Optical design of a compact and practical UV beamline at HiSOR-BL12

M. Sawada, H. Namatame and M. Taniguchi
Hiroshima Synchrotron Radiation Center, Hiroshima University,
2-313 Kagamiyama, Higashi-Hiroshima 739-0046, Japan
E-mail: sawa@hiroshima-u.ac.jp

Abstract. A practical ultraviolet beamline is designed for UV circular dichroism experiment, which will be constructed at HiSOR-BL12. The beamline optics is based on a Wadsworth-type design with a normal incidence grating monochromator that covers a photon energy range between 2 eV and 10 eV. In the design, minimization of number of mirrors and wide acceptance angles of the optical elements contribute to high beam flux of monochromatic photons. The limiting and practical resolutions of the monochromator for 6 eV photons are 9 meV and 50 meV, respectively. The monochromator can be assembled compactly with good resolving power that is guaranteed by minimization of defocus and aberration of the grating.

1. Introduction
Since synchrotron radiation (SR) has a characteristic feature of a continuous wavelength light with specified polarization, a SR beamline that can provide monochromatic ultraviolet (UV) photons is an ideal experiment station for the spectroscopic methods including circular dichroism (CD) for biological and biochemical materials. UV-CD is a powerful experimental method to investigate stereore structures of the biomaterials in natural states. Recently, UV-CD experiments have become an important technique in SR research fields, because they can provide complementary information on higher-order structures of proteins to that obtained from X-ray diffraction experiment. UV-CD is quicker and more accessible than X-ray diffraction technique that requires preparation of the crystallized samples, and also to perform kinetics experiments involving structural changes in biomolecule in solution environment. The need of UV beamlines appropriate to UV-CD experiments is increasing nowadays, and their optical design should be optimized for a typical photon energy range corresponding to the spectral range of CD measurements in biomaterials.

The Wadsworth-type monochromator has been employed as an optical layout of the UV beamline in SR facilities since long ago [1-3]. The beamline based on the Wadsworth mount is characterized by the entrance-slitless design with a normal incidence grating, which allows us to introduce a direct quasi-parallel SR beam into the grating, and consequently to obtain the high flux monochromatic photons available for the experiments. So far, some modified types of Wadsworth monochromator have been suggested [4-6], one of which is designed so that the aberration of the grating is reduced by pre-mirrors insuring the parallelism of the incident light, and by a large curvature radius of the grating, to achieve a high resolving power. In the modified designs, large or complicated optical systems with a number of mirrors tend to be required for a good performance of the monochromator. On the other hand, a simple optical layout might be preferable for the UV-CD beamline rather than ultimate specifications, because the required resolution for the UV-CD experiment is not so high (E/ΔE ~ 100).
In order to construct a beamline appropriate to the UV-CD experiment at a bending magnet port of a second-generation SR ring, we have newly designed a practical UV beamline with a compact type of monochromator based on the Wadsworth mount. The beamline is composed of a minimum number of optical elements that can accept all photon beams emitted from the light source with large solid angle, so that high photon flux of monochromatic light can be provided for the experiment. The resolution of the monochromator is high enough to execute the UV-CD experiment despite its compact size. The designed beamline has been installed actually at HiSOR-BL12 in Hiroshima Synchrotron Radiation Center, Japan.

2. Optical design
The beamline HiSOR-BL12 is specialized for spectrometry within a narrowband region between 2 eV (620 nm) and 10 eV (124 nm) in photon energy (wave length). Normal incidence optics can be employed for the beamline design, since a reflection coefficient of aluminium mirrors is beyond 90% for s-polarized light with small reflection angle within the photon energy range. The reflectance of s-polarized light is essential in the UV-CD beamline, because the UV-CD polarimeter generates circularly polarized light from the horizontal polarization component of SR with a photoelastic modulator (PEM) element. The Optical design of HiSOR-BL12 is based on the following concepts: (1) To collect a large number of photons, vertical and horizontal angular acceptance from the SR source should be as large as possible. (2) To achieve a good throughput of the beamline, a minimum number of optical elements should be used. (3) We adapt a modified type of the Wadsworth mount without entrance slit, whose optical arrangement should be faithful to the ideal diffraction condition minimizing the aberration and the defocus on the exit slit. (4) The monochromator should be compact provided that the resolving power and the photon flux are enough.

The schematic drawing and the parameters of the optical elements of HiSOR-BL12 are shown Fig. 1 and Table 1, respectively. The beamline is composed of three reflective elements, where the horizontal focusing is independent of the optics in the vertical plane. Only the first toroidal mirror (M0) contributes to the horizontal focus through the sagittal curvature of the mirror. The tangential curvature on the M0 mirror surface injects a parallel beam of light into the grating (GR). The GR and refocusing mirror (MF) has no curvature in the horizontal direction, whose tangential focusing in the vertical plane is utilized for both monochromatization and vertical convergence into the focal point. The size of optical area of the M0 mirror covers a wide acceptance angle of SR light emitted from the source point, the angle of which is 15 mrad horizontally and 10 mrad vertically, which are maximum angles of angular acceptance for the beamline ports of the HiSOR ring.

![Figure 1. Beamline layout of HiSOR-BL12.](image-url)
Table 1. Specification of optical elements of HiSOR-BL12.

| Optical element | Curve       | Coating    | Optical area (V × H mm) | Curvature (mm) | Vertical focus (Deg.) | Horizontal focus (Deg.) | Angle a (Deg.) |
|-----------------|-------------|------------|-------------------------|----------------|-----------------------|-------------------------|-----------------|
| Focusing mirror (M0) | Toroid     | MgF₂/Al   | 35.0 × 52.5             | 7319.8         | 4133.5                |                         | 17              |
| Grating (GR)     | Cylinder    | MgF₂/Al   | 41.2 × 46.5             | 2000.6         | -                     |                         | 14              |
| Refocusing mirror (MF) | Elliptical cylinder | Pt       | 233.6 × 27.9            | f₁=1000        | f₂=3000                | -                       | 80              |

*Incident angle and deviation angle are given for mirror and grating, respectively.*

The monochromator consists of the mirror M0, the reflection grating GR and the exit slit S, which are assembled into a mechanism as shown in Fig. 2 schematically. The M0 is mounted on an angle adjustment stage equipped with a water-cooling unit to reduce heat load of the mirror. To minimize the aberration, the GR is rotated over the axis that coincides with the horizontal line passing through the GR center on its surface. The incident (α) and deflection angle (β) of the GR can be controlled by a sine bar connected to a motorized linear motion stage, constrained to a constant deviation angle (α−β = 14°). A laminar-type grating with a groove density of 300 lines/mm is installed on the grating mount, whose rotation range between α = 12.4° (for 2 eV) and 8.1° (for 10 eV) is covered sufficiently by the sine bar mechanism. The grating has been designed and manufactured such that the resolution limit contributed by the surface roughness and the slope error is much smaller than the required resolution. The exit slit S is a movable vertical slit whose width can be adjusted manually, it is mounted on a motorised stage to allow us to change the slit position along the optical path continually. We can set the slit at the proper position corresponding to the focal distance of the GR, which depends on the monochromatic photon energy. All of the monochromator components are monolithically mounted on a rigid base plate, which are integrated compactly in a longitudinal dimension of 1.6 m.

The overall optical efficiency of the beamline is critically dependent on a product of reflection coefficients of the mirrors and grating, the value of which is estimated at 0.34 for the monochromatic photon energy of 10 eV. At the focal point, high beam flux of 2×10¹⁴ photons/sec is expected with the

![Figure 2. Schematic drawing of the modified Wadsworth-type monochromator at HiSOR-BL12.](image_url)
A slit width of 1 mm corresponding to the practical resolution, when the electron beam current of 300 mA is accumulated in the SR storage ring. In order to investigate the spot size at the focal point and the resolving power of the monochromator, ray trace simulations have been carried out with the optical simulation program SHADOW, whose results are partly shown in Fig. 3. Calculated rays at the focal point are shown in Fig. 3(a), whose spot size is $3\,\text{mm} \times 3\,\text{mm}$ in FWHM, and is sufficiently smaller than the typical optical size (~10 mm) of sample cells, sensor surfaces of detectors, PEM and polarizers in the UV-CD instruments. The simulations show also that the resolving power ($E/\Delta E$) of 120 is achieved with a wide slit width of 1 mm at the photon energy of 6 eV, enough for the UV-CD experiment. Simulated rays with photon energy of 5.991, 6.0 and 6.009 are displayed in Fig. 3(b), where each bunch of the rays with different photon energy distributes separately from the others in vertical direction on the slit surface. From the ray trace survey, the limiting resolutions are estimated at 1, 4, 9, 18 and 26 meV at the photon energy of 2, 4, 6, 8 and 10 eV, respectively. It is concluded that our compact and high efficiency monochromator has a potential to realize much higher resolving power than the original requirement for the UV-CD experiment.

3. Summary

A compact and practical UV beamline with a modified type of Wadsworth monochromator has been designed successfully, which has been installed actually at HiSOR-BL12. The high efficiency design with only three optical elements ensures high beam flux of monochromatic photons at the focal point. A good resolving power higher than the required specification for the UV-CD experiment is achievable, in spite of the compact and simple configuration of the monochromator.

References

[1] Skibowski M and Steinmann W 1962 *J. Opt. Soc. Am.* 57 122
[2] Howells M, Norris C and Williams G 1977 *J. Phys. E* 10 259
[3] Howells M 1982 *Nucl. Instrum. Methods* 195 215
[4] Ederer D E and Cole B E, 1980 *Nucl. Instrum. Methods* 172 185
[5] Ito T, Kada T, Okada S, Hieda K, Kobayashi K, Maezawa H and Ito A 1984 *Radiation Research* 98 65
[6] Kimura S, Ito T, Nakamura E, Hosaka M and Katoh M 2007 *AIP series of conference proceedings* 879 527