spectra, or pseudo-photoabsorption spectra, under a $\sim 1\times10^{-6}$ Torr vacuum condition.

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

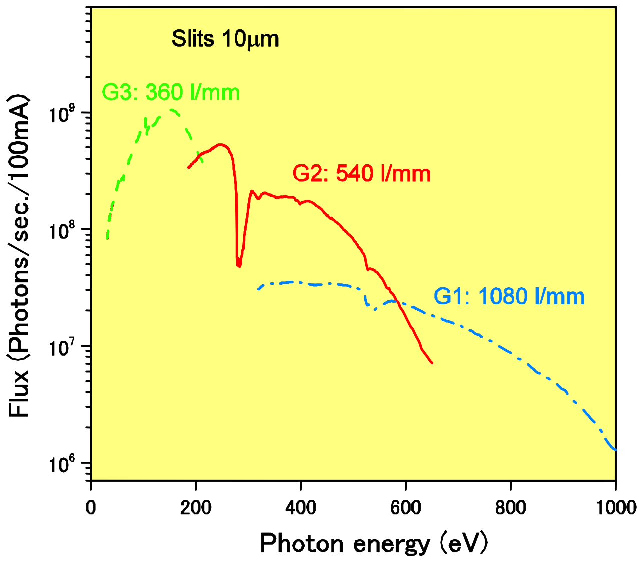


Fig. 1 Throughput from the constant-deviation constant-length spherical grating monochromator on BL8B1.

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
Experiments	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 exitslit. It covers the wide range from 2 to 150eV 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 0.004-0.3eV 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.

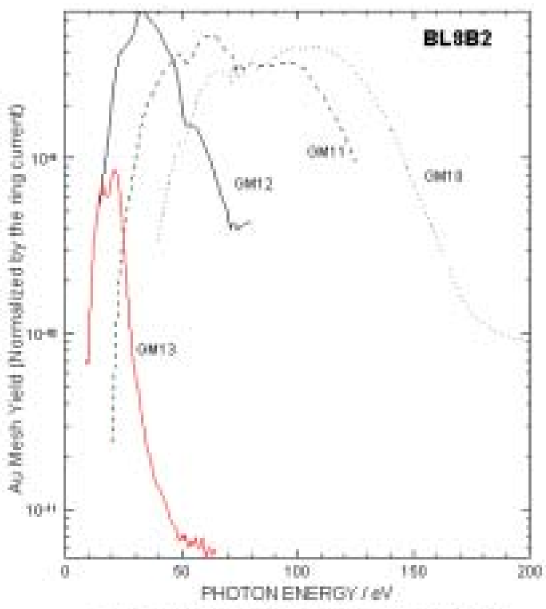


Figure 1 Throughput spectra of plane-grating monochromator at BL8B2(slit=100um).

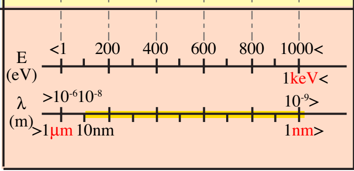
Beamline Specifications

Monochromator	Plane-grating monochromator
Wavelength Range	9- 600nm
Resolution	E/ΔE = 1000
Experiment	Angle-resolved UPS

Beamlines at UVSOR-II

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	1.9 eV 40 eV	Solid (Reflection & Absorption)	M. Hasumoto hasumoto@ims.ac.jp
2B	18m Spherical Grating	20 eV 200 eV	Gas (Photoionization, Photodissociation)	K. Mitsuke mitsuke@ims.ac.jp
3U	Varied-Line-Spacing Plane Grating Monochromator	40 eV 600 eV	Gas (Photoionization, Photodissociation) & Solid (Photoemission)	T. Hatsui hatsui@ims.ac.jp
3B	3m Normal Incidence	3 eV 40 eV	Gas (Photoemission)	K. Mitsuke mitsuke@ims.ac.jp
4A1	Multi-Layered-Mirror Monochromator	50 eV 95 eV	Irradiation	T. Urisu urisu@ims.ac.jp
4A2	None		Irradiation	T. Urisu urisu@ims.ac.jp
4B	Varied-Line-Spacing Plane Grating Monochromator	80 eV 800 eV	Gas (Photoionization, Photodissociation) & Solid (Photoemission)	E. Shigemasa sigemasa@ims.ac.jp
5U (FEL*)	None	(OK****)	FEL*	J. Yamazaki yamazaki@ims.ac.jp
5U	SGM-TRAIN**	5 eV 250 eV	Solid (Photoemission)	T. Ito tito@ims.ac.jp
5B	Plane Grating	5 eV 600 eV	Calibration, Gas (Photodissociation) & Solid (Absorption)	M. Hasumoto hasumoto@ims.ac.jp
6B (IR)	Martin-Puplett FT-TIR, Michelson FT-IR***	0.25 meV 2.5 eV	Solid (Reflection & Absorption)	S. Kimura kimura@ims.ac.jp
7U	None		Irradiation	Y. Nonogaki nonogaki@ims.ac.jp
7B	3m Normal Incidence	1.2 eV 30 eV	Solid (Reflection & Absorption)	M. Hasumoto hasumoto@ims.ac.jp
8A	None (Filter)		Irradiation & User's Instruments	E. Nakamura eiken@ims.ac.jp
8B1	15m Constant Deviation Grazing Incidence	30 eV 600 eV	Gas (Photoionization, Photodissociation) & Solid (Absorption)	Y. Hikosaka hikosaka@ims.ac.jp
8B2	Plane Grating	1.9 eV 150 eV	Solid (Photoemission)	D. Yoshimura daisukey@ims.ac.jp

FEL*: Free Electron Laser
FT-IR***:
Fourier Transform interferometer in the Infrared
OK*****: with an Optical Klystron
U: with an Undulator



SGM-TRAIN**:
Spherical Grating Monochromator with Translating and Rotating Assembly Including Normal incidence mount

Table I. Station masters and supervisors of open beamlines in 2003

Beamline	Station Master	Sub Master	Supervisor
1A	N. Kondo	E. Shigemasa	E. Shigemasa
1B	M. Hasumoto	S. Kimura	S. Kimura
5U	T. Ito	S. Kimura	S. Kimura
5B	M. Hasumoto	E. Nakamura	E. Shigemasa
6B	S. Kimura	E. Nakamura	S. Kimura
7B	M. Hasumoto	S. Kimura	S. Kimura
8A	E. Nakamura	Y . Hikosaka*	E. Shigemasa
8B1	Y . Hikosaka*	E. Nakamura	E. Shigemasa

*Dr. Y . Hikosaka arrived at his post on October 1, thereafter the name of "E. Shigemasa" in Table I is replaced by "Y . Hikosaka" accordingly.

Table II. Representatives of in-house beamlines in 2003.

Beamline	Representative	Affiliation
2B	K. Mitsuke	Dep. VUV Photoscience
3U	N. Kosugi	Dep. VUV Photoscience
3B	K. Mitsuke	Dep. VUV Photoscience
4A	T. Urisu	Dep. VUV Photoscience
4B	E. Shigemasa	UVSOR
7U	T. Urisu	Dep. VUV Photoscience
8B2	T. Urisu	Dep. VUV Photoscience