Light Source in 2007

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1. Status of UVSOR-II

In the fiscal year 2007, we have operated the UVSOR-II accelerators from April ’07 to March ’08. We had totally 36 weeks for the users operation, 34 weeks in multi-bunch mode and 2 weeks in single-bunch mode. We had 9 weeks dedicated for machine studies, although one week was canceled as described later. The monthly statistics of the operation time and the integrated beam current are shown in Figure 1.

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. The beam injection is twice a day, at 9am and 3pm. The filling beam current is 350 mA in the multi-bunch mode and 100 mA in the single bunch mode. Occasionally, we operate the machine after 9pm for beam-line conditioning, free electron laser experiments and so on.

In this fiscal year, we had no major reconstruction on accelerators. Thus, we only had short shut-downs for maintenance works and for holidays. We had three 1-week shut-down, in May, September and March, and two 2-week ones in August and around the New Years Day.

In this fiscal year, we had two rather serious troubles. In May, the power supply for the septum magnet of the storage ring was malfunctioned. Many power transistors were broken and it took about one week to recover. We exchanged a machine study week, which had been planned in the next week of this happening, with the users’ week. In October, we had a trouble on a booster synchrotron magnet. We had an electrical short of a bus bar of the bending magnet to the ground. It was partly melted down. Fortunately, it was recovered within a few days.

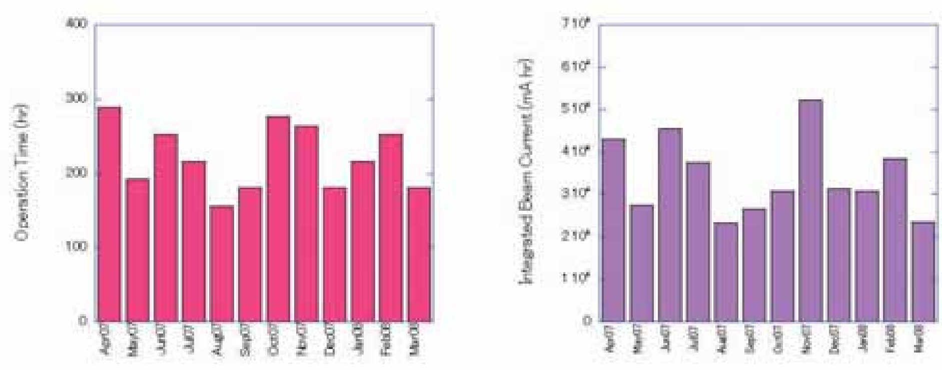


Fig. 1. Monthly statistics of the operation time (left) and of the integrated beam current (right).

2. Improvements

Full Energy Injection

The bending magnet power supply of the beam transport line was replaced in the last March, as shown in Figure 2. The new power supply is capable of transporting the full energy (750 MeV) beam to the storage ring. The power supplies of the booster synchrotron had been already replaced last year, to be compatible with the full energy acceleration.

In April, we have started testing the full-energy acceleration on the booster synchrotron, the beam transport and the injection to the storage ring [1]. In July, we have started operating the machine with the full-energy injection in the users' runs. The injection rate is about 0.5 mA/sec and to reach the filling current, 350 mA, it takes about 15 minutes. The repetition rate of the injection at 750 MeV was reduced to 1 Hz, which had been 3 Hz at 600 MeV, not to increase the peak electric power of the booster synchrotron. Even with this lower repetition rate, the total time required for the injection procedure is almost the same as before, partly because the acceleration on the storage ring was not necessary and also because we re-fill the electrons on the remaining electrons at the second injection of the day.

In the machine studies, we have tested the top-up injection. The electron beam current was successfully kept constant for more than 30 minutes, as shown in Figure 3. This was just a demonstration and there are many subjects that we must prepare before introducing this technique to the users' runs.

Fig. 2. New Magnet Power Supply for Bending Magnets on Beam Transport Line

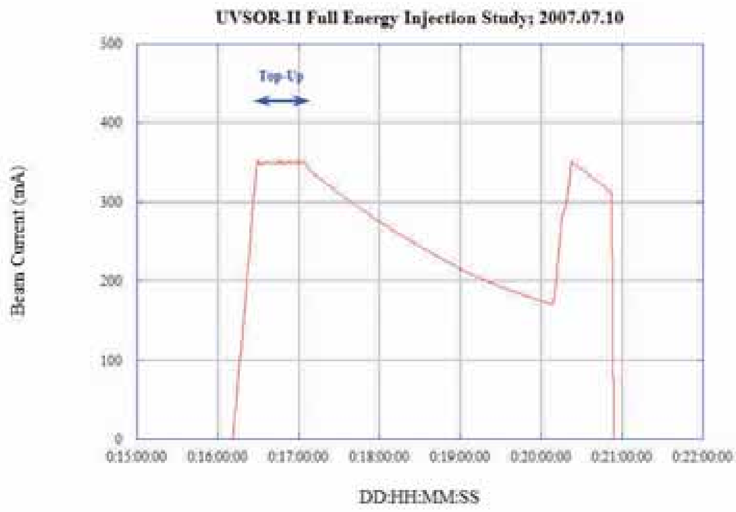


Fig. 3. Top-Up Operation Test. The beam current was kept constant for about 30 minutes.

Progress of New Undulator for BL7U

The new undulator for BL7U, a variable polarization undulator of APPLE-II type, is now opened for users. A feed-forward system to correct the orbit movement caused by the pole gap changes is successfully commissioned [2]. The orbit movement is corrected within 10 microns. The users can change the pole gap from the beam line anytime. They also can change the polarization at a fixed gap, 100 mm during the runs. A beam lifetime shortening is observed for vertically polarized mode, which may be caused by the non-linear effect of the undulator on the electron dynamics. Some sophisticated correction scheme should be introduced.

3. Researches and Developments

Free Electron Laser

The oscillating wavelength of the UVSOR-II Free Electron Laser is approaching the VUV region. In this fiscal year, an oscillation at 199 nm was realized, as shown in Figure 4 [3]. Laser oscillation around 190 nm, which seems promising, will be the target of the next fiscal year. By using this high power laser in deep UV region, some users' experiments are in progress [4].

To get coherent radiation in even shorter wavelength region, which seems hard to reach with the resonator type free electron laser, coherent harmonic generation (CHG) is under investigation, collaborating with French researchers. Coherent 3rd harmonics of Ti:Sa laser was successfully produced and the properties of the radiation and the mechanisms were investigated[5].

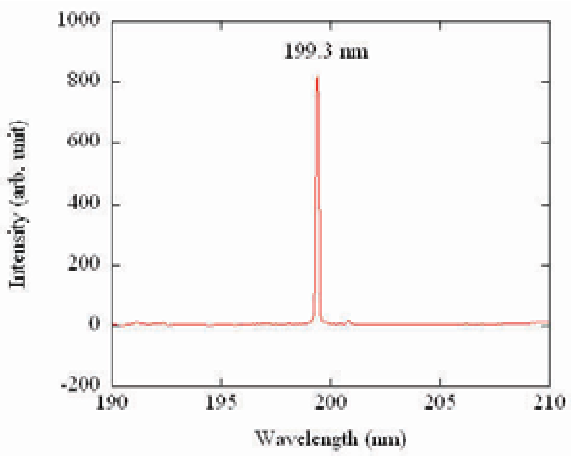


Fig. 4. Spectrum of the UVSOR-II Free Electron Laser at 199 nm

Laser Bunch Slicing

Terahertz coherent synchrotron radiation has been intensively studied by using laser bunch slicing technique [6]. In this scheme, ultra-short laser pulses are injected to the storage ring. As the result of the interaction between the laser pulses and an electron bunch in an undulator, a part of the electron bunch is energy-modulated. As this bunch is proceeding in the ring, the energy-modulated electrons escape from the interacting part of the bunch and finally a dip is created. Such an electron bunch emits coherent synchrotron radiation in the wavelength region longer than the dip width. If we use a femto-second laser pulse, we can create a dip of sub-millimeter width, which corresponds to the terahertz radiation wavelength. We have demonstrated that, by changing the laser pulse width, we could control the radiation spectra.

We have developed the laser slicing technique to produce periodic density structures by using amplitude modulated laser pulses [7]. We have succeeded in producing narrow-band coherent synchrotron radiation in the uniform magnetic field of the bending magnet. We have also demonstrated that we could control the spectral peak by changing the modulation frequency, and also that we could control the spectral width by changing the number of the modulation.

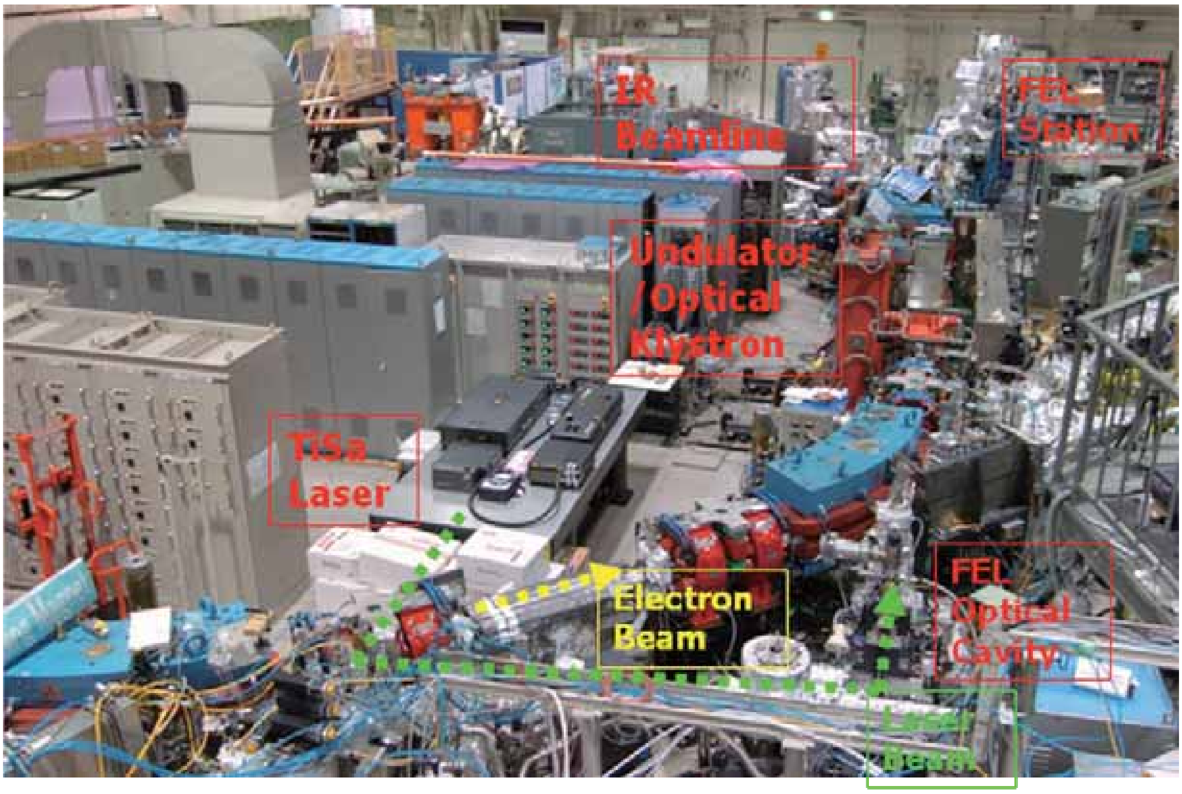


Fig. 5. Experimental set-up of the laser bunch slicing

REFERENCES

[1] A. Mochihashi et al., in this report

[2] K. Hayashi et al., in this report

[3] M. Hosaka et al., in this report

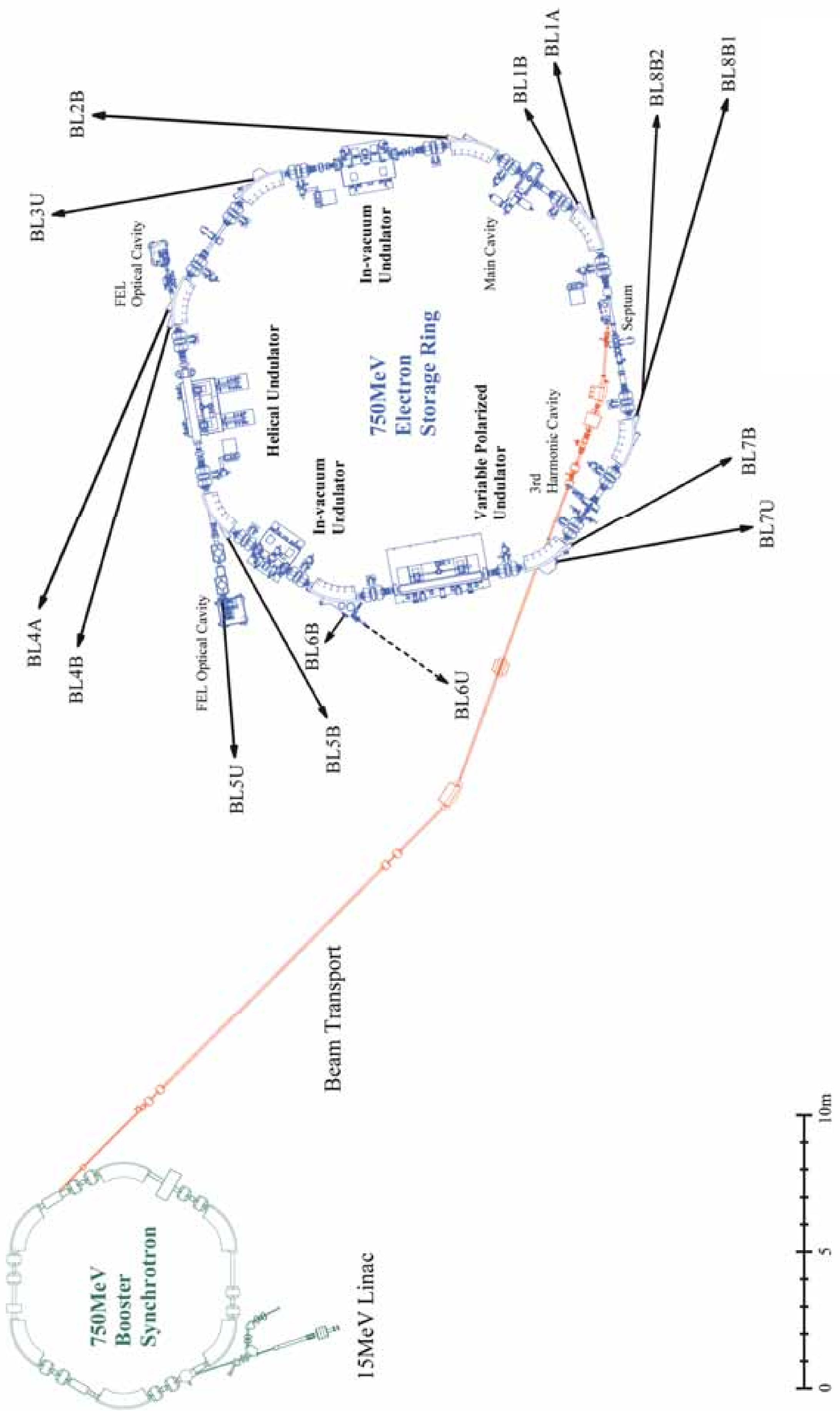
[4] K. Kobayashi et al., in this report

[5] M. Labat, M. Hosaka, A. Mochihashi, M. Shimada, M. Katoh, G. Lambert, T. Hara, Y. Takashima, M. E. Couprie, Euro. Phys. J. D Vol. 44, No. 1 (2007) 187-200

[6] M. Shimada et al., in this report

[7] M. Shimada et al., in this report

UVSOR Accelerator Complex



Parameters of Injection Linear Accelerator

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

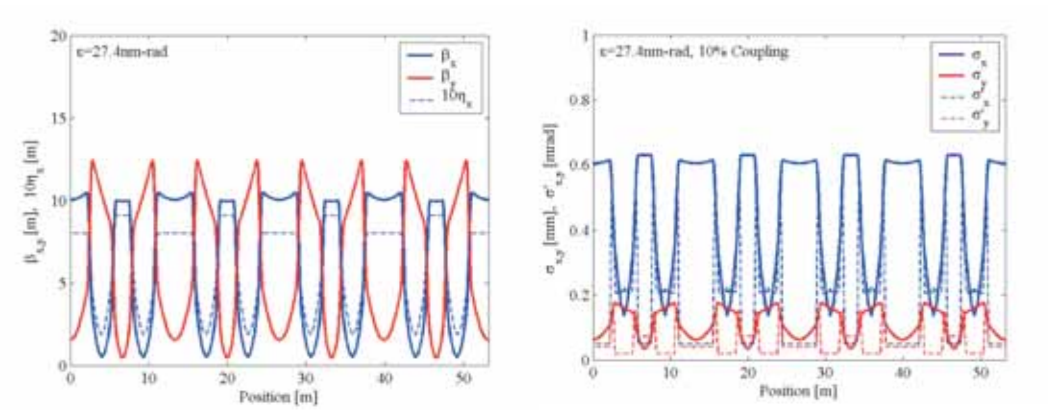
Parameters of Booster Synchrotron

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
Vertical	1.25
Momentum Compaction	0.138
Repetition Rate	1 Hz (750 MeV)

Parameters of UVSOR-II Storage Ring

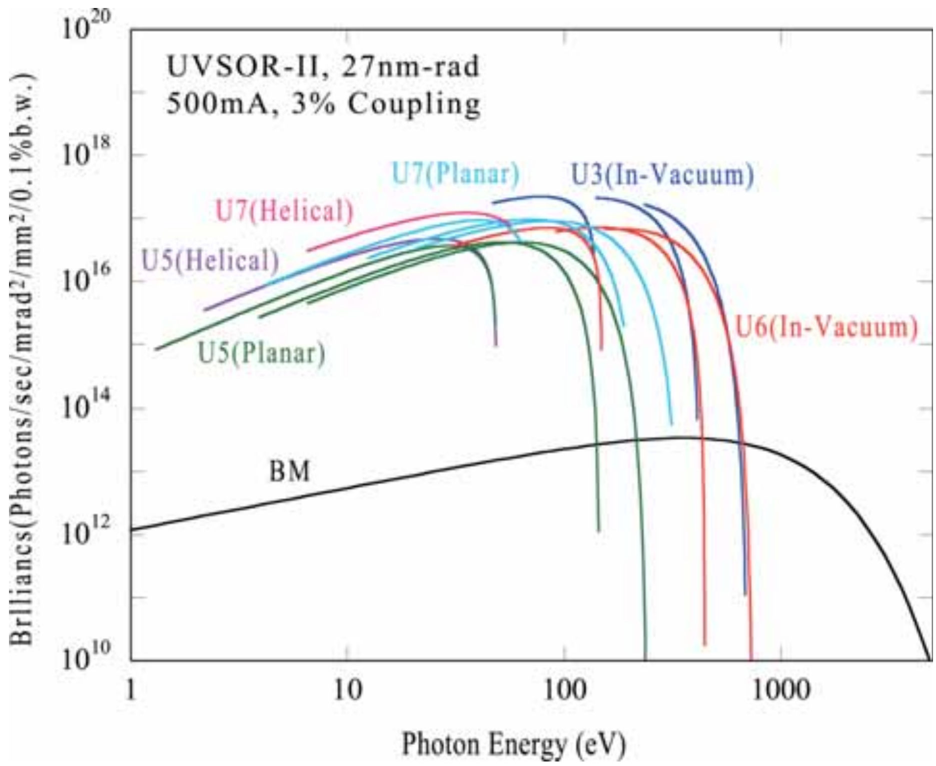
Energy	750 MeV
Injection Energy	750 MeV
Maximum Stored Current	500 mA (multi bunch) 100 mA (single bunch)
Natural Emittance	27.4 nm-rad
Circumference	53.2 m
RF Frequency	90.1 MHz
Harmonic Number	16
Bending Radius	2.2 m
Lattice	Extended DBA × 4
Straight Section	(4 m × 4) + (1.5 m × 4)
RF Voltage	100 kV
Betatron Tune Horizontal 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	108 ps

Electron Beam Optics of UVSOR-II Storage Ring



Horizontal/vertical betatron functions and dispersion function (left), and horizontal/vertical electron beam sizes and beam divergences (right) of UVSOR-II

Parameters of the insertion devices



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

BL3U In-vacuum Undulator

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

BL6U 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

BL5U Helical Undulator / Optical Klystron

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

BL7U Apple-II variable polarization undulator

Number of Periods	40
Period Length	76mm
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 2007

Eiji SHIGEMASA

UVSOR Facility, Institute for Molecular Science

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 three insertion devices are available for utilizing synchrotron radiation at UVSOR. There is a total of fourteen operational beamlines in 2007, which are classified into two categories. Nine of them are so-called "Open beamlines", which are open to scientists of universities and research institutes belonging to the government, public organizations, private enterprises and those of foreign countries. The rest of the five beamlines are so-called "In-house beamlines", and are dedicated to the use of research groups within IMS. 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 one non-monochromatized station for irradiation of white-light, as shown in the appended table 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) as well as upgraded (BL5U and BL6B) beamlines synchronized with the UVSOR-II project have routinely been operated, and a number of outcome has emerged through the utilization of these beamlines. Concerning the utilization for the long straight section between B06 and B07, a UVSOR workshop has been held in March 2005. A high resolution and high flux variable polarization beamline for spectroscopy in the VUV range has been proposed and possible scientific cases performed on this beamline have been discussed there. The construction of the new beamline BL7U has been completed during the regular summer shutdown in 2006 as planned. BL7U is composed of a modified Wadsworth-type monochromator with three interchangeable spherical gratings (R=10 m; 1200, 2400, and 3600 lines/mm), and a hemispherical photoelectron analyzer (MBS ‘Peter’ A-1), where high-resolution angle-resolved photoemission experiments can be performed. A new APPLE-II type undulator for the light source of BL7U has successfully been installed at the end of October 2006. Practical utilization by users at BL7U has begun, including a sort of performance tests for the experimental system by highly active and internationally appreciated users.

Regarding 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 is expected to start from the summer of 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. 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 was uploaded on the UVSOR web page in the summer of 2007), on the occasion of conducting the actual experimental procedures. Those wishing to use the open and in-house beamlines are recommended to contact the station master/supervisor and the representative, respectively. For updated information of UVSOR, http://www.uvsor.ims.ac.jp/.

Table I. Station masters and supervisors of open beamlines

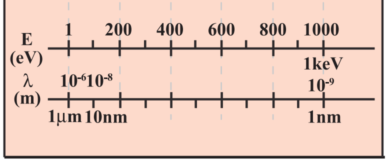
Beamline	Station Master	Sub Master	Supervisor
1A	N. Kondo	E. Shigemasa	E. Shigemasa
1B	M. Hasumoto	S. Kimura	S. Kimura
5U	T. Ito	M. Sakai	S. Kimura
5B	M. Hasumoto	E. Nakamura	E. Shigemasa
6B	S. Kimura	E. Nakamura	S. Kimura
7U	T. Ito	M. Sakai	S. Kimura
7B	M. Hasumoto	S. Kimura	S. Kimura
8B1	Y. Hikosaka	E. Nakamura	E. Shigemasa
8B2	M. Tsunekawa	E. Nakamura	S. Kimura

Table II. Representatives of in-house beamlines

Beamline	Representative	Affiliation
2B	K. Mitsuke	Dep. Photo-Molecular Science
3U	N. Kosugi	Dep. Photo-Molecular Science
4A	T. Urisu	Dep. Life & Coordination-Complex Molecular Science
4B	E. Shigemasa	UVSOR

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	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)	T. Ito tito@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	40 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)	T. Ito tito@ims.ac.jp
7B	3m Normal Incidence	1.2 eV 25eV	Solid (Reflection, Absorption)	M. Hasumoto hasumoto@ims.ac.jp
8B1	15m Constant Deviation Grazing Incidence	30 eV 800eV	Solid (Absorption)	Y. Hikosaka hikosaka@ims.ac.jp
8B2	Plane Grating	1.9 eV 150 eV	Solid (Photoemission)	M. Tsunekawa tsunekaw@ims.ac.jp
FEL	None	1.6 eV 6.2 eV	Free Electron Laser	J. Yamazaki yamazaki@ims.ac.jp
CSR	None	0.5meV 5meV	Coherent Synchrotton Radiation	M. Katoh mkatoh@ims.ac.jp



* Spherical Grating Monochromator with Translating and Rotating Assembly Including Normal incidence mount

**Under Construction

BL1A

Soft X-Ray Beamline for Photoabsorption Spectroscopy

BL1A is a soft X-ray beamline for photoabsorption spectroscopy. The beamline is equipped with a focusing premirror and a double crystal monochromator [1]. The monochromator serves soft X-rays in the energy region from 585 to 4000 eV by using several kinds of single crystals such as β-Al_2O_3, beryl, KTP ($KTiOPO_4$), quartz, InSb, and Ge. The throughput spectra measured by a Si photodiode (AXUV-100, IRD Inc.) are shown in Fig. 1. Typical energy resolution (E/ΔE) of the monochromator is about 1500 for beryl and InSb. There are no experimental setups specific of this beamline, except for a small vacuum chamber equipped with an electron multiplier (EM) detector. Photoabsorption spectra for powdery samples are usually measured in a total electron yield mode, with the use of the EM detector.

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

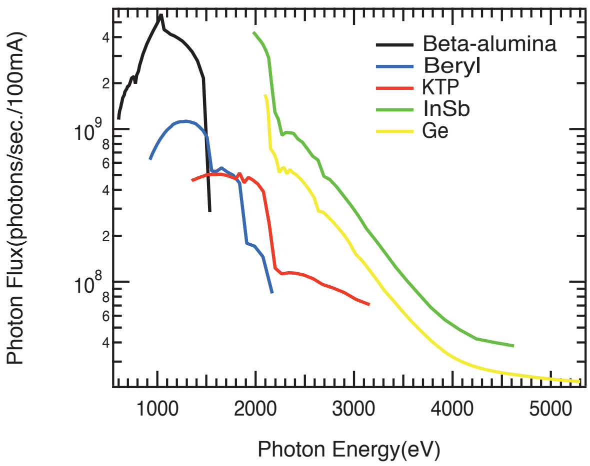


Fig. 1. Throughput spectra of the double crystal monochromator at BL1A.

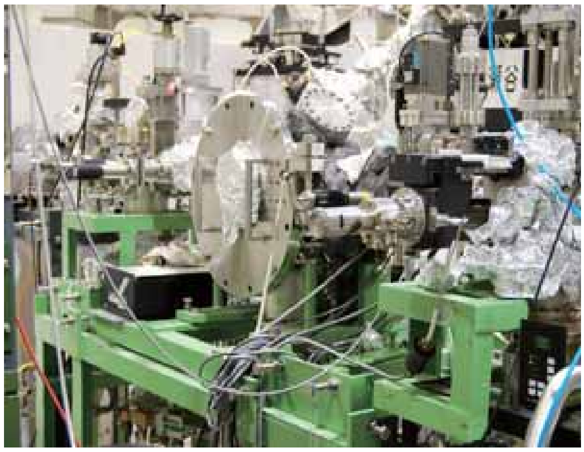


Fig. 2. A side view of BL1A.

Beamline Specifications

Monochromator	Double crystal monochromator
Monochromator crystals: (2d value, energy range)	β-Al_2O_3 (22.53 Å, 585-1609 eV), beryl (15.965 Å, 826-2271 eV), KTP (10.95 Å, 1205-3310 eV), quartz (8.512 Å, 1550-4000 eV), InSb (7.481 Å, 1764-4000 eV), Ge (6.532 Å, 2094-4000 eV)
Resolution	E/ΔE = 1500 for beryl and InSb
Experiments	Photoabsorption spectroscopy

BL1B

Seya-Namioka Monochromator for General Purposes

BL1B has been constructed to perform various spectroscopic investigations such as absorption, reflectivity, and luminescence in condensed matters. This beamline consists of a pre-focusing mirror, a 1-m Seya-Namioka type monochromator, and post-focusing mirrors with different focal lengths. Three gratings of 600, 1200, and 2400 l/mm can cover the wavelength region ranging from 40 to 650 nm ($h\nu = 2 - 30$ eV). The post mirror with a longer focal length is usually used with an LiF window to separate the vacuum condition of the monochromator from a main experimental station, which make experiments for liquids and bio-specimens possible, while the other is mainly utilized for solid-state spectroscopy. The output flux from this monochromator is about 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.

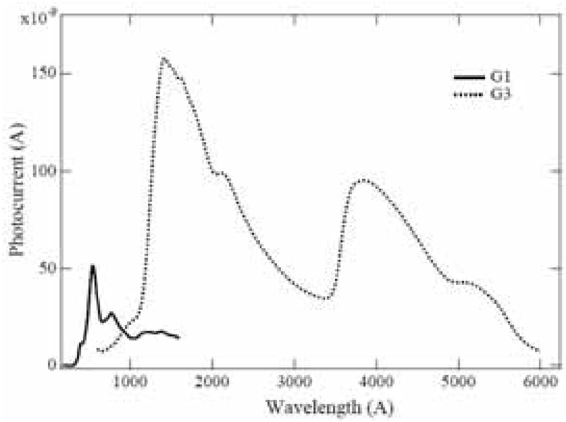


Fig. 1. Photocurrent at the sample position at BL1B.

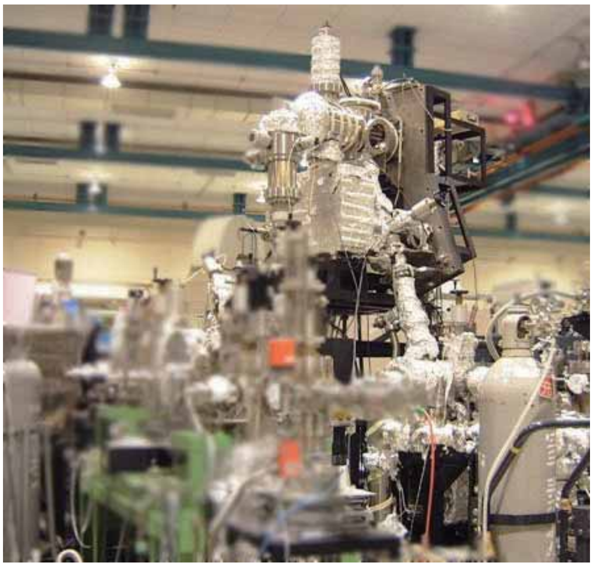


Fig. 2. Photo of BL1B.

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.

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

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

[1] M. Ono, H. Yoshida, H. Hattori, K. Mitsuke, Nucl. Instrum. Meth. Phys. Res. A **467-468** (2001) 577.
[2] H. Yoshida, K. Mitsuke, J. Synchrotron Radiat. **5** (1998) 774.
[3] J. Kou, T. Mori, Y. Kubozono, K. Mitsuke, Phys. Chem. Chem. Phys. **7** (2005) 119.

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-vaccum undulator composed of 50 periods of 3.8 cm period length. The emitted photons are monochromatized by the varied-line-spacing plane grating monochromator (VLS-PGM) designed for various spectroscopic investigations in the soft x-ray range including soft x-ray emission studies. Three holographically ruled laminar profile plane gratings are designed to cover the photon energy range from 60 eV to 800 eV. The beamline has two endstations, namely XES setup and Multi-purpose setup. The XES setup is used for soft x-ray emission spectroscopy. The beam is horizontally focused onto the sample position by plane-elliptical mirror, M2X. In the Multi-purpose setup, the beam is focused by the toroidal mirror M2. Between the sample position and M2, the differential pumping is placed.

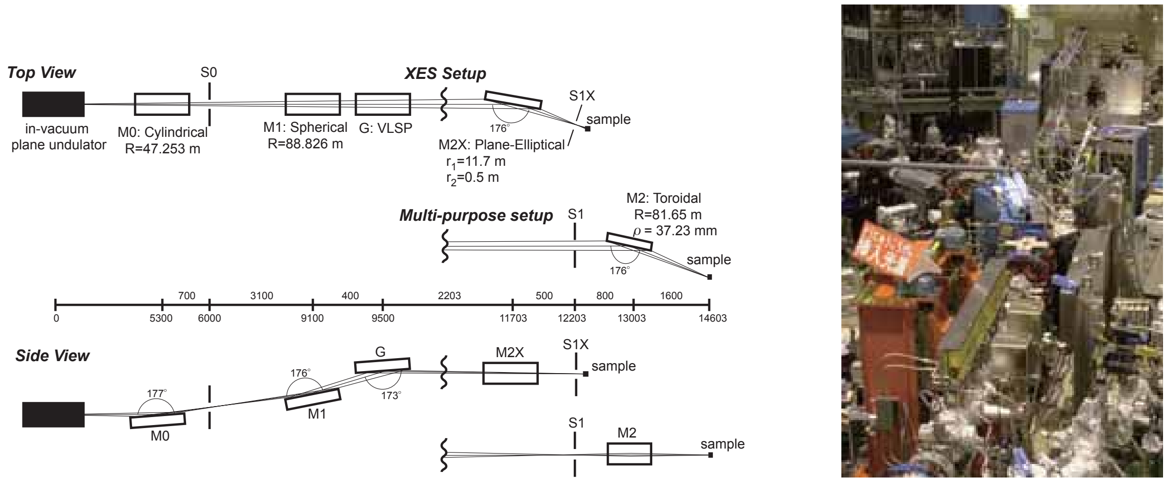


Fig. 1. Schematic layout (left) and the photography (right) of the BL3U. The distances along the beam from the center of the in-vacuum plane undulator are shown in mm. S1X and M2X can be replaced with the other exit slit S1 so that experiments can be carried out at either the XES or multi-purpose endstation.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

Beamline Specifications

Monochromator	Varied-line-spacing plane grating monochromator
Energy Range	60-800 eV
Resolution	E/ΔE > 10 000
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

BL4A1 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.

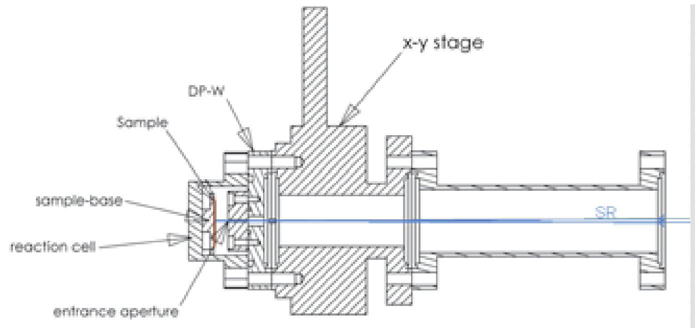


Fig. 1. Section view of differential pump apparatus installed in the etching chamber (reaction cell) and the entrance of beam.

Fig. 2. A side view of the end-station at BL4A1.

Beamline Specifications

Monochromator	Multilayered mirror monochromator
Wavelength Range	13.3 ~ 22.5 nm
Resolution	5 ~ 9 eV (FWHM)
Experiment	Irradiation
Miscellaneous	Not-in-use for SR users

BL4B

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

The beamline BL4B equipped with a varied-line-spacing plane grating monochromator (VLS-PGM) was constructed for various spectroscopic investigations in a gas phase and/or on solids in the soft X-ray range. Three holographically ruled laminar profile plane gratings with SiO_2 substrates are designed to cover the photon energy range from 25 eV to 800 eV. The gratings with the groove densities of 100, 267, and 800 l/mm cover the spectral ranges of 25-100, 60-300, and 200-1000 eV, respectively, and are interchangeable without breaking the vacuum. Fig. 1 shows the absolute photon flux for each grating measured by a Si photodiode (IRD Inc.), with the entrance- and exit-slit openings set at 50 and 50 μm, respectively. The maximum resolving power (E/ΔE) achieved for each grating is more than 5000.

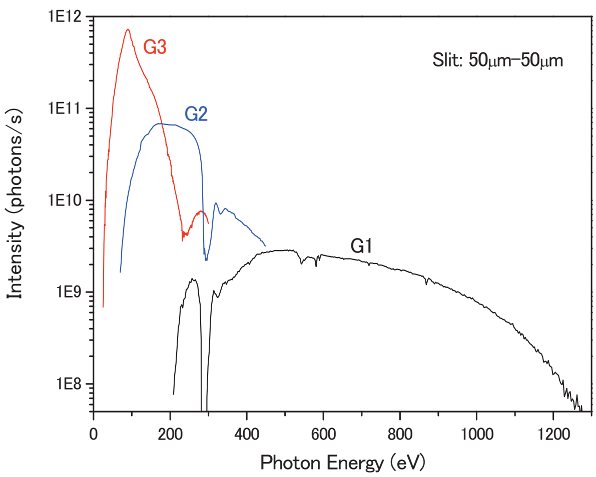


Fig. 1. Throughput from the VLS-PGM monochromator on BL4B.

Fig. 2. Photo of BL4B.

Beamline Specifications

Monochromator	Varied-line-spacing Plane Grating Monochromator
Energy range	25-1000 eV
Resolution	E/ΔE > 5000 (at maximum)
Experiments	Soft X-ray spectroscopy (mainly, angle-resolved photoion spectroscopy for gaseous targets and photoelectron spectroscopy for gaseous and solid targets)

BL5U

Photoemission Spectroscopy of Solids and Surfaces

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

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

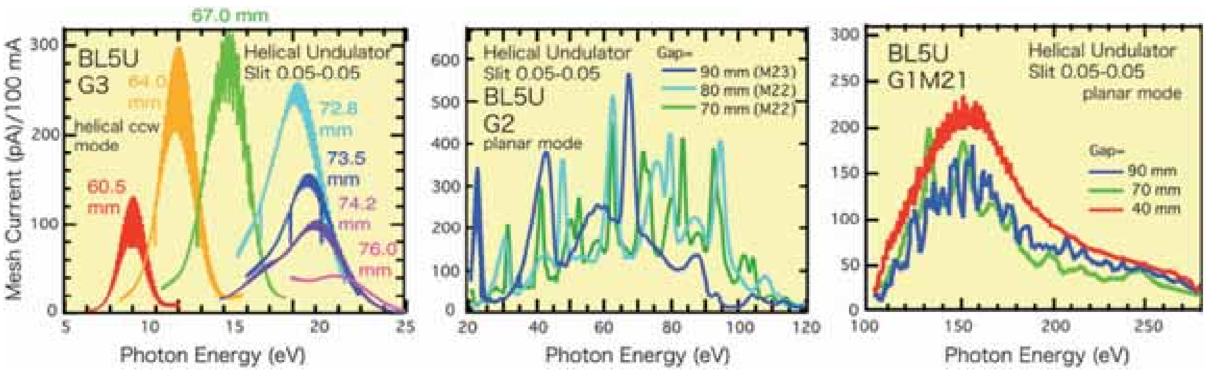


Fig. 1. Throughput spectra from the SGM-TRAIN monochromator at BL5U.

Beamline Specifications

Monochromator	SGM-TRAIN
Energy Range	5-250 eV
Resolution	$h\nu/\Delta E$ >2,000 for < 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)

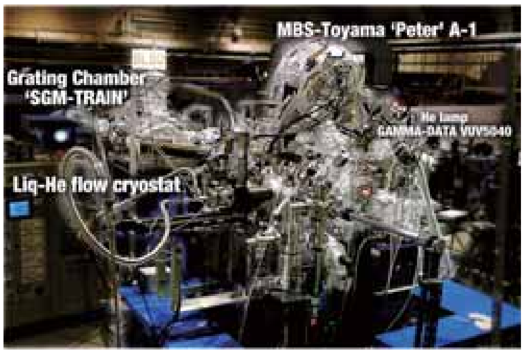


Fig. 2. High-resolution angle-resolved photoemission apparatus at BL5U.

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).

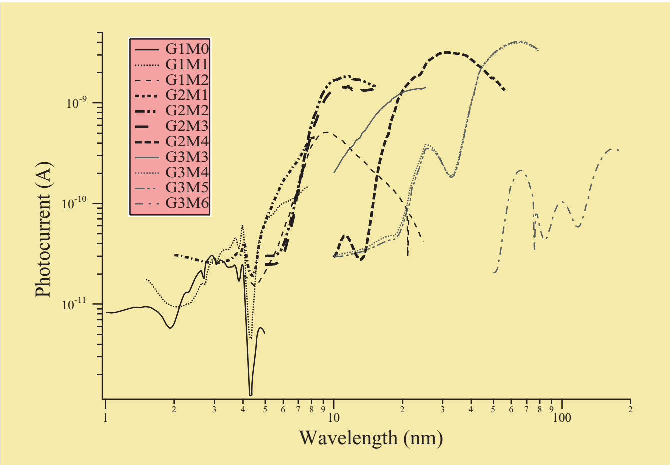


Fig. 1. Throughput spectra for possible combinations of gratings and mirrors at BL5B measured by a gold mesh.

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/ΔE ~ 500
Experiments	Calibration of optical elements, absorption of solids, photo-stimulated desorption from rare gas solids

BL6B

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.

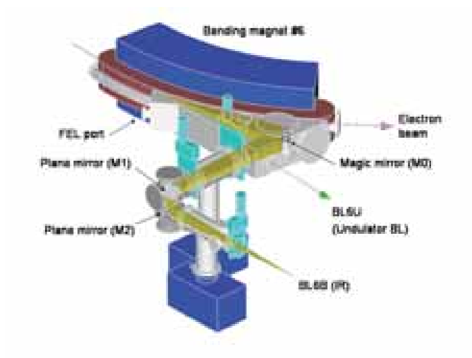


Fig. 1. The design of optics and front end of BL6B.

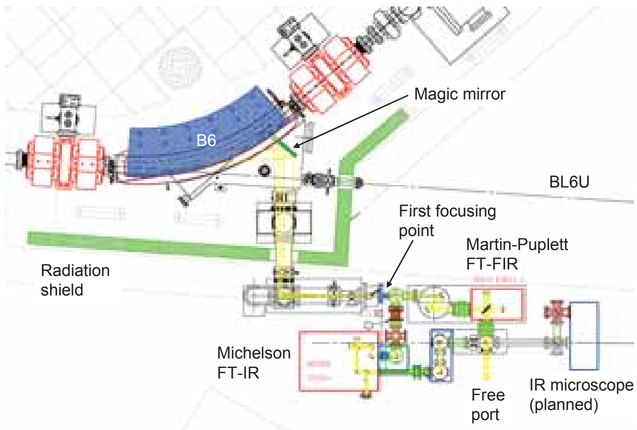


Fig. 2. Schematic figure of top view of BL6B.

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

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 $10^{11} \sim 10^{12}$ 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) 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.

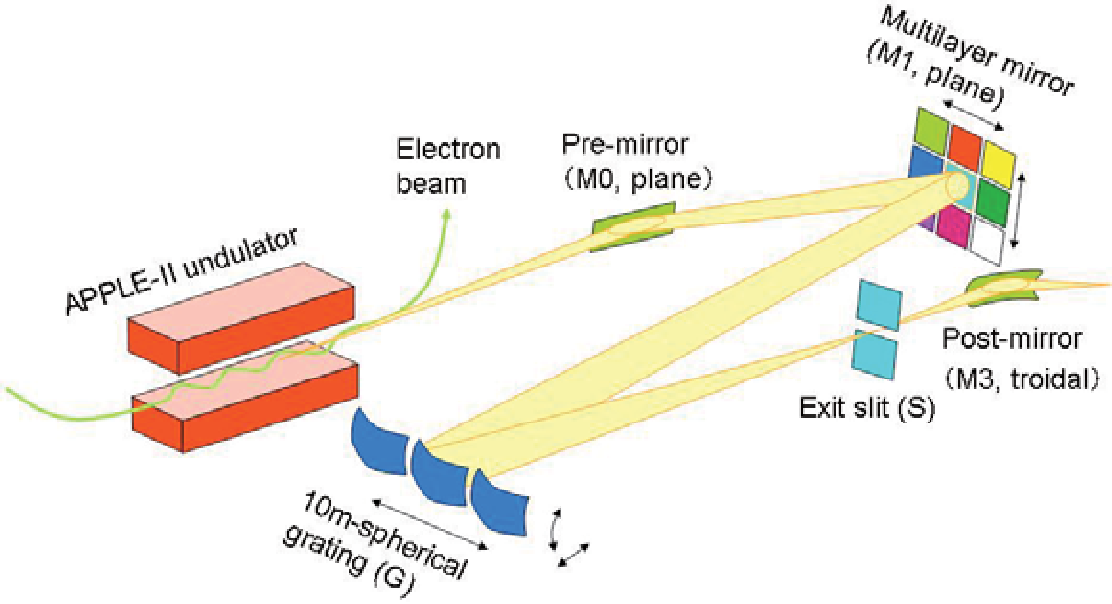


Fig.1. Schematic figure of BL7U.

Beamline Specifications

Light source	APPLE-II type undulator (λ_u = 76mm, N = 36)
Monochromator	10-m Normal Incidence Monochromator (modified Wadsworth-type)
Photon energy range	6 ~ 40 eV (λ = 30 ~ 200 nm)
Resolution ($h\nu/\Delta h\nu$)	$1\times10^4 \sim 5\times10^4$
Photon flux on sample	$\geq10^{12} \sim 10^{11}$ ph/s (depend on $h\nu$)
Beam size on sample	200(H)×50(V) μm^2
Experiments	Angle-resolved photoemission of solids (MB Scientific A-1 analyzer)

BL7B

3-m Normal Incidence Monochromator for Solid-State Spectroscopy

BL7B has been constructed to provide sufficiently high resolution for conventional solid-state spectroscopy, enough intensity for luminescence measurements, a wide wavelength coverage for Kramers-Kronig analyses, and the minimum deformation to the polarization characteristic of the incident synchrotron radiation. This beamline consists of a 3-m normal incidence monochromator which covers the vacuum ultraviolet, ultraviolet, visible and infrared, *i.e.* the wavelength region of 40 -1000 nm, with three gratings (1200, 600, and 300 l/mm). Two interchangeable refocusing mirrors provide two different focusing positions. For the mirror with the longer focal length, an LiF or a 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.

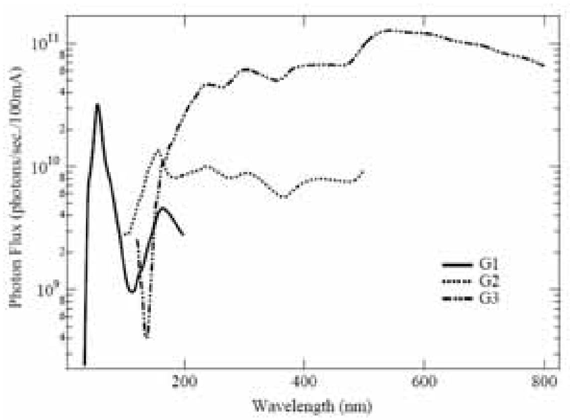


Fig. 1. Throughput spectra of BL7B measured by a silicon photodiode.

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

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

Fig. 1. Photo of BL8B1.

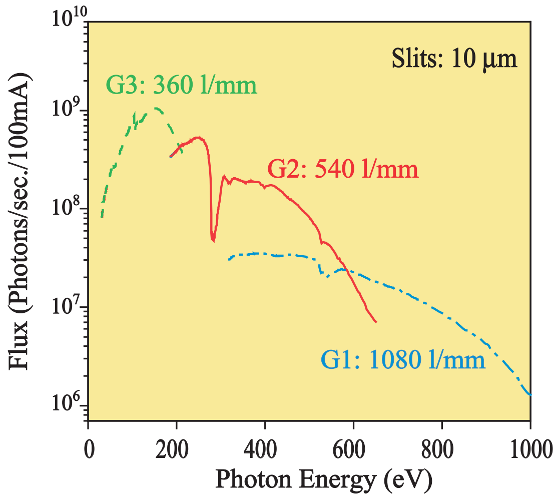


Fig. 2. Throughput of the monochromator at BL8B1.

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
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 exit slit. It covers the wide range from 2 to 130eV with exchanging two gratings (G1: 1200l/mm, G2: 450l/mm) and five cylindrical mirrors. The toroidal mirror focuses the divergent radiation onto the sample in the measurement chamber. The spot size of the zeroth-order visible light at the sample surface is about $1\times1mm^2$. Figure 1 shows the throughput spectra of PGM (slit=100µm). The energy resolution at a slit width of 100µm was found to be $E/\Delta E = 1000$ in the wavelength range from 2 to 130eV. A hemi-spherical electron energy analyzer of 75mm mean radius with an angular resolution less than 2° can be rotated around vertical and horizontal axes. The sample mounted on a manipulator can be also rotated around two axes.

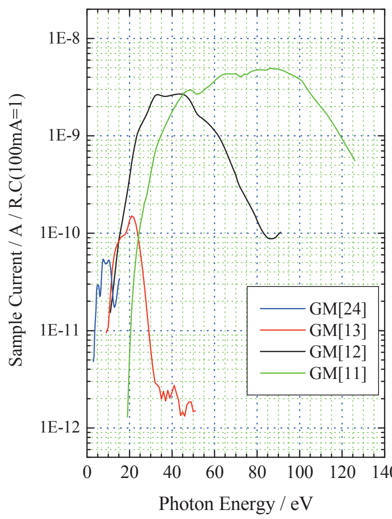


Fig. 1. Throughput spectra of plane-grating monochromator at BL8B2 (slit=100µm).

Fig. 2. A photo of BL8B2.

Beamline Specifications

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