

Performance of the post-focusing mirror system at the reflectometry beamline BL-11D of the Photon Factory

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Abstract. Beamline BL-11D of the Photon Factory was recently opened for the characterization of extreme-ultraviolet and soft X-ray optical components. For reflectometry of multilayers for soft X-ray microscope optics, a small focus size on the sample surface matching the small acceptances of the curved multilayer samples is required. The post-focusing mirror system of BL-11D is composed of horizontally and vertically focusing elliptical mirrors. The performance was evaluated by microscopic beam profile observation, by a knife-edge scan test, and by the Ronchi test. The FWHM beam size was $120\text{ }\mu\text{m}$ (H) \times $30\text{ }\mu\text{m}$ (V) with an insignificant spherical aberration, which is smaller than the requirement.

1. Introduction

Multilayer characterization tools are crucial for the development of extreme ultraviolet (EUV) and soft X-ray imaging optics based on multilayer reflectors deposited on the mirror substrates. Beamline 6.3.2 of the Advanced Light Source is a standard facility for these operations [1]. In Japan, although some reflectometry beamlines are in operation, none of them specialize in the characterization of curved multilayer samples. An adequately focused incident beam as well as a multi-axis sample stage are required. In our previous study, periodic thicknesses of concave EUV multilayers were measured at a high accuracy by reflectometry using a 1-mm-diameter parallel beam at BL-12A of the Photon Factory (PF) [2], where the beam size was less critical because of the larger acceptance of the EUV multilayer. In Schwarzschild-type soft X-ray microscope optics, however, a mirror substrate with a 10-mm radius of curvature is used with a multilayer coating having a period number of several hundred, e.g., 600 period Cr/Sc multilayer at 400 eV [3]. The angular acceptance $|\Delta(\cos\phi)|/\cos\phi = \tan\phi\Delta\phi$, which is equivalent to the bandwidth $\Delta\lambda/\lambda$, is approximately the inverse of the period number, and $\Delta\phi$ is 1° when ϕ is 5° . For a substrate with a 10-mm radius of curvature, a $200\text{-}\mu\text{m}$ beam size in the tangential plane, or $800\text{-}\mu\text{m}$ beam size in the sagittal plane, causes a 1° -angle of incidence variation along the sample surface. Thus, the required FWHM beam size is smaller than $800\text{ }\mu\text{m}$ (H) \times $200\text{ }\mu\text{m}$ (V).

The EUV and soft X-ray beamline BL-11D at PF has been dedicated to photoelectron spectroscopy studies since 1996 [4]. It was fitted with a post-focusing mirror system composed of horizontally and vertically focusing mirrors, HPFM and VPFM, respectively, and a FWHM beam size of 1 mm (H) \times $100\text{ }\mu\text{m}$ (V) was achieved [4]. In 2010, BL-12A was closed, and BL-11D was redesigned for the characterization of optical components with the installation of a reflectometer. The requirement for the post-focusing mirror system has become clearer as having a FWHM beam size small enough for the smallest possible acceptance of mirror samples, i.e., $800\text{ }\mu\text{m}$ (H) \times $200\text{ }\mu\text{m}$ (V).

In the present paper, the performance of the post-focusing mirror system is evaluated. The beam



profile is observed using an EUV microscope, and the beam size is measured by the knife-edge scan test. For long-term reliability of the focusing performance, particularly in the vertical direction, the aberration characteristics are studied using the Ronchi test.

2. Experimental

The optical layout of beamline BL-11D is described here. A schematic side view is shown in figure 1, including the distance of each component from the source. The monochromator is composed of the entrance slit S1, the focusing cylindrical mirror Mf, the deviation-angle-changing plane mirror Mp, the spherical grating G, and the exit slit S2. In the horizontal plane, the cylindrical mirror M0, which is the first deflecting mirror, forms an intermediate focus between S1 and Mf. The elliptic mirror HPFM refocuses the beam to the center of the reflectometer 30.3 m from the source. M0 and HPFM form a 4:1 demagnified image of the source. In the vertical plane, the elliptic mirror VPFM forms a 1:1 image of S2 to the reflectometer. The grazing angles of incidence of M0, M0', Mf, VPFM, and HPFM are all 2° . The upstream and downstream ends of the backside of VPFM are supported by piezo-actuators V1 and V2, respectively; those for HPFM are H1 and H2. During the photoelectron spectroscopy activities over 10 years, the voltages applied to the piezo-actuators have been fixed as V_{V1} , V_{V2} , V_{H1} , $V_{H2} = 300$ V, 800 V, 500 V, 300 V, respectively.

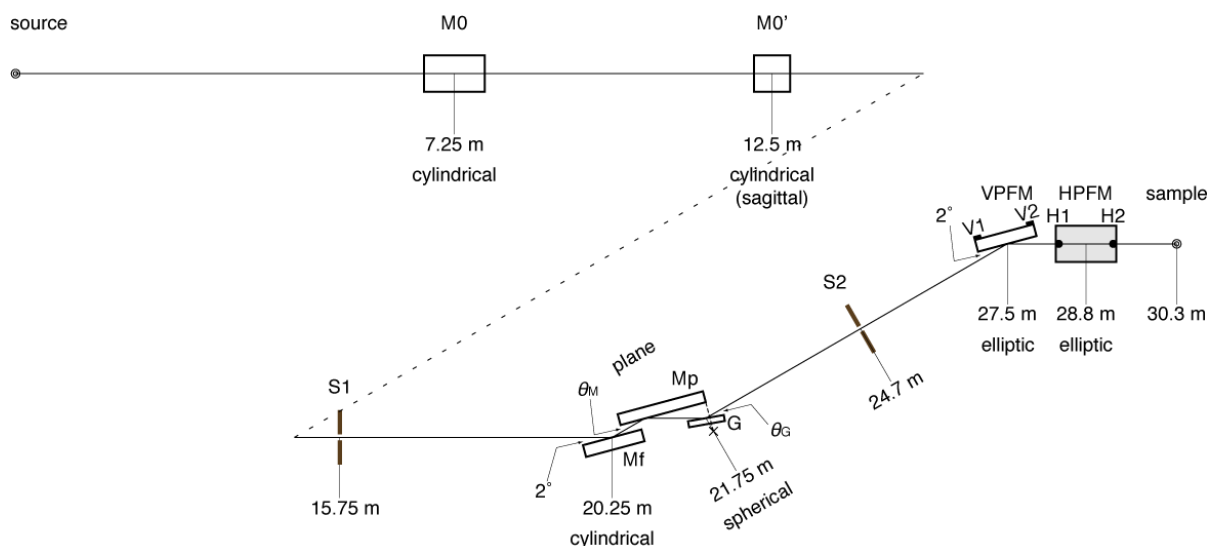


Figure 1. Side view of the beamline optics at BL-11D, PF.

Using an EUV scintillator microscope [5], we observed the beam profile at 92 eV. The reflectometer chamber was moved out of the optical path, and the scintillator plane was set at the sample position. Voltages applied to the piezo-actuators were V_{V1} , V_{V2} , V_{H1} , $V_{H2} = 300$ V, 800 V, 500 V, 300 V, as before.

A knife-edge scan test was carried out at 275 eV. The reflectometer chamber was put back in the optical path. Figure 2(a) shows the side view of the reflectometer with the knife-edge scan test setup. A photodiode AXUV100Ti/C2 (IRD, Inc.) was used as a detector. The turntable sample stage is shown in gray, and its plan view is inset. A knife labeled “-90” was set with its edge along the vertical axis at a position of $z = -90$ mm, where z is the coordinate along the beam axis with the origin at the center of the reflectometer. The horizontal beam size at $z = -90$ mm can be measured by a horizontal scan of the knife “-90.” Knives were also set at positions of $z = -70$ mm, -50 mm, -30 mm, -10 mm, and $+10$ mm. With the sample stage turned by 180° , the beam size at $z = +90$ mm can be measured with the knife “-90.” A knife labeled “0” was set at the center of the sample stage with its edge along the horizontal axis for the vertical scan. Voltages applied to the piezo-actuators were not changed in

the horizontal scan and changed to V_{V1} , $V_{V2} = 300$ V, 800 V; 100 V, 400 V; 100 V, 200 V; and 0 V, 0 V in the vertical scan.

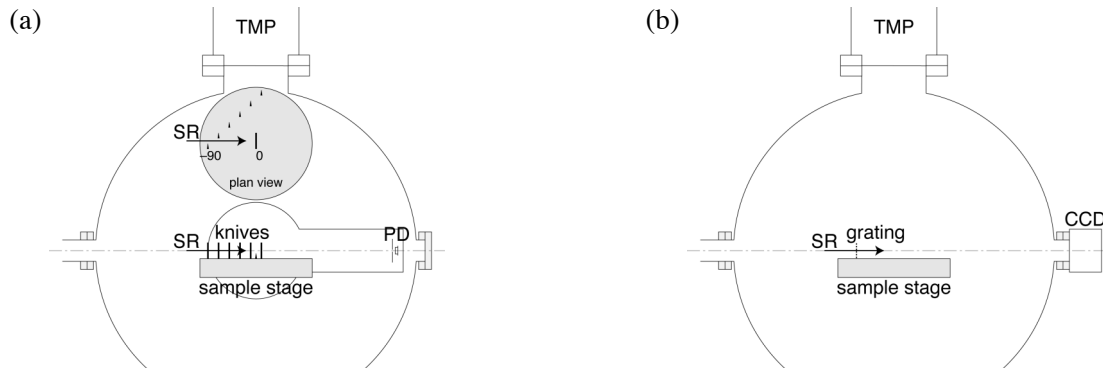


Figure 2. Side view of the reflectometer with the setup for (a) knife-edge scan test and (b) Ronchi test.

The setup for the Ronchi test is illustrated in figure 2(b). A transmission grating with a 50- μm period (NTT-AT Corp.) was set on the sample stage at $z = -70$ mm with its slits horizontal (with its periodicity vertical). The fringe pattern was observed by a soft X-ray CCD camera BK-501X (BITRAN Corp.) mounted at the downstream end of the reflectometer chamber. The distance between the grating and the camera was 800 mm. Voltages applied to the VPFM were V_{V1} , $V_{V2} = 0$ V, 0 V.

3. Results and discussions

Figure 3(a) shows the observed EUV microscope image in grayscale on a white background. The S2 opening was 20 μm , and the vertical beam size was 80 μm . Figure 3(b) shows the vertical spot size dependence on the S2 opening supporting the 1:1 imaging of the VPFM. Independent of the S2 opening, the horizontal beam size was 200 μm , which agrees with a quarter of the electron beam size. Thus, basically the performances of VPFM and HPFM agreed with the optical design of the beamline.

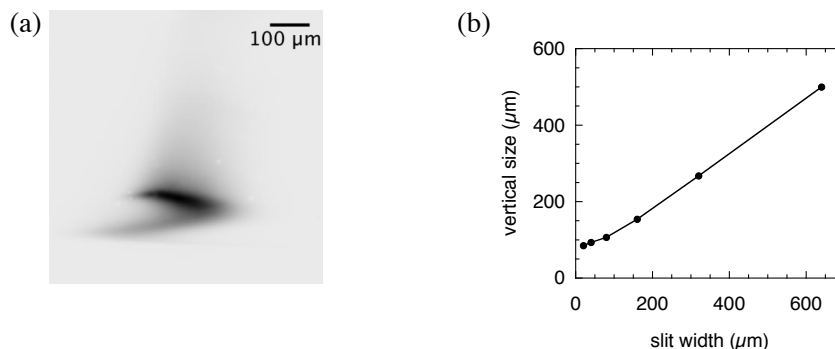


Figure 3. (a) Beam profile and (b) vertical size dependence on the S2 opening.

Figure 4(a) shows the results of horizontal knife-edge scans with the baseline shifted in proportion to z . The beam waist was found just at the center and was 120- μm wide. Figure 4(b) shows the results of vertical knife-edge scans with the baseline shifted by 1. The S2 opening was fixed at 30 μm . As V_{V1} and V_{V2} decreased, the beam size became smaller, which means the focal point is upstream before the center of the reflectometer chamber. At V_{V1} , $V_{V2} = 0$ V, 0 V, the beam size was the smallest at 30 μm , the same as the S2 opening. Thus, no unexpected broadening was observed, and a sufficiently small FWHM beam size of 120 μm (H) \times 30 μm (V) was confirmed.

A Ronchi test was carried out with the best focus condition of V_{V1} , $V_{V2} = 0$ V, 0 V. Figure 5 shows the observed fringes with the sample stage scanned downward in 8- μm steps. The observed fringes near the center moved downward while fringes near the top and bottom moved upward. A fringe disappeared into line "B," and a new fringe appeared out of line "A." This behavior shows a spherical

aberration where the focal length is shorter around the mirror center. If necessary, the focus will be improved by applying a tensile stress on the backside of the VPFM around its center.

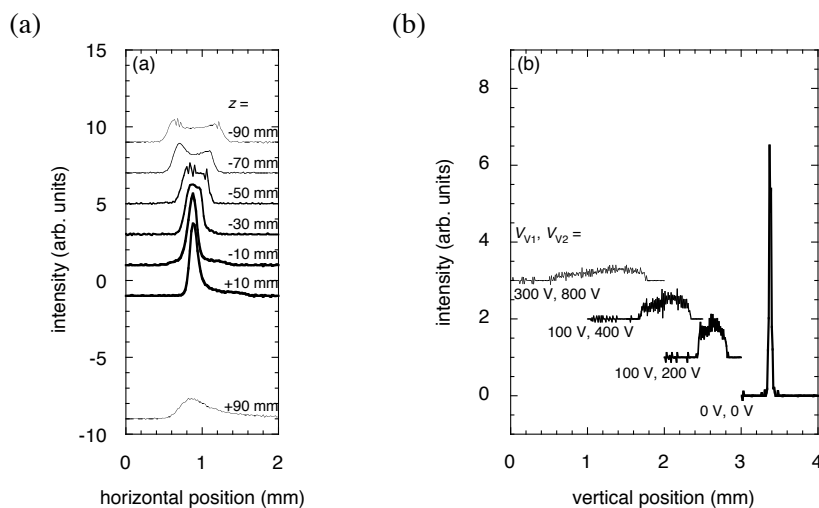


Figure 4. Knife-edge scan along (a) horizontal and (b) vertical axes.

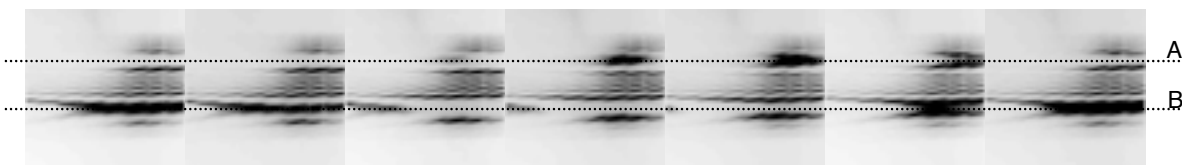


Figure 5. Ronchi fringes with a 50- μ m-period grating shifted downward in 8- μ m steps.

4. Conclusions

We evaluated the performance of the post-focusing mirror system at BL-11D, PF. Microscopic observations of the beam profile, beam size measurements by the knife-edge scan test, and characterization of the aberration by the Ronchi test were carried out. As a result, the FWHM beam size was confirmed to be 120 μ m (H) \times 30 μ m (V) with an insignificant spherical aberration that is small enough for reflectometry of soft X-ray multilayer microscope optics.

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