Photoemission Spectroscopy and Photoemission Electron Microscopy Beamline at the Siam Photon Laboratory

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Abstract. A beamline to utilize radiation from the first undulator at the Siam Photon Laboratory was designed and constructed. The beamline employs a varied line-spacing plane grating monochromator with three interchangeable gratings, which provides energy between 40-160 and 220-1040 eV. There are two optical branches downstream of the monochromator allowing two different measurement techniques, i.e. photoemission spectroscopy and photoemission electron microscopy, to be utilized in a time-sharing mode. In this report, the detailed descriptions of the beamline as well as the performance of the beamline and the commissioning results will be presented. Problems found during the undulator commissioning will also be discussed.

1. Introduction
The first undulator beamline, BL3.2, at the Siam Photon Laboratory (SPL) was constructed for research in the fields of materials science, condensed matter physics, and chemical analysis using soft x-ray photoemission electron spectroscopy (PES) and microscopy (PEEM) techniques. A varied-line-spacing plane grating monochromator in BL3.2 was designed to deliver photons with energies between 40-160 and 220-1040 eV, covering the 1s core level of C, N, O, and the 2p core levels of 3d transition metals. The major mechanical components of BL3.2 and PES system were transferred and modified from the decommissioned PES beamline (BL4) which used a bending magnet source at SPL [1]. However, the optical mirrors and gratings were re-designed to utilize the undulator radiation at the higher resolving power and photon energy than those in the bending magnet beamline. The early optical design concept of BL3.2 was reported elsewhere [2]. In this report, we summarize the final optics design and early commissioning results of BL3.2.

2. Beamline optics
This section describes the modification of beamline optics from the previously reported parameters [2]. The actual parameters of the mirrors installed in BL3.2 are given in table 1. The major differences from the previously designed values are geometrical parameters in the M0 and M2T toroidal mirrors which improve the horizontal beam focus to a demagnification of 10. According to the changes in the optics, the optical-axis distances were also modified as sketched in figure 1.
3. The construction of the undulator beamline

A planar Halbach-type undulator (U60) from Danfysik was installed in January 2008 at one of the four long straight sections in the storage ring of the Siam Photon Source to produce the VUV and soft x-rays for BL3.2. Prior to the installation of U60 in the storage ring, the U60 gap control software was developed and magnetic field variations with the undulator gap were also measured at SPL [3, 4]. The optical beamline system was constructed in January 2010 providing the VUV and soft x-rays undulator radiation for the beamline commissioning as well as user’s preliminary experiments. Two experimental end-stations of BL3.2a for PES and BL3.2b for PEEM were connected to the two branches of the beamline in May 2010.

4. The commissioning of the undulator

The performance of the undulator beamline strongly depends on the machine operation of the storage ring. Since the undulator gap change perturbs the local and global electron beam orbits, the electron orbit feedback and/or feedforward systems with electron and photon beam monitoring are required to maintain the beam stability during the beam service at SPL. 20 electron beam position monitors (BPMs) in the storage ring were commissioned in 2011. They have been used for global slow orbit correction together with 16 horizontal and 12 vertical corrector magnets prior to the beam service at the moment. Since March 2012, to minimize the effect of the U60 gap changes to other beamlines, the feedforward electron beam position correction has been in operation using the two local-bump magnets of U60. The feedforward look-up parameters were evaluated using the electron BPMs and two 4-blade photon BPMs. In BL3.2, the corrected electron orbit effect was checked with the wire-type photon BPMs and red-shift measurements to align the central cone radiation of U60 to the beamline axis.

Table 1. Parameters for the BL3.2 mirrors

| Surface type | Angle of incidence (°) | R (mm)   | p (mm)  |
|--------------|------------------------|----------|---------|
| M0           | Toroidal               | 87       | 232,360 | 312     |
| M1/1         | Spherical              | 88.5     | 171,907 | -       |
| M1/2         | Spherical              | 86       | 63,230  | -       |
| M2V          | Cylindrical            | 87.75    | 62,961  | -       |
| M2H          | Cylindrical            | 87       | 50,320  | -       |
| M2Cy         | Cylindrical            | 87       | -       | 67      |
| M2T          | Toroidal               | 87.75    | 97,327  | 210     |

Figure 1. A schematic diagram of optical layout in BL3.2.
5. The performance of the beamline

Gas-phase photoionization spectra were recorded using a gas cell being located at BL3.2a to evaluate the resolving power of the monochromator and to calibrate the photon energy. The gas cell consists of a gate valve, a gas-inlet valve, and two sets of OFHC electrodes located beside the optical path. The gate valve attached with a 0.1-micron-thick parylene N window (Lebow Co.) was used to vacuum-isolate the gas cell from the optical beamline, allowing the measurements to be carried out at pressures up to $1 \times 10^{-2}$ mbar. The gas-phase photoionization yield was measured from drain current from the one-side electrode plates while the counter electrode plates were being biased at $+20 \text{V}$ to extract excited electrons and repel ions. The Si photodiode (AXUV100 coated with Al 40 nm; IRD Inc.) was also installed at the end of the gas cell to evaluate the total flux of photons coming into measurement system. The Si photodiode was calibrated in the argon gas photoionization yield at the photon energy of 91.84 eV under the double gas cell operation mode [5]. The standard transmission data of the parylene N window was taken into account when evaluating the total flux of photons coming into the gas cell.

Photoionization spectrum taken from the $2,0_3$ resonance of doubly excited helium is shown in figure 2. In figure 2, the measured spectrum represented by open circles was fitted with a Fano profile convoluted with a Gaussian ($\Delta E$: FWHM). Fano parameter $q=-2.4$ and line width $\gamma=0.002$ eV are based on the previously reported data in the high resolution experiments performed elsewhere [6]. It should be noted that the photon-energy scale used for figures in this report was calibrated using the Fermi edge of gold PES spectra.

This result reveals a resolving power ($E/\Delta E$) of 10000 at the total flux of $1 \times 10^{10} \text{ph/s}/100 \text{mA}$, which is the goal of our monochromator design. An entrance-slit width (S1) and an exit-slit width (S2) of 75 and 17 micron, respectively, are calculated from the analytical expressions using the resolving power of 10000, the $2,0_3$ resonant excitation energy ($E$), and the grating’s groove density of 600 lines/mm as constants. The exit-slit tilt and position were optimized to obtain the highest resolution during the measurement. The measured resolving powers defined by various slit widths were found to be higher than those calculated from analytical expression. This might be due to the thermal load effect on the entrance slit. It is noted that the water-cooling system was not installed to the slit at the time of the measurements. Thermal expansion of the tungsten blade of the slit was observed, resulting in the actual width of the entrance slit being smaller than the setting value.

![Figure 2](image_url)

**Figure 2.** Photoionization spectrum measured on $2,0_3$ resonance of doubly excited helium. Open circles represent the experimental result, solid line the fitting curve using the Fano profile convoluted with a Gaussian. Resonance energy, Fano parameters ($q$), line width and Gaussian width (FWHM) used in fitting are described in the inset.
Photoionization spectrum taken from the vibrational states of nitrogen $1s \rightarrow \pi^*$ is shown in figure 3 using a grating with groove density of 1200 lines/mm. In figure 3, the measured spectrum represented by open circles was fitted by a Voigt function with a fixed Lorentzian line width of 116 meV based on the previously reported data [7]. The instrumental resolution evaluated from a Gaussian width ($\Delta E=0.0216$ eV) in the Voigt fitting exhibits a resolving power ($E/\Delta E=18396$) over 10000 at about 400 eV of photon energy. The ratio $r$ between the amplitude of the first minimum and that of the third maximum of the background-subtracted spectrum was also used to avoid the uncertainties produced by different fitting procedures [8, 9]. The value of $r=0.748$ obtained by the fitting as shown in figure 3 is in good agreement with the previously reported data at a resolving power of 11000 [7]. However, the measured total flux of photons in the photodiode behind the gas cell was found to be less than the designed value. This might be due to the significant absorption of carbon contamination on optical mirrors and error in the transmission data of the parylene foil used at the gas cell.

The beamline will facilitate soft x-ray research activities in Thailand providing an innovative and scientific environment for scientific and industrial users worldwide.

![Photoionization spectrum of $\text{N}_2\ 1s^1\pi^*$ excitation. Open circles represent the experimental result, solid lines the Voigt profile, and dashed line the cubic spline background.](image)

**Figure 3.** Photoionization spectrum of $\text{N}_2\ 1s^1\pi^*$ excitation. Open circles represent the experimental result, solid lines the Voigt profile, and dashed line the cubic spline background.

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