# Characterization of Beryllium Windows using Coherent X-rays

Beryllium foils are widely used as extracting windows at the end of hard X-ray beamlines, detector windows, and entrance windows of a vacuum chamber for some X-ray applications, because of their high X-rays transmittance and ultrahigh vacuum compatibility. However, an increase in non-uniformity, speckles at transmission images, and serious deterioration of spatial coherence due to surface roughness and defects have been pointed out [1-3]. Using spatially coherent X-rays at the 1-km beamline, we found that speckles (bright X-ray spots) are due to Fresnel diffraction from surface pits and presumably from internal voids in beryllium foils that are fabricated by conventional foiling processes [4]. Our objectives in this work are to characterize several types of beryllium in foiling and obtain a high quality beryllium foil for coherent X-ray applications.

Several commercially available beryllium foils were examined. A powder foil (sample #1) was produced by hot isostatically pressing of beryllium powders. An ingot foil (sample #2) was produced by hot rolling of the beryllium ingot, which was cast from a vacuum-melted and refined flake. A physical-vapor-deposited (PVD) beryllium foil (sample #3) was also characterized. The surface roughness was set to be less than 0.1 µm rms by polishing. The thickness ranged from about 100 to 250 µm.

We carried out the experiments at the 1-km beamline **BL29XU** with spatial coherence area (FWHM) of 0.14 mm in the horizontal direction and 5.9 mm in the vertical direction for 0.1-nm X-rays. The geometrical spatial resolutions (FWHM) at a sample-to-detector distance of 1 m are 0.68 µm in the horizontal direction and 17 nm in the vertical direction. We performed high spatial resolution experiments using the coherent beams at the beamline. We guided the 0.1-nm X-rays through the long transport channel to the 1-km end station. We used a Kapton window at the end of the 1-km beamline. A Hamamatsu zooming tube C5333 with a spatial resolution of 0.3 µm was used to obtain transmission X-ray images. We observed the images of the sample placed 90 mm (near image) or 1400 mm (far image) away from the detector.

Figure 1 shows the X-ray images of three samples under near- and far-image conditions. We found bright X-ray spots in samples #1 and #2 due to Fresnel diffraction from deficiencies. We picked up typical X-ray spots from far images as shown by blue circles in the images and compared with the results of

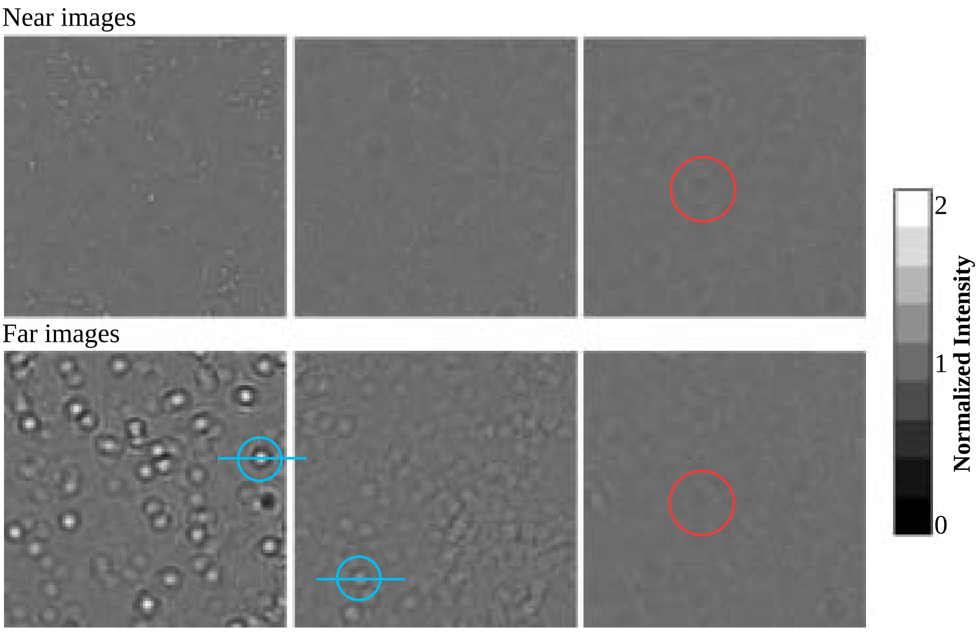


Fig. 1. X-ray images of sample #1 (left), sample #2 (center), and sample #3 (right). Upper panels: near images (distance 90 mm); lower panels: far images (1400 mm). The area is 300×300 µm$^2$. Dark spots such as indicated by red circles come from a Kapton window 3 m upstream of the detector, because they do not show distance dependence.

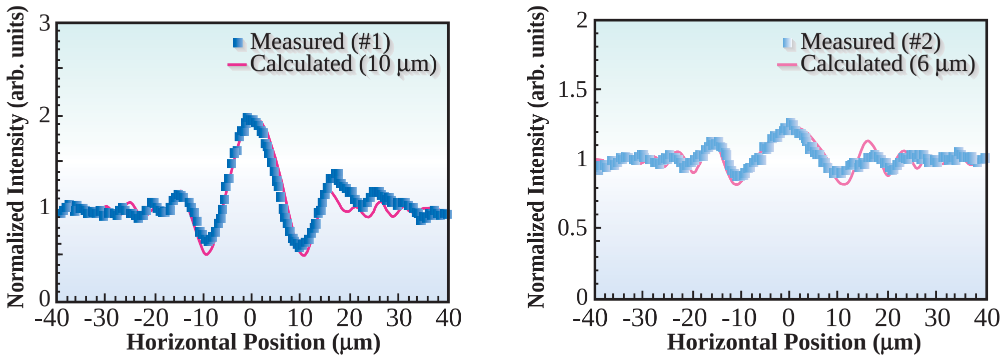


Fig. 2. Comparison of measured intensities at typical X-ray spots indicated by blue circles in Fig. 1 with calculation of Fresnel diffraction from spherical voids of 10 µm diameter for sample #1 and of 6 µm diameter for sample #2.

Fresnel diffraction calculation by assuming spherical voids in the beryllium. The measured intensity distributions are well reproduced by calculation, assuming several to ten microns of voids as shown in Fig. 2.

We counted X-ray spots as a function of beryllium thickness to clarify that defects are not only surface pits but also internal voids. We used wedged beryllium foils and changed the thickness from 0.2 mm to 1 mm. Figure 3 shows X-ray spot densities as a function of beryllium thickness. The distance between beryllium and the zooming tube was set to be 200 mm to obtain near images. The densities are proportional to the thickness for both samples #1 and #2. The thickness dependence of defect density suggests strongly that the defects are inside the beryllium foils. We estimated the defect densities of $5\times10^3$ mm$^{-3}$ for sample #1 and $6\times10^3$ mm$^{-3}$ for sample #2.

Compared with samples #1 and #2, the PVD foil (#3) yields highly uniform beams after the transmission of the window, as shown in Fig. 1. The PVD process eliminates the internal voids in principle and the PVD foil is considered to be the best material for coherent X-ray applications.

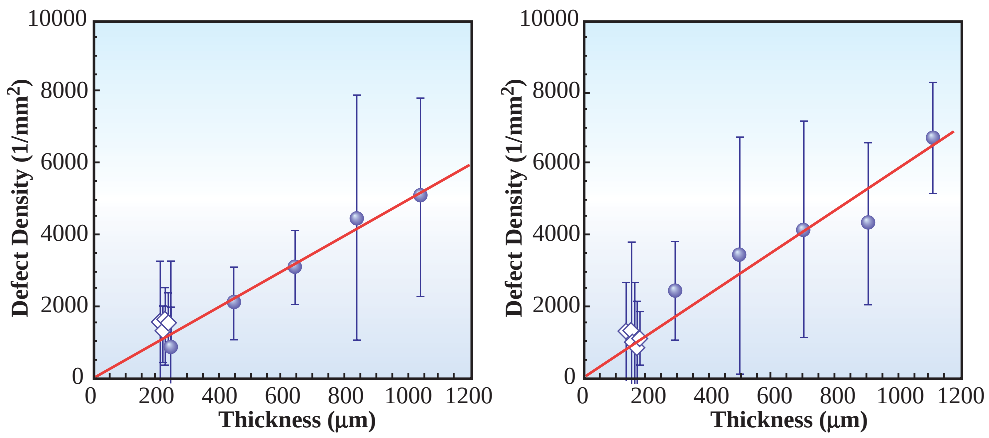


Fig. 3. X-ray spot densities as a function of beryllium thickness. Left: sample #1, right: sample #2.

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**References**

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