Improvement of Illumination Optics of the Full-field Imaging Soft X-ray Microscope

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In the full-field imaging soft x-ray microscope (SXRM) with two Fresnel zone plate optics, the combination of a plane mirror, a condenser zone plate (CZP) and a pinhole works not only as an illumination to the sample but also as a linear monochromator [1]. The linear monochromator uses difference of focal lengths by chromatic aberration of the CZP. Then, the plane mirror works to suppress the higher diffraction from the CZP, which has the same focal length with the main wavelength. The performance of this optics essentially determines the contrast and the spatial resolution of the image. However, in our SXRM, the CZP produces +2nd order diffraction of half wavelength of the target wavelength because of its figure error [2]. For example, when the target wavelength of 2.4 nm is used, that of 1.2 nm makes unignorable out-of-focus image on the stigmatic image of the main wavelength as background noise. In this study, the illumination optics has been improved to suppress the +2nd order diffraction and obtain proper energy resolution for better imaging.

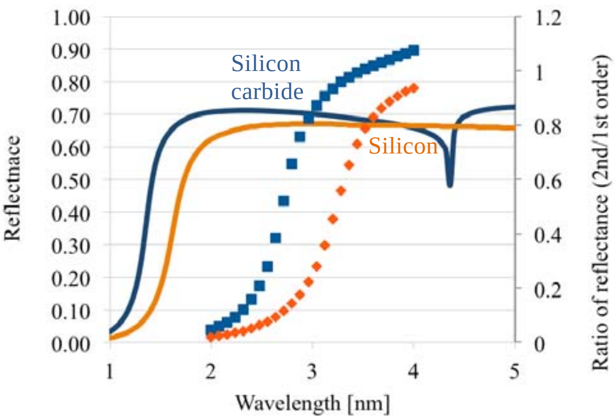
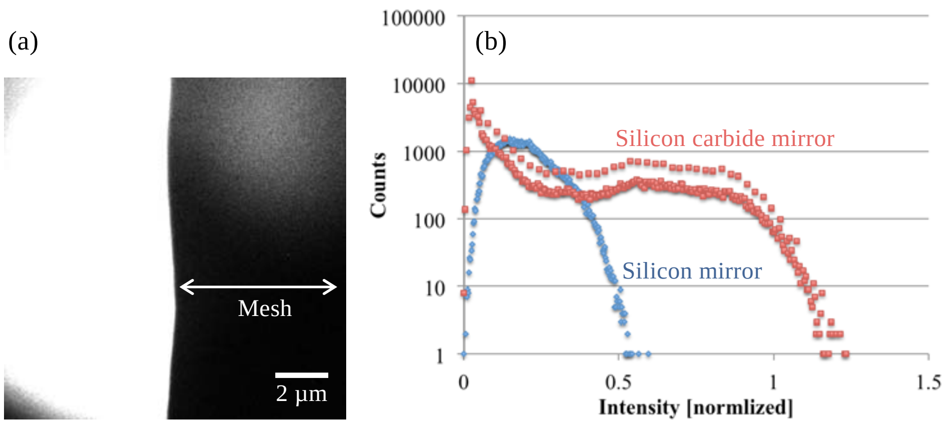


Fig. 1: Reflectance as solid lines and ratios of reflectance of +2nd and +1st order (i.e. ratio of the main and its half wavelengths) as dots of the silicon and the silicon carbide mirrors at the grazing incidence angle of 40 mrad.

Our SXRM system was designed to use the wavelength of the water window region (2.3-4.4 nm). For the improvement of the performance of the illumination optics in this region, especially the wavelength of 2.4 nm, just below the K-edge of oxygen, a wedge-shaped slit and a silicon plane mirror were installed. The energy resolution of the linear monochromator is determined by the size of the CZP and the pinhole approximately. Then, the demagnified light source image by the CZP should be smaller than the size of the pinhole for the expected monochromatic performance [3]. The slit, whose horizontal size varies from 0.37 to 1.9 mm, set downstream the light source was used as a virtual source and reduces the horizontal size of the light source. The energy resolution, $E/\Delta E$, of 300 was expected by using the pinhole of 15 μm diameter. On the other hand, the silicon plane mirror was installed to suppress the $+2^{nd}$ order diffraction from the CZP, which was the wavelength of 1.2 nm in use of 2.4 nm. The reflectance of the silicon and the silicon carbide mirror at the grazing incidence angle of 40 mrad are plotted as solid lines in Fig. 1. The cut-off wavelength changes from 1.0 to 1.2 nm by changing the current silicon carbide mirror to the silicon one. The ratios of reflectance of $+2^{nd}$ and $+1^{st}$ orders are also plotted as dots. From these plots, the ratio is expected to decrease from 0.16 to 0.05 (32%) at the wavelength of 2.4 nm.

The images by using the silicon and the silicon carbide mirrors were compared. For simplicity, an edge of a nickel #150 mesh was used as a sample and was placed to cover the right half of the field of view. The image with using the silicon carbide mirror is shown by enhancing the low intensity in Fig. 2(a), for example. The histograms of the covered areas were plotted in Fig. 2(b) by subtracting the dark image and normalizing the intensities by the ring current. By comparing the total sums of products of the intensities and the counts, the $+2^{nd}$ order was reduced to 71%. This reduction was less than the expected. As one of the reasons, the performance of the silicon mirror, such as roughness of the surface and the figure error, causes scattering or divergence of the x-rays. Recently, the new quartz mirror was in preparation.



Figs. 2: (a) Contrast enhanced image of the edge of the mesh (for example using silicon carbide mirror) and their histograms of covered areas by the mesh with using the silicon and the silicon carbide mirror.

References

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