# X-Ray Transmission Optics Development

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*Primary CNF Tools Used: Plasma-Therm deep Si etcher, Xactix $XeF_2$ etcher*

## Abstract:

**We report the development and performance tests of x-ray transmission mirrors (XTM) fabricated using a new process that is both simpler and has higher yield than prior techniques. The new approach requires only two etch steps, and yet yields more structurally stable devices and accommodates greater versatility for tailoring devices to specific applications. The performance of these devices, namely their transmission and reflection characteristics in the x-ray regime, were tested at the G2 station at the Cornell High Energy Synchrotron Source and agree with theoretical models.**

## Summary of Research:

X-ray transmission mirrors (XTMs) are a novel class of x-ray optics. As with traditional x-ray mirrors, they operate on the principle of total external reflection (TER): for a given incidence angle, only x-ray energies below a certain critical angle are reflected, so that the mirror acts as a low-pass filter for x-rays. However, unlike a regular x-ray mirror, XTMs transmit the incident x-ray beam rather than absorbing it and can thus act as an efficient high-pass filter. This operating mechanism is illustrated in Figure 1. Because XTMs operate at glancing incident angles, transmitting the incident beam with minimal absorption losses requires XTMs to be designed as thin as possible.

Despite being introduced over 30 years ago [1], XTMs have not been adopted widely in the synchrotron community owing, primarily, to practical challenges of fabricating such optics to be structurally stable. There are many potential applications of XTMs. First, they function as a high-pass x-ray energy filter with sharper energy cut-off and rejection than absorption filters [1,2]. Secondly, together with a total reflection mirror, transmission mirrors can be used as a high flux, tunable x-ray bandwidth optic for applications such as Laue diffraction [3]. They also show promise as a front-end x-ray optic to alleviate the high heat load of a white x-ray beam by reflecting the lower energy components of the spectrum. In this report, we present a new nanofabricated approach developed to fabricate XTMs in a silicon wafer substrate that has resulted in a higher yield of XTIM optics fabricated.

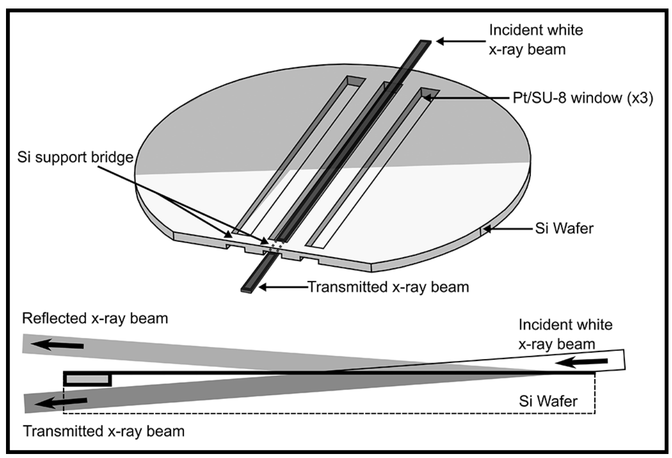


*Figure 1: The drawing of a transmission mirror optic showing a 3D representation (top) and a 2D cross-sectional view (bottom) illustrating the mode of operation. By taking advantage of aspect ratio dependent etching (ARDE), a bridge as indicated is created at the downstream of the optic, which functions as the supporting structure for holding up the thin XTM.*

Figure 1 shows the principle of operation of an XTM operating at glancing angles. Ideally, the exit path of both the reflected and transmitted beam after interacting with the mirror must be clear. This requirement indicates there should not be any structures at the downstream of wafer in the path where the beam exits the mirror. To avoid blocking the reflected beam, our XTM design was made to support the membrane from the bottom. This support structure was accomplished with a custom designed etch mask designed to induce a spatial etch rate variation on same wafer using a single deep reactive etch (DRIE) run. In this case, we get to choose which areas of the final optic etches faster and which areas are etched slower.

Starting with a double-side polished silicon wafer, a silicon dioxide etch mask is patterned on the backside to define the eventual support frame of the XTM when the wafer is etched deep. A special, thin formulation of SU-8 (SU-8 TF 6000, ~ 300 nm thick) is spun-on the front side of the wafer. Because the SU-8 film functions as the template membrane for the XTM mirror, care is taken to ramp up the spin speed of the wafer chuck to minimize the overall wafer thickness variation of the SU-8 film. To crosslink the SU-8, a flood exposure on the SÜSS MicroTec MA6 for 4s at a power of 12 mW/ $cm^2$ is enough, which is followed by a 300°C 3hr anneal to relieve any inherent stresses built-up in the SU-8. A 10-nm thick platinum film is sputtered over the SU-8 on the topside of the wafer. The rest of the processing is a deep reactive ion etch (DRIE) on the backside to create the XTM windows after which an isotropic $XeF_2$ etch finishes off the support bridge structures of the XTM and clears any residual silicon to fully expose the XTM window membranes.

The mirrors were tested at the G2 station at the Cornell High Energy Synchrotron Source (CHESS). The incident beam used was a 0.1 mm tall by 0.5 mm wide x-ray beam. The mirror was then rocked in the beam while the reflection and transmission response was recorded by the MYTHEN single-photon-counting silicon microstrip detector located further downstream of the mirror.

Figure 2 shows the 2D plot of the captured reflection and transmission response for each rotation angle. Integrating the reflected and transmitted beam intensities shows the complementary response function of the mirror which agrees to the predicted behavior as seen in Figure 3.

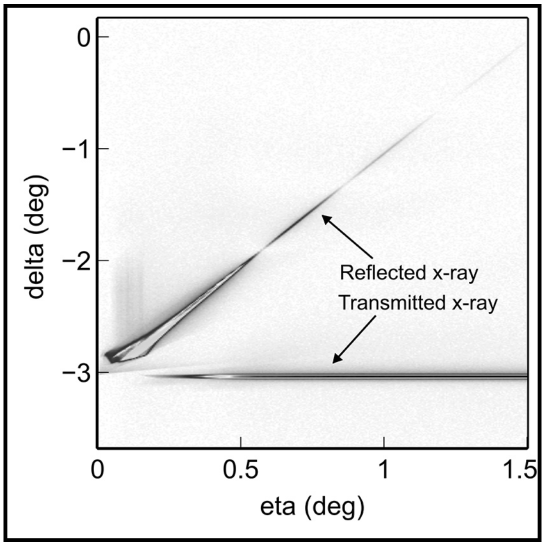


*Figure 2: A 2D representation of the reflected and transmitted beam exiting an XTM optic at different incident grazing angles.*

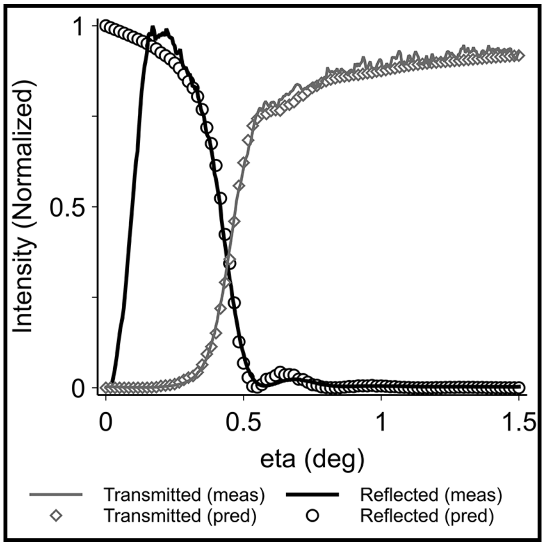


*Figure 3: Measured (scaled) and calculated integrated intensities of the reflected and transmitted x-ray beams.*

### References:

[1] Lairson, B. M., and D. H. Bilderback. "Transmission x-ray mirror -A new optical element." Nuclear Instruments and Methods in Physics Research 195, no. 1-2 (1982): 79-83.

[2] Cornaby, Sterling, and Donald H. Bilderback. "Silicon nitride transmission X-ray mirrors." Journal of synchrotron radiation 15, no. 4 (2008): 371-373.

[3] S. Cornaby, D. M. E. Szebenyi, D.-M. Smilgies, D. J. Schuller, R. Gillilan, Q. Hao and D. H. Bilderback. "Feasibility of one-shot-per-crystal structure determination using Laue diffraction." Acta Crystallographica Section D: Biological Crystallography 66, no. 1(2010): 2-11.