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New soft X-ray beamline BL07LSU for long undulator of SPring-8: Design and status

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ABSTRACT

We report the design and current status of a soft X-ray beamline BL07LSU with a 27-m-long undulator at SPring-8. The long undulator consists of eight figure-8 undulator segments, and generates circularly and linearly polarized soft X-rays. This beamline covers a wide energy range (250–2000 eV) with both high energy resolution and high photon flux. Commissioning of this beamline was started with only four undulator segments since October 2009. The resolving power was evaluated to be 10,000 at 401 eV by total-ion yield X-ray absorption spectra of N_2.

1. Introduction

At SPring-8, four soft X-ray beamlines provide a high photon flux of 10^{11} photons/s/0.01% B.W. with a high resolving power of $E/\Delta E > 10^4$ [1–4]. The insertion devices (IDs) are installed in a 4.5-m-long standard straight section. A new soft X-ray beamline BL07LSU with a 27-m-long undulator, University-of-Tokyo Synchrotron Radiation Outstation Beamline, is being constructed by the University of Tokyo in collaboration with SPring-8 to realize advanced spectroscopy such as nano-beam photoemission spectroscopy, time-resolved spectroscopy, and extremely high-resolution soft X-ray emission spectroscopy. These experiments require high energy resolving power ($E/\Delta E > 10^4$), high photon flux ($> 10^{12}$ photons/s/0.01% B.W.), circularly and linearly polarized light, and small beam size (of a few micrometers) at the sample position in the photon energy range 250–2000 eV.

2. Design of BL07LSU

2.1. Insertion device of BL07LSU

A new ID, a polarization-controlled soft X-ray undulator, has been developed and it is based on the new concept of polarization control proposed in Ref. [5]. It has been installed in one of the four 27-m-long straight sections at SPring-8 in order to provide linearly and circularly polarized high-flux photon beams. This ID consists of eight 2.7-m-long figure-8 undulator segments [6] with a periodic length of 10 cm as well as seven phase shifters. Four segments generate horizontally polarized radiation as the first harmonic, while the other four generate vertically polarized radiation. These two types of segments are installed alternately along the length. The circularly polarized radiation is also available by the coherent superposition of the two linear polarization states. The typical degree of circular polarization is calculated to about 90% using a synchrotron calculation code SPECTRA [7], which depends on the angular acceptance of the beam line.

The helicity of the circular polarization (clockwise/counterclockwise) and the plane of linear polarization (horizontal/vertical) can be specified by adjusting the phases between the segments and/or changing the gap. The radiation point is not displaced by switching the helicity in the helical mode. In contrast, linear polarization switching causes the radiation point to shift along the longitudinal direction by 3.4 m.

The brilliance of this ID is expected to be more than 10^{18} photons/s/mm^2/mrad^2/0.01% B.W. regardless of the polarization states according to calculations, which is approximately four times larger than that of the figure-8 undulator installed in the BL27SU [6] at SPring-8.

2.2. Beamline layout of BL07LSU

To achieve a small beam size at the sample position, the optical layout is designed such that the photon divergence angle at the exit

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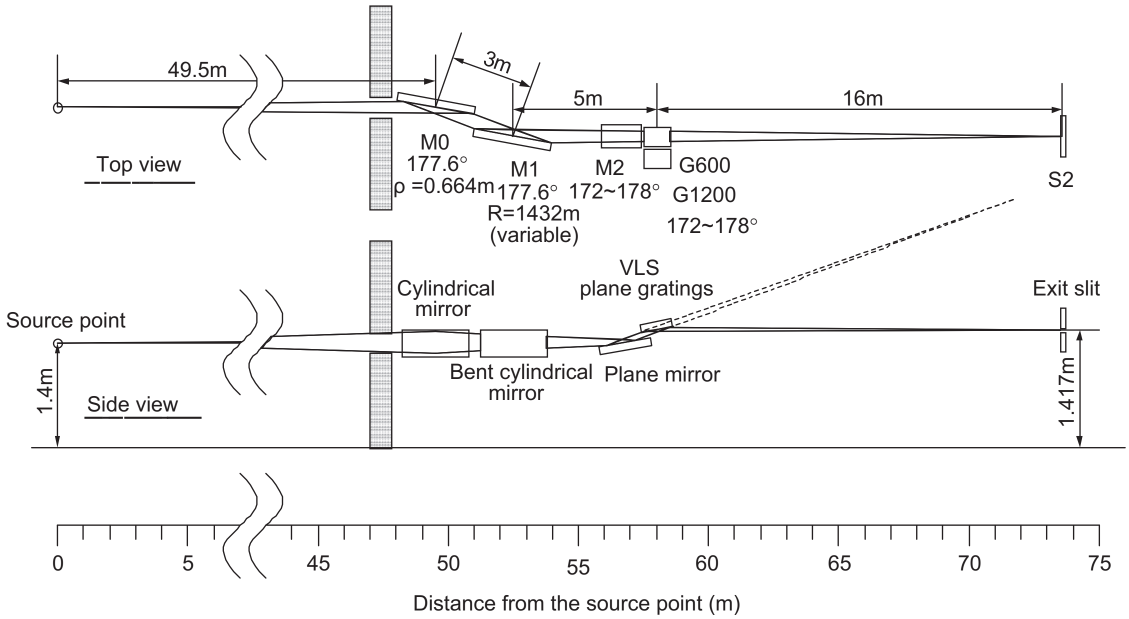

Fig. 1. Optical layout of BL07LSU at SPring-8.

slit is not excessively large. For the first mirror, the maximum heat load is 160 W. The included angles and coating materials are optimized to restrict power density on the optical elements. An entrance-slitless variable-included-angle Monk–Gillieson mounting monochromator with a varied-line-spacing plane grating has been employed, as shown in Fig. 1. The entrance-slitless layout effectively restricts the magnification of the monochromator and facilitates high transmission.

The cylindrical mirror M0 reflects the photon beam horizontally and focuses the beam vertically, that is in the direction of the energy dispersion, to the virtual focal point behind the grating. The effects of the surface slope error and the thermal deformation on the energy resolving power is reduced by sagittal focusing. The bent-cylindrical mirror M1 reflects the photon beam horizontally and focuses the beam horizontally to the exit slit. The included angles of M0 and M1 are chosen to be 177.6° taking into consideration the balance between the reflectivity and the heat load of all the mirrors and gratings equipped with an indirect water-cooled system. In order to reduce the heat load of the plane mirror M2 and gratings Gr, half of the reflecting surface of M1 is an Au-coated Si substrate and the remaining half is uncoated Si. The Si surface is selected to be in the energy range of 250–1500 eV in order to reduce the reflectivity of the unnecessary higher-order photons.

The plane mirror M2 varies with the included angle of grating in the range 172–178° by off-axis rotation [8] in order to optimize the resolving power. The distance between the rotation axis and the M2 surface is determined to be 25.5 mm, and the misalignment attributed to the rotation of M2 is estimated to be less than 2 μm.

The included angle of grating and groove parameters were optimized by minimizing the aberrations according to a procedure described in literature [9], taking into consideration the reflectivity, diffraction efficiency, and heat load. The groove density is expressed as $N=N_0\ (1+a_1w+a_2w^2+a_3w^3)$, where N_0 is the groove density at the center position of the grating. The distance between the virtual focal point and grating, r_1, the distance between grating and exit slit, r_2, and the groove density coefficients, a_i, were optimized for two gratings, G600 and G1200, whose groove densities at the center are 600 and 1200 lines/mm, respectively. The optimized parameters for the two gratings are $r_1=-15.34$ m, $r_2=16$ m, $a_1=1.2426\times10^{-4}$ mm^{-1}, $a_2=1.157\times10^{-8}$ mm^{-2}, and

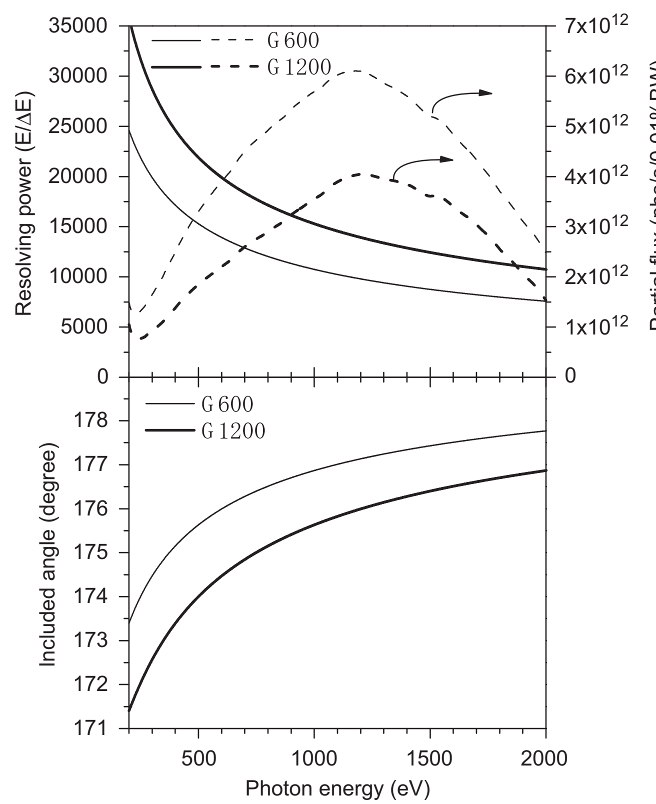

Fig. 2. Calculated energy resolving power, photon flux at exit slit and optimized included angle for G600 (solid line) and G1200 (bold line). Energy resolving power is calculated with an exit slit width of 25 μm. Photon flux is calculated with front end slit opening of 2 mm × 2 mm.

$a_3=9.559\times10^{-13}$ mm^{-3}. Both the gratings cover the energy range of 250–2000 eV.

Fig. 2 shows the energy resolving power, the photon flux, and the optimized included angle which are calculated for circular polarization mode of eight segments. The resolving power and photon flux are calculated with an exit slit width of 25 μm and a front-end slit opening of 2 mm × 2 mm located 44 m from the

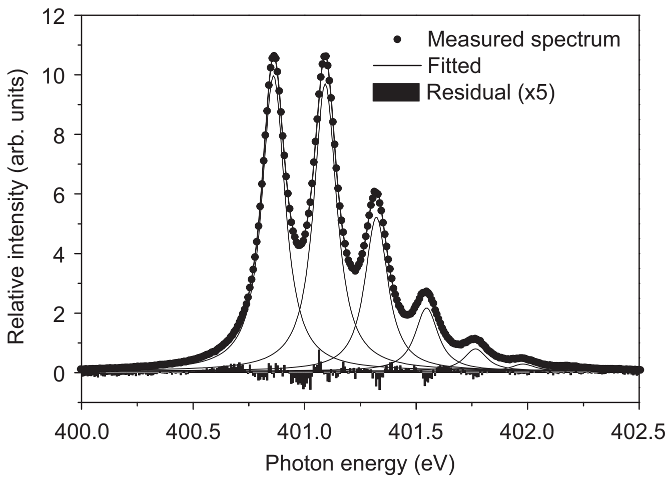

Fig. 3. Total-ion yield spectrum of N_2 at the N $1s \rightarrow \pi^*$ region.

source point. The energy resolving power was estimated to be $E/\Delta E = 10^4$ in almost the entire energy region for G1200 with a photon flux of 10^{12} photons/s/0.01% B.W. Using the ray-tracing program SHADOW [10], we have confirmed that the resolution and the beam size at the exit slit are only slightly affected by the displacement of the source point caused by linear polarization switching.

Four experimental stations, a time-resolved soft X-ray spectroscopy (TR-SX spectroscopy), a free-port, a three-dimensional scanning photoelectron microscope (3D nano-ESCA), and an ultra-high-resolution soft X-ray emission spectroscopy (HORNET) station are located along the beamline. The distances between the exit slit and the TR-SX spectroscopy, free-port, 3D nano-ESCA, and HORNET stations are about 7, 12, 17, and 23 m, respectively. The TR-SX spectroscopy, free-port, and HORNET stations are equipped with refocusing mirror systems. The 3D nano-ESCA station is equipped with the Fresnel zone plate.

3. Present status of BL07LSU

The commissioning of the beamline began in October 2009. Four horizontal figure-8 undulator segments and three phase shifters have been installed. A monochromator with 600 lines/mm grating has also been installed. The experiments at the end stations are being carried out simultaneously with the commissioning.

The partial photon flux was measured using Si photodiodes (IRD Inc. AXUV-100) installed after the exit slit. The typical photon flux at 870 eV with a front-end slit opening of $0.5\,mm \times 0.5\,mm$ is 1.0×10^{11} photons/s/0.01% B.W. The designed photon flux ($>10^{12}$ photons/s/0.01% B.W.) could be achieved by opening the front-end slit.

Total-ion yield (TIY) X-ray absorption spectra were measured at core-excitation region to assess the energy resolution of the monochromator. Fig. 3 shows the TIY spectrum of N_2 obtained at the K-edge, $1s \rightarrow \pi^*$ transition. The TIY spectrum is fitted with a set of eight peaks with the Voigt function. The estimated Gauss width of the Voigt function is 38 meV, which corresponds to a resolving power ($E/\Delta E$) of approximately 10,000. The resolving power is planned to be evaluated with higher accuracy by X-ray photoemission spectra of gases using a high-resolution electron spectrometer.

4. Conclusion

A new soft X-ray beamline BL07LSU was designed to provide a high-flux and high-resolution photon beam with both circular and linear polarizations. Four segments of horizontal figure-8 undulator and three phase shifters have been installed. The commissioning of the beamline began in October 2009. A resolving power of 10,000 at a photon energy of 401 eV was achieved using the monochromator with 600 lines/mm grating.

Another four segments of the vertical figure-8 undulator and four phase shifters have been installed in summer 2010. The complete polarization-controlled soft X-ray undulator allows to control the helicity of the circular polarization and the linear polarization. A 1200 lines/mm grating will be installed in summer 2011.

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