II

Current Status of Light Sources and Beamlines
1. Status of UVSOR Accelerators

In the fiscal year 2013, we operated UVSOR-III from June to February, for 35 weeks for users, which is one week shorter than usual. This shorter operation period was due to the shutdown in April and May 2013 and in March 2014. The former was for an inspection of the main RF cavity and the latter was for an upgrade program on the beam-line BL5U, which included an upgrade on the undulator U5, both of which will be described later.

We operated the machine for 33 weeks in the multi-bunch top-up mode, in which the beam current was kept at 300 mA with the top-up injection, and 2 weeks in the single-bunch/multi-bunch hybrid mode, in which the machine is operated in single-bunch top-up mode during daytime and in the multi-bunch top-up mode during nighttime. The beam current in the single bunch mode is also kept constant at 50 mA with the top-up injection. The monthly statistics of the operation time and the integrated beam current are shown in Fig. 1.

The weekly operation schedule is as follows. On Monday, from 9 am to 9 pm, the machine is operated for machine studies. On Tuesday and Wednesday, from 9am to 9pm, the machine is operated for users. From Thursday 9am to Friday 9pm, the machine is operated for 36 hours continuously for users. Thus, the beam time for users in a week is 60 hours. Usually, we have a few weeks dedicated for machine study, however, in 2013, we did not have them to keep the beam time for users against the rather long shutdowns.

In this fiscal year, we had a few machine troubles on the injector, on the control system and on the reference signal generator. The last one caused sudden beam losses a few times a day. However, fortunately, in all cases the beam time for users could be secured by extending the operation time in the same weeks.

2. Improvements and Developments

Vacuum Pressure Rise in the Main RF Cavity

In 2012, we observed pressure rises in the RF accelerating cavity during the operation, to $10^{-6}$ Pa level, which was much higher than the normal value around $10^{-7}$ Pa. Soon, we found that the rises could be avoided by increasing the RF voltage to a certain level. However, month by month, the level was getting higher and higher. Therefore, we decided to open the cavity and to inspect its inside. In April 2013, the cavity was removed from the ring and the big flange was opened as shown in Fig. 2. We found some contamination inside. It was oil-like material and its origin is still unknown. We wiped out them and reconstructed the cavity. After setting it to the ring, we baked the cavity at around 200 degree C, which was higher than before. After this work, we found that the pressure rise was almost completely suppressed. After one year operation, we found no problem anymore.

Vacuum Pressure Rise in the Main RF Cavity

Reconstruction of BL5U Polarization Variable Undulator

The undulator for BL5U was designed and constructed in 1996 to provide polarization variable synchrotron radiation to the BL5U beam-line and also to work for the resonator free electron laser as an optical klystron. Since a new optical klystron has been constructed and installed last year at the straight section #1, we decided to remodel this undulator to a normal undulator with higher brightness. The old undulator had three magnet arrays on each pole to produce helical and horizontal linear polarized light. In March 2014, we have changed this magnetic configuration to the APPLE-II one with a shorter period length, 60 mm, as utilizing the present mechanical frame (Fig. 3). The magnetic field measurement was also carried out in the storage ring. The new undulator will be commissioned in May, 2014.
Electron gun developments towards future quantum beam sources

Electron guns of two types are being developed. One is a spin polarized electron gun. This is being developed towards inverse photo-electron spectroscopy in collaboration with Nagoya University. In FY2013, we have developed a measurement system for temporal response of the gun [1] and a Wien filter to transport the polarized beam [2]. Another electron gun is a superconducting photocathode one towards future high repetition rate free electron laser. At UVSOR, the photocathode part is mainly being developed, in collaboration with KEK [3].

References
[1] T. Inagaki et al., in these reports
[2] Y. Kajiura et al., in these reports
[3] R. Inagaki et al., in these reports

Masahiro KATOH (UVSOR Facility)
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: $\sim$1.6 MeV
- Repetition Rate: 2.6 Hz

**Booster Synchrotron**
- Energy: 750 MeV
- Injection: 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)

**UVSOR-III Storage-Ring**
- Energy: 750 MeV
- Injection Energy: 750 MeV
- Maximum Storage Current: 500 mA (multi bunch)
  - 100 mA (single bunch)
- Normal operation current: 300 mA (multi bunch)
  - (Top-up mode): 50 mA (single bunch)
- Natural Emissance: 17.5 nm-rad
- Harmonic Number: 16
- Bending Radius: 2.2 m
- Lattice: Extended DBA×4
- Straight Section: (4 m×4)+(1.5 m×4)
- RF Voltage: 120 kV
- Betatron Tune: Horizontal 3.75
  - Vertical 3.20
- Momentum Compaction: 0.030
- Natural Chromaticity: Horizontal -8.1
  - Vertical -7.3
- Energy Spread: 5.26×10^{-4}
- Coupling Ratio: 1%
- Natural Bunch Length: 128 ps

Electron Beam Optics of UVSOR-III Storage Ring

Horizontal/vertical betatron functions $\beta_x, \beta_y$ and dispersion function $\eta_x$, $\eta_y$.

Horizontal/vertical electron beam size $\sigma_x, \sigma_y$ and beam divergences $\sigma_x', \sigma_y'$.
### Insertion Device

Brilliance of radiation from the insertion devices (U3, U4, U5, U6 and U7) and a bending magnet of UVSOR-III

---

**U1 Apple-II Undulator / Optical Klystron**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Periods</td>
<td>10 + 10</td>
</tr>
<tr>
<td>Period length</td>
<td>88 mm</td>
</tr>
<tr>
<td>Pole Length</td>
<td>0.968 m + 0.968 m</td>
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<tr>
<td>Pole Gap</td>
<td>24-200 mm</td>
</tr>
<tr>
<td>Deflection Parameter</td>
<td>7.36 (Max. Horizontal)</td>
</tr>
<tr>
<td></td>
<td>4.93 (Max. Vertical)</td>
</tr>
<tr>
<td></td>
<td>4.06 (Max. Helical)</td>
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</table>

**U3 In-vacuum Undulator**

<table>
<thead>
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<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Number of Periods</td>
<td>50</td>
</tr>
<tr>
<td>Period length</td>
<td>38 mm</td>
</tr>
<tr>
<td>Pole Length</td>
<td>1.9 m</td>
</tr>
<tr>
<td>Pole Gap</td>
<td>15-40 mm</td>
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<tr>
<td>Deflection Parameter</td>
<td>2.0 - 0.24</td>
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**U4 In-vacuum Undulator**

<table>
<thead>
<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>Number of Periods</td>
<td>26</td>
</tr>
<tr>
<td>Period length</td>
<td>38 mm</td>
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<tr>
<td>Pole Length</td>
<td>0.99 m</td>
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<tr>
<td>Pole Gap</td>
<td>13-40 mm</td>
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<tr>
<td>Deflection Parameter</td>
<td>2.4 - 0.19</td>
</tr>
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**U5 Helical Undulator / Optical Klystron**

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<tr>
<td>Number of Periods</td>
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<tr>
<td>Period length</td>
<td>110 mm</td>
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<tr>
<td>Pole Length</td>
<td>2.35 m</td>
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<tr>
<td>Pole Gap</td>
<td>30 - 150 mm</td>
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<tr>
<td>Deflection Parameter</td>
<td>4.6 - 0.07 (Helical)</td>
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<tr>
<td></td>
<td>8.5 - 0.15 (Linear)</td>
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</table>

**U6 In-vacuum Undulator**

<table>
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</thead>
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<td>Number of Periods</td>
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<tr>
<td>Period length</td>
<td>36 mm</td>
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<tr>
<td>Pole Length</td>
<td>0.94 m</td>
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<td>Pole Gap</td>
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**U7 Apple-II**

**Variable Polarization Undulator**

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<tr>
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<td>Period length</td>
<td>76 mm</td>
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<tr>
<td>Pole Length</td>
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<td>Pole Gap</td>
<td>24-200 mm</td>
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<tr>
<td>Deflection Parameter</td>
<td>5.4 (Max. Horizontal)</td>
</tr>
<tr>
<td></td>
<td>3.6 (Max. Vertical)</td>
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<tr>
<td></td>
<td>3.0 (Max. Helical)</td>
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**Bending Magnets**

<table>
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<tr>
<td>Bending Radius</td>
<td>2.2 m</td>
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<tr>
<td>Critical Energy</td>
<td>425 eV</td>
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</tbody>
</table>
Beamlines in 2013

Eiji SHIGEMASA
UVSOR Facility, Institute for Molecular Science

The UVSOR facility is one of the highest brilliance light sources in the extreme-ultraviolet region among synchrotron radiation facilities with electron energy less than 1 GeV, thanks to the successful accomplishment of the upgrade project on the storage ring (UVSOR-III project). The natural emittance of the UVSOR-III storage ring reaches to 17.5 nm-rad.

Eight bending magnets and five insertion devices are available as synchrotron light sources at UVSOR. There has been a total of fourteen operational beamlines in 2013, which are classified into two categories. Twelve of them are the 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 two beamlines are the “In-house beamlines”, and are dedicated to the use of research groups within IMS.

There is one soft X-ray station equipped with a double-crystal monochromator, and eight extreme ultraviolet and soft X-ray stations with a grazing incidence monochromator, three vacuum ultraviolet stations with a normal incidence monochromator and two infrared (IR) stations equipped with a Fourier-Transform interferometer, as shown in the appended table (next page) for all available beamlines at UVSOR in 2013.

BL4U, which is equipped with a scanning transmission soft X-ray microscope (STXM), has been newly constructed in 2012. BL4U has been open to users since June 2013, immediately after the shutdown term. Many new results have already emerged from BL4U. The performance of BL4U is close to the theoretically expected one, except in the photon energy region near the C-K shell ionization threshold, due to the so-called “carbon contamination” for the optical elements. In order to improve this situation, the first mirror was recoated by gold and the inner wall of the vacuum chamber as well as all the parts of the mirror holder were washed by hot water to remove the carbon containing elements from the surfaces. As a result, the photon intensity in the C-K edge region has been improved, but has gradually decreased with time. The same cleaning treatment to the grating chamber is planned to be performed during the shutdown term in the spring of 2014.

BL2B, which has long been utilized as an in-house beamline, has been reorganized as an open beamline in 2013. This has been conducted as one of the long-term project proposals. The experimental setup of the angle-resolved photoelectron spectroscopy (ARPES) for inorganic thin films has been brought from Chiba University. The mirror exchanging mechanism in the grating chamber of the BL2B monochromator has been repaired, and the inter-lock system and monochromator control software have been prepared. The commissioning and performance tests will be started from May 2014.

The reconstruction of BL5U has been initiated in 2013. The previous system at BL5U, the SGM-TRAIN monochromator and the APRES end-station, has been stopped its operation in December 2013. The constructions of a new soft X-ray beamline and a spin-resolved photoemission experimental setup have been started since January 2014. As a new undulator for BL5U, an Apple-II type with the period length of 60 mm, whose total length is about 2.5 m, is chosen. The spectral region from 20 eV to 200 eV will be covered with the first and higher harmonic radiation. A variable included angle Monk-Gillieson mounting with an entrance slit-less configuration, which is the same as those installed at BL4U and BL6U, has been selected. The spin-resolved photoemission setup will be equipped with a high-resolution hemispherical electron energy analyzer (MBS A-1) with a highly efficient Mott detector. In pursuit of realizing photoemission experiments with very high spatial resolution, a specially designed post-focusing mirror system is planned to be introduced, where a small beam spot at the sample position (less than 10 μm in diameter) is expected to be achieved. The beamline commissioning of BL5U will be started from May 2014. BL5U will be open to users in the spring of 2015.

In order to promote beamline upgrades and developments of new experimental techniques by users, a new research proposal category named, the “long-term project proposal”, has been introduced in 2012. The available period of this proposal category is three years. One proposal on BL1U has been accepted in 2013. Further discussion toward formulating a basic plan on the beamline construction with users, will be continued.

All users are required to refer to the beamline manuals and the UVSOR guidebook (the latest revision in PDF format uploaded on the UVSOR web site in June 2010), 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.
**Beamlines at UVSOR**

<table>
<thead>
<tr>
<th>Beaml ine</th>
<th>Monochromator / Spectrometer</th>
<th>Energy Range</th>
<th>Targets</th>
<th>Techniques</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL1U</td>
<td>Free electron laser</td>
<td>1.6 - 13.9 eV</td>
<td></td>
<td></td>
<td>M. Katoh <a href="mailto:mKatoh@ims.ac.jp">mKatoh@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL1B</td>
<td>Martin-Puplett FT-FIR</td>
<td>0.5 - 30 meV</td>
<td>Solid</td>
<td>Reflection Absorption</td>
<td>F. Teshima <a href="mailto:tetsu@ims.ac.jp">tetsu@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL2A</td>
<td>Double crystal</td>
<td>585 eV - 4 keV</td>
<td>Solid</td>
<td>Reflection Absorption</td>
<td>N. Kondo <a href="mailto:nkondo@ims.ac.jp">nkondo@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL2B</td>
<td>18-m spherical grating (Dragon)</td>
<td>24 - 205 eV</td>
<td>Gas</td>
<td>Photoionization, Photodissociation</td>
<td>S. Kera <a href="mailto:kera@ims.ac.jp">kera@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL3U*</td>
<td>Varied-line-spacing plane grating (Monk-Gillieson)</td>
<td>60 - 800 eV</td>
<td>Gas Liquid Solid</td>
<td>Absorption, Photoemission, Emission</td>
<td>N. Kosugi <a href="mailto:kosugi@ims.ac.jp">kosugi@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL3B</td>
<td>2.5-m off-plane Eagle</td>
<td>1.7 - 30 eV</td>
<td>Solid</td>
<td>Reflection Absorption</td>
<td>M. Hasumoto <a href="mailto:hasumoto@ims.ac.jp">hasumoto@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL4U</td>
<td>Varied-line-spacing plane grating (Monk-Gillieson)</td>
<td>130 - 700 eV</td>
<td>Gas Liquid Solid</td>
<td>Absorption (Microscopy)</td>
<td>T. Ohigashi <a href="mailto:ohigashi@ims.ac.jp">ohigashi@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL4B</td>
<td>Varied-line-spacing plane grating (Monk-Gillieson)</td>
<td>25 eV - 1 keV</td>
<td>Gas Solid</td>
<td>Photoionization, Photodissociation, Photoemission</td>
<td>E. Shigemasa <a href="mailto:sigemasa@ims.ac.jp">sigemasa@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL5U</td>
<td>Spherical grating (SGM-TRAIN†)</td>
<td>5 - 250 eV</td>
<td>Solid</td>
<td>Photoemission</td>
<td>M. Sakai <a href="mailto:sakai@ims.ac.jp">sakai@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL5B</td>
<td>Plane grating</td>
<td>6 - 600 eV</td>
<td>Solid</td>
<td>Calibration Absorption</td>
<td>M. Hasumoto <a href="mailto:hasumoto@ims.ac.jp">hasumoto@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL6U*</td>
<td>Variable-included-angle varied-line-spacing plane grating</td>
<td>30 - 500 eV</td>
<td>Gas Solid</td>
<td>Photoionization, Photodissociation, Photoemission</td>
<td>E. Shigemasa <a href="mailto:sigemasa@ims.ac.jp">sigemasa@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL6B</td>
<td>Michelson FT-IR</td>
<td>3 meV - 2.5 eV</td>
<td>Solid</td>
<td>Reflection Absorption</td>
<td>F. Teshima <a href="mailto:tetsu@ims.ac.jp">tetsu@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL7U</td>
<td>10-m normal incidence (modified Wadsworth)</td>
<td>6 - 40 eV</td>
<td>Solid</td>
<td>Photoemission</td>
<td>M. Matsunami <a href="mailto:matunami@ims.ac.jp">matunami@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL7B</td>
<td>3-m normal incidence</td>
<td>1.2 - 25 eV</td>
<td>Solid</td>
<td>Reflection Absorption</td>
<td>M. Hasumoto <a href="mailto:hasumoto@ims.ac.jp">hasumoto@ims.ac.jp</a></td>
</tr>
<tr>
<td>BL8B</td>
<td>Plane grating</td>
<td>1.9 - 150 eV</td>
<td>Solid</td>
<td>Photoemission</td>
<td>S. Kera <a href="mailto:kera@ims.ac.jp">kera@ims.ac.jp</a></td>
</tr>
</tbody>
</table>

Yellow columns represent undulator beamlines.

†In-house beamline.

†Spherical grating monochromator with translating and rotating assembly including normal incidence mount.
**BL1U**  
*Free Electron Laser*

**Description**  
The free electron laser (FEL) at UVSOR-II is being moved to a dedicated long straight section (S1). The FEL is equipped with a variably polarized optical klystron of 3 m in length and an optical cavity of 13.3 m in length. By using various multilayer mirrors for the cavity, the FEL can provide coherent light in a wide wavelength range from 800 nm to 199 nm. The pulse duration is typically several tens of picoseconds. The repetition rate is approximately 11 MHz. The average output power depends on the wavelength but its typical value is several hundred milliwatts. Output power higher than 1 W was recorded at 230 nm and 570 nm. The FEL can be operated in top-up injection mode. Users can use the FEL for several hours with quasi-constant output power. The laser pulses are naturally synchronized with the synchrotron radiation pulses that are provided at other synchrotron radiation beamlines. The laser beam can be transported to the beamlines using a mirror system for pump and probe experiments if requested.

![Fig. 1. Schematic of the 13.3 m-long optical cavity.](image)

**Technical Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>199-800 nm</td>
</tr>
<tr>
<td>Spectral band width</td>
<td>$\sim 10^{-4}$</td>
</tr>
<tr>
<td>Polarization</td>
<td>Circular/linear</td>
</tr>
<tr>
<td>Pulse rate</td>
<td>11.26 MHz</td>
</tr>
<tr>
<td>Max. average power</td>
<td>$\sim 1$ W</td>
</tr>
<tr>
<td>Cavity type</td>
<td>Fabry-Perot</td>
</tr>
<tr>
<td>Cavity length</td>
<td>13.3 m</td>
</tr>
<tr>
<td>Cavity mirror</td>
<td>HfO₂, Ta₂O₅, Al₂O₃ multilayer</td>
</tr>
</tbody>
</table>

![Fig. 2. Left and right circularly polarized FEL being delivered to B4 for an application experiment.](image)

![Fig. 3. The FEL is delivered to BL7B. The FEL is irradiated on a target simultaneously with the SR.](image)
**BL1B**

*Terahertz Spectroscopy Using Coherent Synchrotron Radiation*

**Description**

Coherent synchrotron radiation (CSR) is a powerful light source in the terahertz (THz) region. This beamline has been constructed for basic studies on the properties of THz-CSR. However, it can be also used for measurements of reflectivity and transmission spectra of solids using conventional synchrotron radiation.

The emitted THz light is collected by a three-dimensional magic mirror (3D-MM, M0) of the same type as those already successfully installed at BL43IR in SPring-8 and BL6B in UVSOR-II. The 3D-MM was installed in bending-magnet chamber #1 and is controlled by a 5-axis pulse motor stage (x, z translation; \( \theta_x \), \( \theta_y \), \( \theta_z \) rotation). The acceptance angle was set at 17.5-34 degrees (total 288 mrad) in the horizontal direction. The vertical angle was set at ±40 mrad to collect the widely expanded THz-CSR.

The beamline is equipped with a Martin-Puplett type interferometer (JASCO FARIS-1) to cover the THz spectral region from 4 to 240 cm\(^{-1}\) \((h\nu = 500 \mu\text{eV}-30 \text{meV})\). There is a reflection/absorption spectroscopy (RAS) end-station for large samples (~ several mm). At the RAS end-station, a liquid-helium-flow type cryostat with a minimum temperature of 4 K is installed.

**Technical Data**

<table>
<thead>
<tr>
<th>Interferometer</th>
<th>Martin-Puplett (JASCO FARIS-1)</th>
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<tbody>
<tr>
<td>Wavenumber range</td>
<td>4-240 cm(^{-1})</td>
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<tr>
<td>(Energy range)</td>
<td>(500 (\mu\text{eV}-30 \text{meV}))</td>
</tr>
<tr>
<td>Resolution in cm(^{-1})</td>
<td>0.25 cm(^{-1})</td>
</tr>
<tr>
<td>Experiments</td>
<td>Reflection/transmission spectroscopy</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Users can use their experimental system in this beamline.</td>
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</tbody>
</table>
BL2A
Soft X-Ray Beamline for Photoabsorption Spectroscopy

Description
BL2A, which was moved its previous location as BL1A in 2011, is a soft X-ray beamline for photoabsorption spectroscopy. The beamline is equipped with a focusing premirror and a double-crystal monochromator [1]. The monochromator serves soft X-rays in the energy region from 585 to 4000 eV using several types of single crystals, such as β-Al₂O₃, beryl, KTP (KTiOPO₄), quartz, InSb, and Ge. The throughput spectra measured using a Si photodiode (AXUV-100, IRD Inc.) are shown in Fig. 1. The typical energy resolution \( \frac{E}{\Delta E} \) of the monochromator is approximately 1500 for beryl and InSb. There are no experimental setups that are specific to this beamline, except for a small vacuum chamber equipped with an electron multiplier (EM) detector. Photoabsorption spectra for powdery samples are usually measured in total electron yield mode, with the use of the EM detector.


![Fig. 1. Throughput spectra of the double-crystal monochromator at BL2A.](image1)

![Fig. 2. Side view of BL2A.](image2)

Technical Data

<table>
<thead>
<tr>
<th>Monochromator crystals: (2d value, energy range)</th>
<th>Double crystal monochromator</th>
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</thead>
<tbody>
<tr>
<td>β-Al₂O₃ (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)</td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>( \frac{E}{\Delta E} = 1500 ) for beryl and InSb</td>
</tr>
<tr>
<td>Experiments</td>
<td>Photoabsorption spectroscopy</td>
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</tbody>
</table>
Photoelectron spectroscopy of molecular solids

Description

This beamline previously dedicated for experiments in the field of gas phase photoionization and reaction dynamics. Then, the beamline has been reconstructed for photoelectron spectroscopy of molecular solids with a new end station, and experiments can be performed from May 2014. The monochromator is a spherical grating Dragon type with 18-m focal length. High throughput ($1 \times 10^{10}$ photons s$^{-1}$) and high resolution ($E/\Delta E = 2000$ - $8000$) are achieved simultaneously under the condition of the ring current of 100 mA [1]. The optical system consists of two pre-focusing mirrors, an entrance slit, three spherical gratings (G1 - G3), two folding mirrors, a movable exit slit, and a refocusing mirror [2]. The monochromator is designed to cover the energy range of 23–205 eV with the three gratings: G1 (2400 lines mm$^{-1}$, $R = 18$ m) at 80–205 eV; G2 (1200 lines mm$^{-1}$, $R = 18$ m) at 40–100 eV; G3 (2400 lines mm$^{-1}$, $R = 9.25$ m) at 23–50 eV. The percentage of the second-order light contamination at $h\nu = 45.6$ eV is 23% for G2 or 7% for G3.

A UHV chamber is placed downstream of the refocusing mirror chamber and equipped silicon photodiode, sapphire plate Au mesh and filters for absolute photon flux measurement, monitor the photon-beam position, relative photon flux measurements and attenuate higher order light, respectively.

The new end station consists of a main chamber with a hemispherical analyzer (SCIENTA R3000) and a liquid-He-cooled cryostat (temperature range of 15-400 K) with 5-axis stage, a sample preparation chamber with a fast-entry load-lock chamber and a cleaning chamber with LEED, ion gun for sputtering and IR heating unit.


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

Fig. 2. End station of BL2B for photoelectron spectroscopy of molecular solids.

Technical Data

<table>
<thead>
<tr>
<th>Monochromator</th>
<th>18 m spherical grating Dragon-type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength Range</td>
<td>23-205 eV</td>
</tr>
<tr>
<td>Resolution</td>
<td>2000–8000 depending on the gratings</td>
</tr>
<tr>
<td>Experiments</td>
<td>Angle-resolved ultraviolet photoemission spectroscopy</td>
</tr>
</tbody>
</table>
**BL3U**

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

**Description**

The beamline BL3U is equipped with an in-vacuum undulator composed of 50 periods of 3.8 cm period length. The emitted photons are monochromatized by the varied-line-spacing plane grating monochromator (VLS-PGM) designed for various spectroscopic investigations in the soft X-ray range including soft X-ray emission studies. Three holographically ruled laminar profile plane gratings are designed to cover the photon energy range from 60 to 800 eV. The beamline has two endstations, namely, XES setup and multi-purpose setup. The XES setup is used for soft X-ray emission spectroscopy. The beam is horizontally focused onto the sample position by a plane-elliptical mirror, M2X. In the multi-purpose setup, the beam is focused by the toroidal mirror M2. Between the sample position and M2, the differential pumping is placed.

![Diagram of BL3U](image)

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

**Technical Data**

<table>
<thead>
<tr>
<th>Monochromator</th>
<th>Varied-line-spacing plane grating monochromator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Range</td>
<td>60-800 eV</td>
</tr>
<tr>
<td>Resolution</td>
<td>( \frac{E}{\Delta E} &gt; 10,000 )</td>
</tr>
<tr>
<td>Experiments</td>
<td>Soft X-ray spectroscopy (XPS, XES, XAS)</td>
</tr>
<tr>
<td>Beam Size (XES Endstation)</td>
<td>Vertical 5-20 µm; Horizontal 41 µm (FWHM)</td>
</tr>
</tbody>
</table>
**BL3B (HOTRLU)**

*VIS-VUV Photoluminescence and Reflection/Absorption Spectroscopy*

**Description**

BL3B has been constructed to study photoluminescence (PL) in the visible (VIS) to vacuum ultraviolet (VUV) region. This beamline consists of a 2.5 m off-plane Eagle type normal-incidence monochromator, which covers the VUV, UV, and VIS regions, i.e., the energy (wavelength) region of 1.7-31 eV (40-730 nm), with three spherical gratings having constant grooving densities of 1200, 600, and 300 l/mm optimized at the photon energies of ~20, ~16, and ~6 eV, respectively. The schematic side view and top view layouts are shown in Figs. 1(a) and 1(b), respectively. The FWHM of the beam spot at the sample position is 0.25 mm (V) × 0.75 mm (H).

Low energy pass filters (LiF, quartz, WG32, OG53) can be inserted automatically to maintain the optical purity in the G3 (300 l/mm) grating region (1.7~11.8 eV). Figure 2 shows the throughput spectra (photon numbers at a beam current of 300 mA) for each grating with entrance and exit slit openings of 0.1 mm (resolving power $E / \Delta E$ of ~2000 (G3, ~6.8 eV)). Since both slits can be opened up to 0.5 mm, a monochromatized photon flux of $10^{10}$ photons/s or higher is available for PL measurements in the whole energy region.

The end station is equipped with a liquid-helium-flow type cryostat for sample cooling and two detectors; one of which is a photomultiplier with sodium salicylate and the other a Si photodiode for reflection/absorption measurement. For the PL measurements in the wide energy region from VIS to VUV, two PL monochromators, comprising not only a conventional VIS monochromator but also a VUV monochromator with a CCD detector, are installed at the end station.


**Technical Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Monochromator</strong></td>
<td>-2.5 m normal-incidence monochromator</td>
</tr>
<tr>
<td><strong>Energy range</strong></td>
<td>1.7-31 eV (40~730 nm)</td>
</tr>
<tr>
<td><strong>Resolution (Δhv/ hv)</strong></td>
<td>$\geq 12000$ (at ~ 6.9 eV, 0.02 mm slits, G1 (1200 l/mm)</td>
</tr>
<tr>
<td><strong>Experiments</strong></td>
<td>Photoluminescence, reflection, and absorption spectroscopy, mainly for solids</td>
</tr>
</tbody>
</table>

Fig. 1. Schematic layout of the BL3B (a) side view and (b) top view.

Fig. 2. Throughput spectra for each grating (G1:1200 l/mm, G2:600 l/mm and G3:300 l/mm) with S1 = S2 = 0.1 mm.
**Description**

In the soft x-ray region, there are several absorption edges of light elements and transition metals. The near edge X-ray absorption fine structure (NEXAFS) brings detailed information about the chemical state of target elements. A scanning transmission X-ray microscope (STXM) in the soft X-ray region is a kind of extended technique of the NEXAFS with high spatial resolution. The STXM has a capability of several additional options, for example, in-situ observations, 3-dimensional observation by computed tomography and ptychography, by utilizing the characteristics of the X-rays. The STXM can be applied to several sciences, such as polymer science, material science, cell biology, environmental science, and so on.

This beamline equips an in-vacuum undulator, a varied-line-spacing plane grating monochromator and a fixed exit slit. The soft X-ray energy range from 130 to 770 eV with the resolving power (E/\(\Delta E\)) of 6,000 is available. The aperture size of the fixed exit slit determines not only the resolving power but also the size of a microprobe. A Fresnel zone plate is used as a focusing optical device through an order select aperture and its focal spot size of \(~30\) nm is available at minimum. An image is acquired by detecting intensities of the transmitted X-rays by a photomultiplier tube with scintillator with scanning a sample 2-dimensionally. By changing the energy of the incident beam, each 2-dimensional NEXAFS image is stacked. A main chamber of STXM is separated from the beamline optics by a silicon nitride membrane of 100-nm thickness; therefore, sample folders can be handled in vacuum or in helium.

**Technical Data**

<table>
<thead>
<tr>
<th>Energy range (E)</th>
<th>150 - 770 eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolving power (E/(\Delta E))</td>
<td>(~6000)</td>
</tr>
<tr>
<td>Focusing optical element</td>
<td>Fresnel zone plate</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>(~30) nm</td>
</tr>
<tr>
<td>Experiments</td>
<td>2-dimentional absorption spectroscopy</td>
</tr>
<tr>
<td>Measurement environment</td>
<td>standard sample folder in vacuum or in helium, specially designed sample cell in ambient condition</td>
</tr>
</tbody>
</table>
**BL4B**

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

**Description**

The beamline BL4B equipped with a varied-line-spacing plane grating monochromator (VLS-PGM) was constructed for various spectroscopic investigations in a gas phase and/or on solids in the soft X-ray range. Three holographically ruled laminar profile plane gratings with SiO$_2$ substrates are designed to cover the photon energy range from 25 to 800 eV. The gratings with groove densities of 100, 267, and 800 l/mm cover the spectral ranges of 25–100, 60–300, and 200-1000 eV, respectively, and are interchangeable without breaking the vacuum. Figure 1 shows the absolute photon flux for each grating measured using a Si photodiode (IRD Inc.), with the entrance- and exit-slit openings set at 50 and 50 µm, respectively. The maximum resolving power ($E/\Delta E$) achieved for each grating exceeds 5000.

![Fig. 1. Throughput from the VLS-PGM monochromator on BL4B.](image1.png)

![Fig. 2. Photo of BL4B.](image2.png)

**Technical Data**

<table>
<thead>
<tr>
<th>Monochromator</th>
<th>Varied-line-spacing Plane Grating Monochromator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>25-1000 eV</td>
</tr>
<tr>
<td>Resolution</td>
<td>$E/\Delta E &gt; 5000$ (at maximum)</td>
</tr>
<tr>
<td>Experiments</td>
<td>Soft X-ray spectroscopy (mainly, angle-resolved photoion spectroscopy for gaseous targets and photoelectron spectroscopy for gaseous and solid targets)</td>
</tr>
</tbody>
</table>
Description

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

The SGM-TRAIN is an improved version of a constant-length SGM that aims at realizing the following points: (1) covering the wide energy range of 5–250 eV, (2) high energy resolving power, (3) use of linearly and circularly polarized undulator light, (4) reduction of higher-order light, and (5) two driving modes (rotation and translation of gratings) by computer control. The second-order light is well suppressed using laminar profile gratings and combinations of mirrors and gratings. This beamline will be totally upgraded after Jan 2014.

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

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

Technical Data

<table>
<thead>
<tr>
<th>Monochromator</th>
<th>SGM-TRAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Range</td>
<td>5-250 eV</td>
</tr>
<tr>
<td>Resolution</td>
<td>$h\nu / \Delta E &gt; 2,000$ for $&lt; 40 \mu m$ slits</td>
</tr>
<tr>
<td>Experiment</td>
<td>ARPES, AIPES, XAS</td>
</tr>
<tr>
<td>Flux</td>
<td>$&lt;10^{11}$ photons/s for $&lt; 40 \mu m$ slits (in the sample position)</td>
</tr>
<tr>
<td>Main Instruments</td>
<td>Hemispherical photoelectron analyzer (MBS-Toyama ‘Peter’ A-1), LEED of reverse type (OMICRON), Liq-He flow cryostat (5-400 K)</td>
</tr>
</tbody>
</table>
BL5B

Calibration Apparatus for Optical Elements and Detectors

Description

BL5B has been constructed to perform calibration measurements for optical elements and detectors. This beamline is composed of a plane grating monochromator (PGM) and three endstations in tandem. The most upstream station is used for the calibration measurements of optical elements, the middle one for optical measurements for solids, and the last for photo-stimulated desorption experiments. The experimental chamber at the most downstream station is sometimes changed to a chamber for photoemission spectroscopy. The calibration chamber shown in Fig. 2 is equipped with a goniometer for the characterization of optical elements, which has six degrees of freedom, X-Y translation of a sample, and interchanging of samples and filters. These are driven by pulse motors in vacuum. Because the polarization of synchrotron radiation is essential for such measurements, the rotation axis can be made in either the horizontal or vertical direction (s- or p-polarization).

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

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

Technical Data

<table>
<thead>
<tr>
<th>Monochromator</th>
<th>Plane Grating Monochromator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>6-600 eV (2-200 nm)</td>
</tr>
<tr>
<td>Resolution</td>
<td>$E / \Delta E \sim 500$</td>
</tr>
<tr>
<td>Experiments</td>
<td>Calibration of optical elements, absorption of solids, photo-stimulated desorption from rare-gas solids</td>
</tr>
</tbody>
</table>
**BL6U**

*Variable-Included-Angle VLS-PGM for Molecular Soft X-Ray Spectroscopy*

**Description**

The beamline BL6U equipped with a variable-included-angle Monk-Gillieson mounting monochromator with a varied-line-spacing plane grating was constructed for various spectroscopic investigations requiring high-brilliance soft X-rays in a gas phase and/or on solids. Through a combination of undulator radiation and sophisticated monochromator design (entrance slit-less configuration and variable-included-angle mechanism), using a single grating, the monochromator can cover the photon energy ranging from 30 to 500 eV, with resolving power of greater than 10000 and photon flux of more than $10^{10}$ photons/s. Figure 1 shows an example of the monochromator throughput spectra measured using a Si photodiode, with the exit-slit opening set at 30 µm, which corresponds to the theoretical resolving power of 10000 at 80 eV.

**Technical Data**

<table>
<thead>
<tr>
<th>Monochromator</th>
<th>Variable-included-angle Varied-line-spacing Plane Grating Monochromator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>40-500 eV</td>
</tr>
<tr>
<td>Resolution</td>
<td>$E / \Delta E &gt; 10000$ (at maximum)</td>
</tr>
<tr>
<td>Experiments</td>
<td>High-resolution soft X-ray spectroscopy (mainly photoelectron spectroscopy for gaseous and solid targets)</td>
</tr>
</tbody>
</table>

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

Fig. 2. Photo of BL6U
**BL6B**  

**Infrared and Terahertz Spectroscopy of Solids**

▶ **Description**

Synchrotron radiation (SR) has good performance (high brilliance and high flux) not only in the VUV and soft X-ray (SX) regions but also in the infrared (IR) and THz regions. BL6B covers the IR and THz regions. The previous beamline, BL6A1, which was constructed in 1985, was the pioneer in IRSR research. The beamline was deactivated at the end of FY2003 and a new IR/THz beamline, BL6B (IR), was constructed in FY2004. The front-end part including bending duct #6 was replaced with a new part having a higher acceptance angle (215 (H) × 80 (V) mrad$^2$) using a magic mirror, as shown in Fig. 1 [1].

The beamline is equipped with a Michelson type (Bruker Vertex70v) interferometer to cover a wide spectral region from 30 to 20,000 cm$^{-1}$ ($h\nu = 4$ meV-$2.5$ eV), as shown in Fig. 2. There are two end-stations; one for reflection/absorption spectroscopy (RAS) of large samples (up to several mm) and the other for IR/THz microscopy (transmission microscopy: TM) of tiny samples (up to several tens of $\mu$m). At the RAS end-station, a liquid-helium-flow type cryostat with a minimum temperature of 10 K is installed. At the TM end-station, pressure- and temperature-dependent THz spectroscopy can be performed. A superconducting magnet with a maximum field of 6 T can be installed by the exchange with the TM end-station.


---

**Technical Data**

<table>
<thead>
<tr>
<th>Interferometer</th>
<th>Michelson (Bruker Vertex70v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavenumber Range</td>
<td>30-20,000 cm$^{-1}$</td>
</tr>
<tr>
<td>(Energy range)</td>
<td>(4 meV-2.5 eV)</td>
</tr>
<tr>
<td>Resolution in cm$^{-1}$</td>
<td>0.1 cm$^{-1}$</td>
</tr>
<tr>
<td>Experiments</td>
<td>Reflectivity and transmission</td>
</tr>
<tr>
<td></td>
<td>Microspectroscopy</td>
</tr>
<tr>
<td></td>
<td>Magneto-optics</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Users can use their experimental system in this beamline.</td>
</tr>
</tbody>
</table>
**BL7U (SAMRAI)**

*Angle-Resolved Photoemission of Solids in the VUV Region*

**Description**

Beamline 7U, named the Symmetry-And Momentum-Resolved electronic structure Analysis Instrument (SAMRAI) for functional materials, was constructed to provide a photon flux with high energy resolution and high flux mainly for high-resolution angle-resolved photoemission spectroscopy of solids [1]. An APPLE-II-type variable-polarization undulator is installed as the light source. The undulator can produce intense VUV light with horizontal/vertical linear and right/left circular polarization. The undulator light is monochromatized by a modified Wadsworth type monochromator with three gratings (10 m radius; 1200, 2400, and 3600 lines/mm optimized at $h\nu = 10, 20,$ and $33 \text{ eV}$). The energy resolution of the light ($h\nu / \Delta h\nu$) is more than $10^4$ with a photon flux of $10^{11}$-$10^{12}$ ph/s or higher on samples in the entire energy region.

The beamline has a photoemission end-station equipped with a 200 mm-radius hemispherical photoelectron analyzer (MB Scientific AB, A-1 analyzer) with a wide-angle electron lens and a liquid-helium-cooled cryostat with 6-axis pulse motor control (AVC Co., Ltd., i-GONIO). The main function of the beamline is to determine the three-dimensional Fermi surface and electronic structure of solids at low temperatures and their temperature dependence in order to reveal the origin of their physical properties.


**Technical Data**

<table>
<thead>
<tr>
<th>Light source</th>
<th>APPLE-II type undulator ($\lambda_u = 76 \text{ mm, } N = 36$) vertical/horizontal linear, right/left circular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monochromator</td>
<td>10 m normal-incidence monochromator (modified Wadsworth type)</td>
</tr>
<tr>
<td>Photon energy range</td>
<td>6–40 eV ($\lambda = 30–200 \text{ nm}$)</td>
</tr>
<tr>
<td>Resolution ($h\nu / \Delta h\nu$)</td>
<td>$1 \times 10^4 - 5 \times 10^4$</td>
</tr>
<tr>
<td>Photon flux on sample</td>
<td>$\geq 10^{13}$-$10^{14}$ ph/s (depending on $h\nu$)</td>
</tr>
<tr>
<td>Beam size on sample</td>
<td>200 (H) $\times$ 50 (V) $\mu$m$^2$</td>
</tr>
<tr>
<td>Experiments</td>
<td>Angle-resolved photoemission of solids (MB Scientific A-1 analyzer, acceptance angle: $\pm$ 18 deg)</td>
</tr>
</tbody>
</table>
**Description**

BL7B has been constructed to provide sufficiently high resolution for conventional solid-state spectroscopy, sufficient intensity for luminescence measurements, wide wavelength coverage for Kramers–Kronig analyses, and minimum deformation to the polarization characteristic of incident synchrotron radiation. This beamline consists of a 3-m normal incidence monochromator, which covers the vacuum ultraviolet, ultraviolet, visible, and infrared, i.e., the wavelength region of 40–1000 nm, with three gratings (1200, 600, and 300 l/mm). Two interchangeable refocusing mirrors provide two different focusing positions. For the mirror with the longer focal length, an LiF or a MgF₂ window valve can be installed between the end valve of the beamline and the focusing position. Figure 1 shows the absolute photon intensity for each grating with the entrance and exit slit openings of 0.5 mm. A silicon photodiode (AXUV-100, IRD Inc.) was utilized to measure the photon intensity and the absolute photon flux was estimated, taking the quantum efficiency of the photodiode into account.

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**Fig. 1.** Throughput spectra of BL7B measured using a silicon photodiode.  
**Fig. 2.** Photo of BL7B.

---

**Technical Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monochromator</td>
<td>3 m Normal-Incidence Monochromator</td>
</tr>
<tr>
<td>Wavelength Range</td>
<td>50-1000 nm (1.2-25 eV)</td>
</tr>
<tr>
<td>Resolution</td>
<td>$E / \Delta E = 4000-8000$ for 0.01 mm slits</td>
</tr>
<tr>
<td>Experiments</td>
<td>Absorption, reflection, and fluorescence spectroscopy, mainly for solids</td>
</tr>
</tbody>
</table>
Description

BL8B is a beamline for the angle-resolved ultraviolet photoemission spectroscopy (ARUPS) system, which is designed to measure various organic solids such as molecular crystals, organic semiconductors, and conducting polymers. This beamline consists of a plane-grating monochromator (PGM), a sample preparation chamber with a fast-entry load-lock chamber, a measurement chamber (base pressure $1 \times 10^{-10}$ Torr), a cleaning chamber (base pressure $1 \times 10^{-10}$ Torr), and a sample evaporation chamber (base pressure $3 \times 10^{-10}$ Torr). The cleaning chamber is equipped with a back-view LEED/AUGER, an ion gun for $\text{Ar}^+$ sputtering, and an infrared heating unit. The PGM consists of premirrors, a plane grating, focusing mirror, and a post-mirror, with an exit slit. It covers the wide range from 2 to 130 eV with two exchanging gratings (G1: 1200 l/mm, G2: 450 l/mm) and five cylindrical mirrors. The toroidal mirror focuses the divergent radiation onto the sample in the measurement chamber. The spot size of the zeroth-order visible light at the sample surface is approximately $1 \times 1 \text{ mm}^2$. Figure 1 shows the throughput spectra of PGM (slit = 100 µm). The energy resolution at a slit width of 100 µm was found to be $E/\Delta E = 1000$ in the wavelength range from 2 to 130 eV. A hemispherical electron energy analyzer of 75 mm mean radius with an angular resolution less than 2° can be rotated around the vertical and horizontal axes. The sample mounted on a manipulator (temperature range 14–320 K) can also be rotated around two axes.

Technical Data

<table>
<thead>
<tr>
<th>Monochromator</th>
<th>Plane-grating monochromator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength Range</td>
<td>9-600 nm</td>
</tr>
<tr>
<td>Resolution</td>
<td>$E/\Delta E = 1000$</td>
</tr>
<tr>
<td>Experiments</td>
<td>Angle-resolved ultraviolet photoemission spectroscopy</td>
</tr>
</tbody>
</table>