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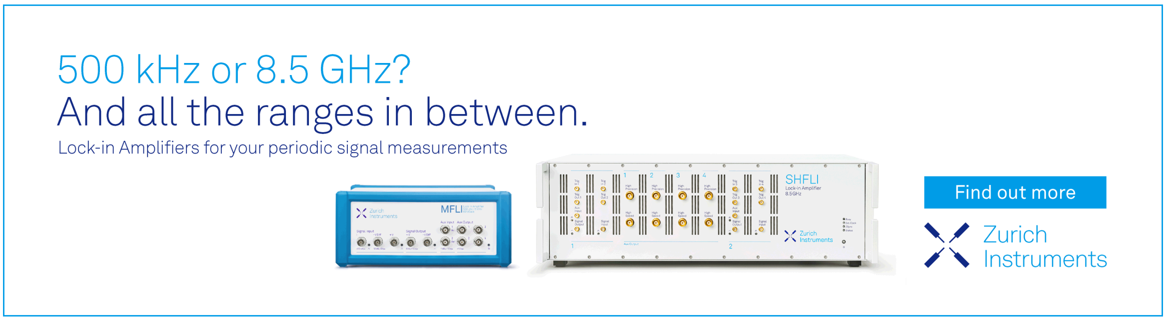

Optical Design of a Wide Spectral Range Soft X-ray Nanoscopy Beamline

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Abstract. A soft X-ray nanoscopy beamline (SXNB) at the Taiwan Photon Source (TPS) is designed to deliver photons of 90 – 2,500 eV from an elliptically polarized undulator to two state-of-the-art microscopy stations hosting the scanning transmission X-ray microscope (STXM) and the photoelectron related imaging and nanoscope (PRINS), respectively. The heart of SXNB is an active grating monochromator (AGM) that optimizes the flux and energy resolution at the same time while maintaining a stable focal spot on the sample. This article describes the design concept, optical layout, and simulation results of SXNB.

INTRODUCTION

Scanning transmission X-ray microscopy and full-field photoelectron microscopy are techniques capable of examining the electronic structure of materials at a resolution of 10's nanometer (nm) [1-2]. To facilitate these two microscopy techniques at TPS, we have designed a new beamline that adopts the concepts of the Dragon beamline design [3-4] and incorporate the high precision 6-actuator optical surface benders developed recently by the NSRRC for the mirrors and gratings [5]. The goal of SXNB design is to deliver a photon beam with a stable focal spot to the microscopy station with satisfactory flux and energy-resolution. In the meantime, due to the needs of microscopy stations, the beamline design pays special attention to the reproducibility of photon energy and beam position during the energy scan.

SOURCE CHARACTERISTICS

The Nanoscopy beamline at TPS is powered by an elliptically polarizing undulator of period 66 mm (EPU66) made in-house to provide the necessary photon brilliance and polarization state. The spectral and optical characteristics of photon emission from EPU66 are calculated from a synchrotron-radiation (SR) calculation code developed at Spring-8 (SPECTRA 10.1) [6-8]. Table 1 lists the input parameters used to produce results shown in the following sections. The choice of EPU period is to cover a wide photon energy range from 90 to 2,500 eV. Figure 1 displays the calculated photon flux as a function of photon energy. According to Fig. 1, EPU66 can provide a photon flux better than 10^{14} photon/sec/0.1% BW up to 3,000 eV. The beam angular divergence of the

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central cone is 58 μrad × 48 μrad (H × V) in full width half maximum (FWHM) that corresponds to an effective source size of 240 μm × 32 μm (H × V) at 280 eV.

TABLE 1. Parameters of EPU66.

Parameters	Value
Electron Energy	3 GeV
Beam Current	500 mA
Magnet Period Length	66 mm
Number of Period	60
Peak Field	0.87 T
Deflection Parameter K_{max}	5.36
Total Magnetic Length	4 m
Minimum Magnet Gap	16.8 mm
Natural Emittance	1.6 nm·rad
Photon Energy	90 ~ 2,500 eV

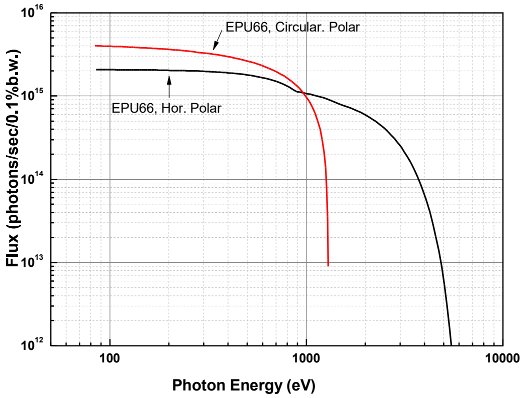


FIGURE 1. Flux of circular and horizontal linear polarization as a function of photon energy.

OPTICAL LAYOUT

The primary design criterions set for SXNB is to deliver the photon flux as high as possible and with an energy resolving power greater than 4,000. In addition, to simplify the beamline operation, the controls of vertical and horizontal photon beam focus are better to be independent. As the expected experiments running at this beamline will conduct micro-spectroscopy investigation routinely, the focal spot at the sample position of either branch needs to be stable during energy scan. In the rest of this section, we describe our optical layout which adopts the concepts of the Dragon beamline design and incorporates active gratings in the monochromator. Figure 2 depicts the optical layout of the SXNB and Table 2 lists the geometric parameters of all optical elements.

To take out most of the heat emitted from EPU66, a set of aperture were installed in the front end. The first optics of SXNB beamline is a water-cooled horizontal plane mirror (HPM) made of Si and it is used to help reduce the heat load on other optical elements. According to a finite element analysis, we find the thermal deformation in a 10 cm x 2 mm illumination surface area on HPM has a radius of curvature larger than 1.4 km, giving negligible influence on beamline performance once the HPM reaches its thermal equilibrium.

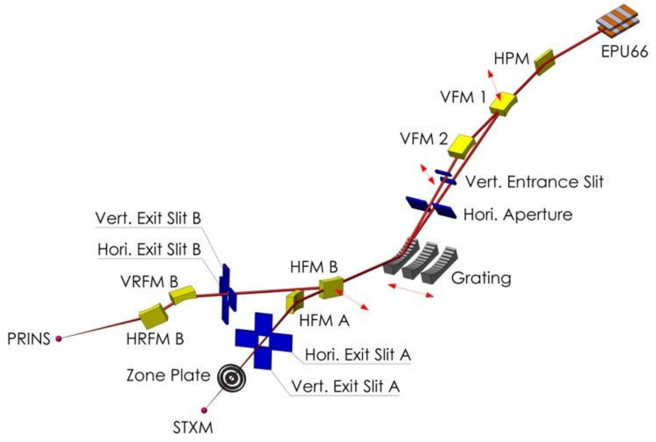


FIGURE 2. Optical layout of SXNB

Right after the HPM, two vertical focusing mirrors (VFM) separated by 2.6 m are placed downstream to form different grating deflection angle for different energy range. VFM 1 is used to focus the beam onto the entrance slit for 900 to 2,500 eV photons (high energy mode) and VFM2 is for 90 to 900 eV photons (low energy mode). The energy mode selection is achieved via moving VFM1 in and out of the beam path. Both VFMs are made active by using high precision 6-actuator optical surface benders. Based on the commissioning results of TPS 41A and 45A beamlines [9], these active mirrors are capable of focusing the photon beam with very high stability and reproducibility as well as reducing the thermal deformation on the mirror surfaces.

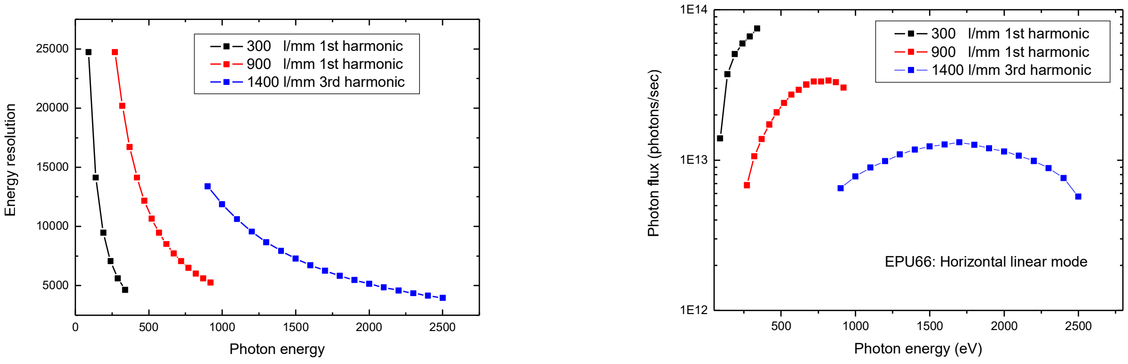
The horizontal angular acceptance of SXNB is defined by the horizontal aperture (H aperture) placed at the upstream of gratings. To cover photon energies from 90 to 2500 eV, three gratings are needed and the ruling density is 300 l/mm, 900 l/mm and 1400 l/mm, respectively. The surface of the 300 l/mm and 900 l/mm gratings are coated with gold, while the 1400 l/mm one is coated with rhodium. Each grating is mounted on the 6-actuator bender to form an active grating, which can focus the beam onto the fixed exit slit during energy scan. The selection of PRINS or STXM branch is achieved by moving the horizontal focusing mirror (HFM) B in and out of the beam path. For the two exit slits located at STXM and PRINS branch, their positions are fixed and serve as the new source points for the microscopes. The photocurrents from the two blades of exit slit will be used as feedback signals for steering the pitch of HFM to optimize the transmitted photon flux. After passing through the exit slit, the photon beam is focused onto the sample position by using a Fresnel zone-plate for STXM and a pair of bendable K-B mirrors for PRINS.

TABLE 2. Optical layer for nanoscopy bemaline. The table shows all the optical elements in each branch and their distance from the center of EPU66.

Optics	Distance(m)	Deflection angle (degrees)
HPM	25.0	2.4
VFM-1	27.4	2.2
VFM-2	30.0	3.0
Vert. Entrance Slit	31.5	0.0
Hori. Aperture	32.0	0.0
Grating	33.5	6.0 or 4.4
HFM-B	36.0	3.0
HFM-A	37.0	2.4
Vert. Exit Slit-A/B	39.5	0.0
Hori. Exit Slit-A/B	39.5	0.0
VRFM-B	42.5	3.0
HRFM-B	44.5	3.0

PERFORMANCE

Figure 3 shows the calculated photon flux after exit slits with the opening of both the vertical entrance slit and vertical exit slit set at 10 µm and that of the horizontal exit slit wide open. For energies between 90 and 900 eV, the calculated photon flux is 0.6~7.6 x 10^{13} photon/sec/0.1%BW with an energy resolving power of 4,000~24,500. For energies between 900 and 2,500 eV, the flux is 0.5~1.2 x 10^{13} photon/sec/0.1%BW with an energy resolving power of 4,000~13,800. The lower flux in the high energy mode is due to the lower flux at higher energies of the EPU66 and a lower diffraction efficiency of the 1400 l/mm grating.



(a) (b)

FIGURE 3. The calculated performance when both entrance and exit slits are set to 10 µm in vertical and wide open in horizontal. Calculated (a) resolving power and (b) photon flux at both exit slits.

SUMMARY

In this report, we describe the design concept and optical layout of SXNB at TPS. Powered by an EPU66, the SXNB is designed to meet the needs of two X-ray microscopy stations, i.e. STXM and PRINS. The optical design adopts the concepts of the Dragon beamline design with the VFMs, gratings, and K-B mirrors each mounted on a high precision 6-actuator optical surface bender developed recently by the NSRRC. Optical calculation and simulation indicate that the SXNB can deliver a photon flux of 0.5~7.6 x 10^{13} photon/sec/0.1%BW to both end stations with an energy resoloving power of 4,000~24,500 for a wide spectral range of 90~2,500 eV.

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