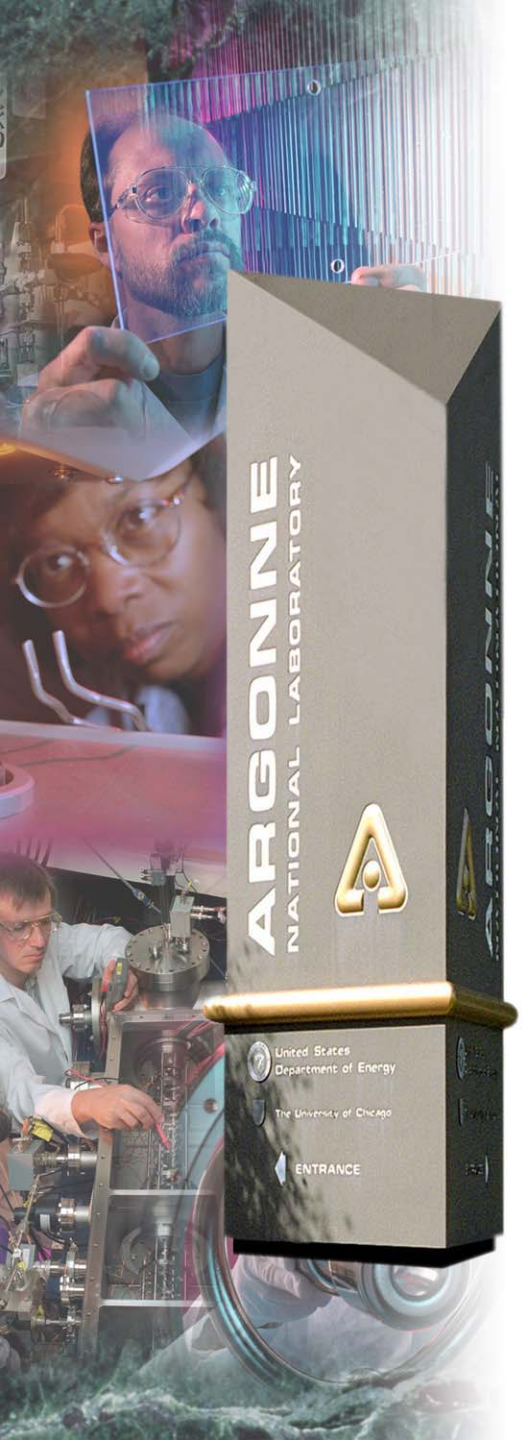

Transmission Multilayer Optics for Sub-10-nm Focusing of Hard X-rays

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Office of Science
U.S. Department of Energy

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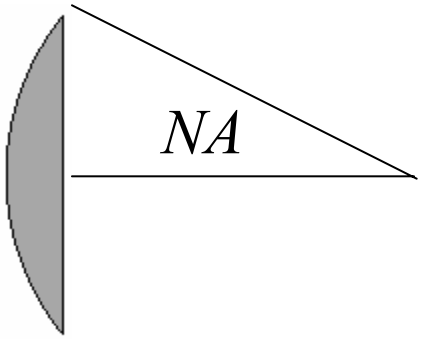
Raleigh Limit for Focusing

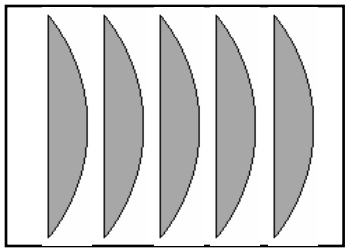
- Raleigh criterion gives diffraction limit for spot size, determined by numerical aperture (NA) of optic
- Development of optics with high numerical aperture for hard x-rays would allow microscopy with ~1nm resolution

$$\Delta(FWHM) = \frac{0.6\ \lambda}{NA}$$

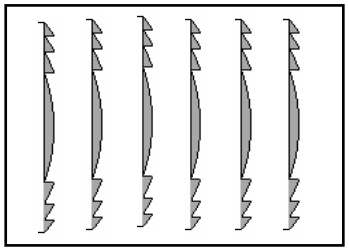


High NA Hard X-ray Focusing Optics

- **Refractive:**



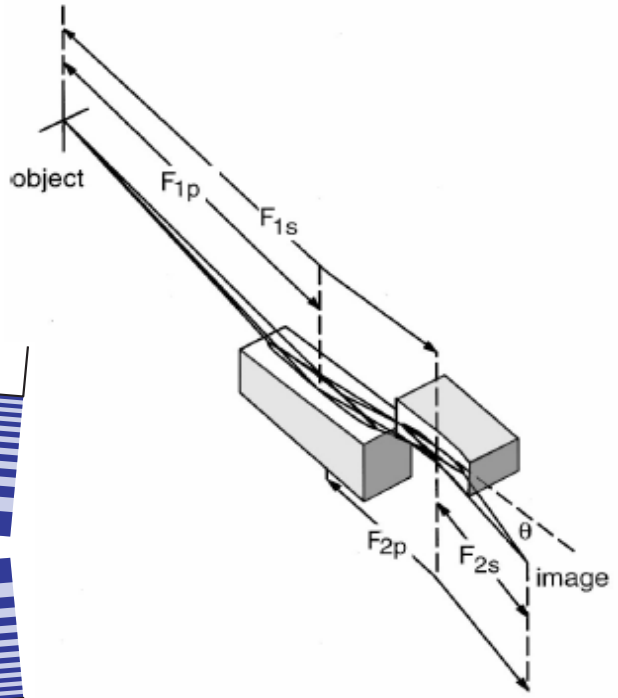
Compound refractive lens



Compound Fresnel lens for high NA

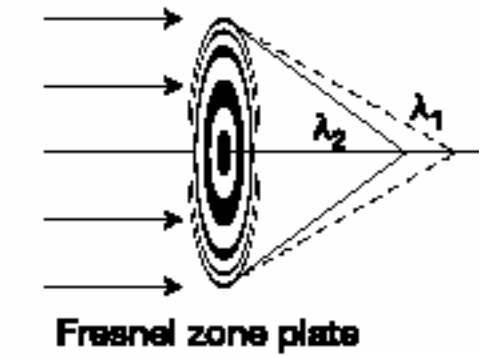
- **Reflective: Kirkpatrick-Baez Mirrors**

Figure by differential deposition, multilayer coated for high NA

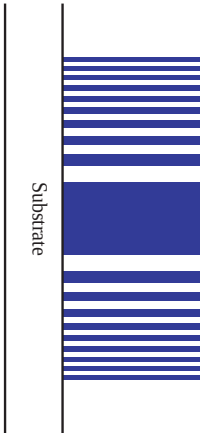


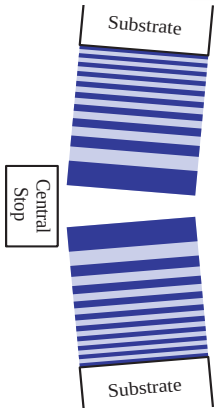
- **Diffractive: Zone Plates**

High aspect ratio, tilted zones for high NA



Lithographic zone plate

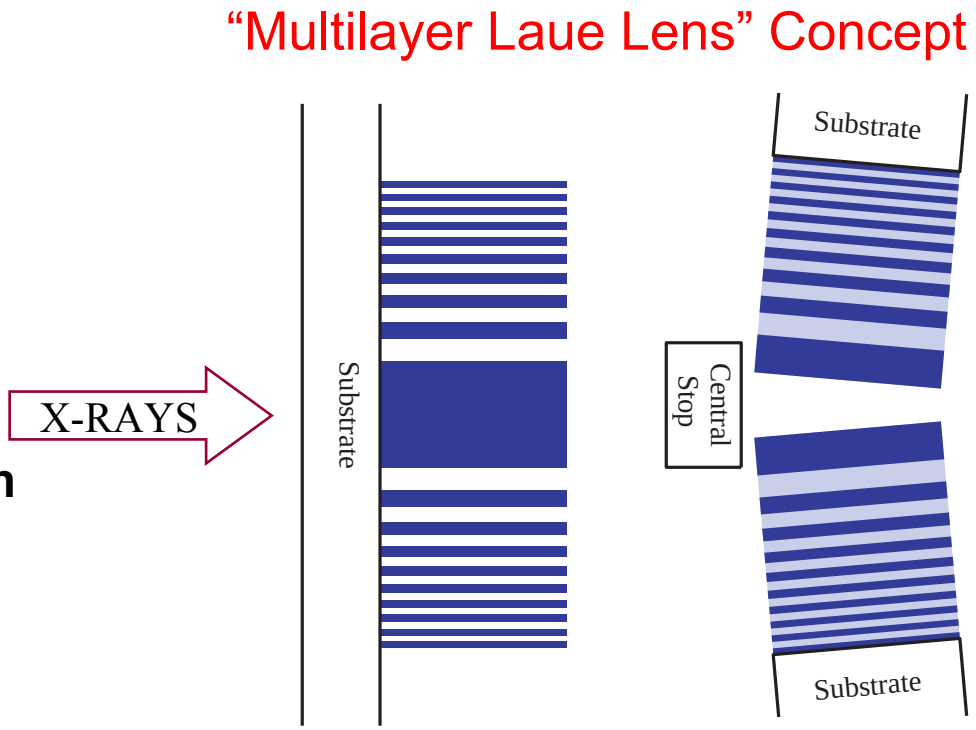




Transmission multilayer

Future Optics for Hard X-ray Focusing

- Zone plate structures for hard x-rays must be several microns thick to achieve high efficiency
- Small focal spot sizes require small zone widths, which implies high aspect ratios (~100)
- It is difficult to produce such high aspect ratio structures using lithography
- Sectioning of multilayers allows very high aspect ratios to be produced

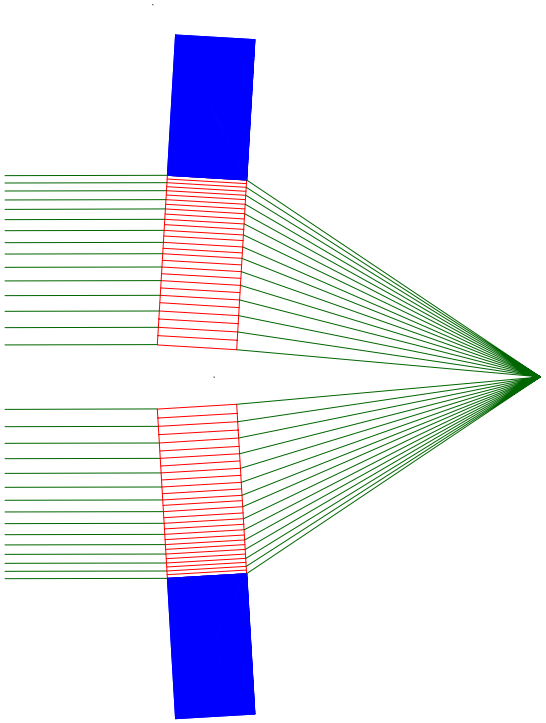


Standard lithographically-fabricated hard x-ray zone plate

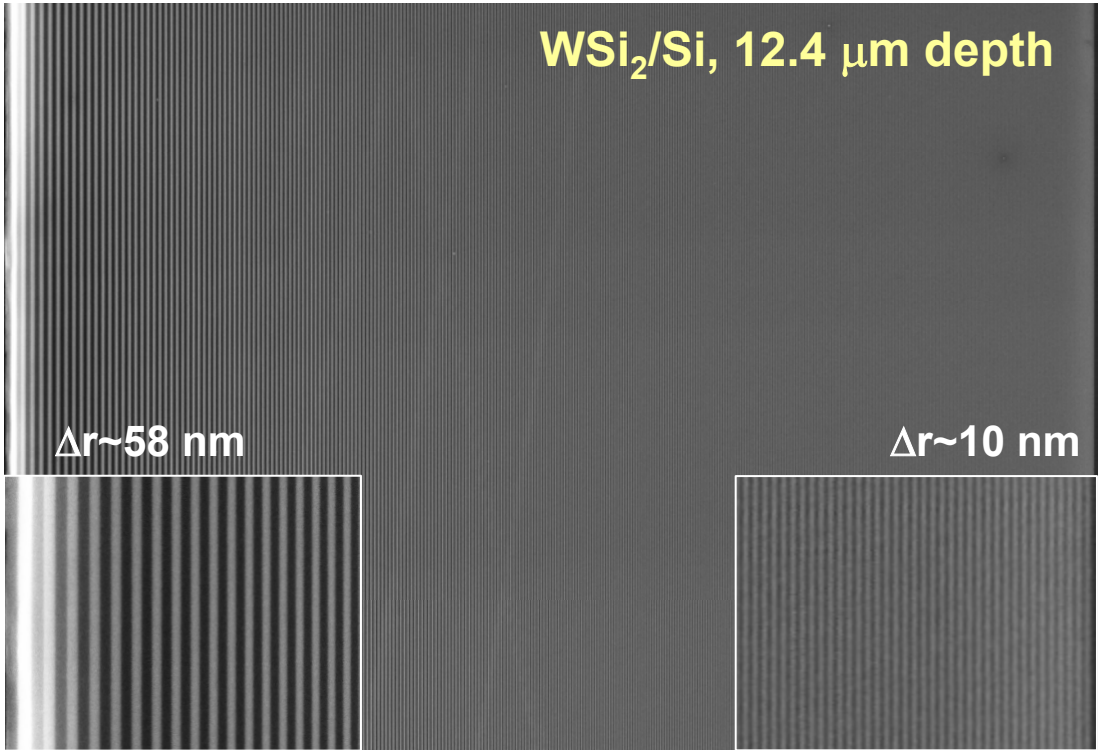
Transmission multilayers fabricated by deposition and sectioning

Recent Result: Transmission Multilayer Lens

"Multilayer Laue Lens" concept



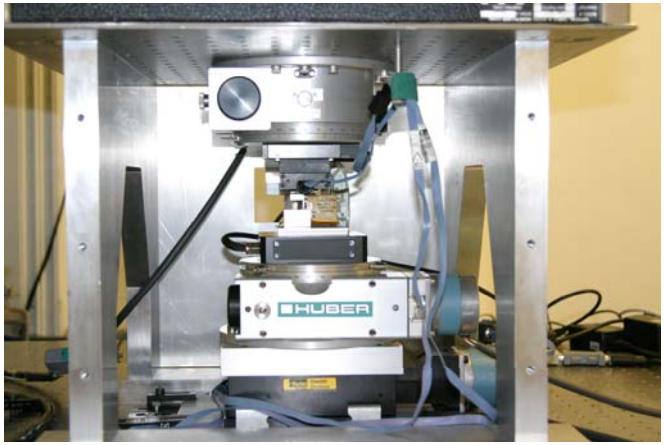
Electron microscope image of cross section

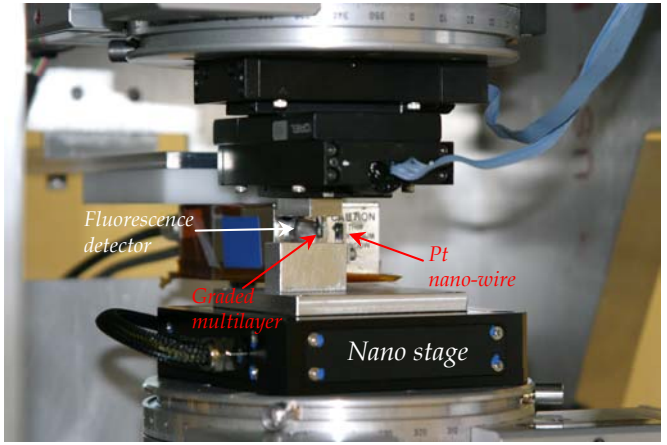


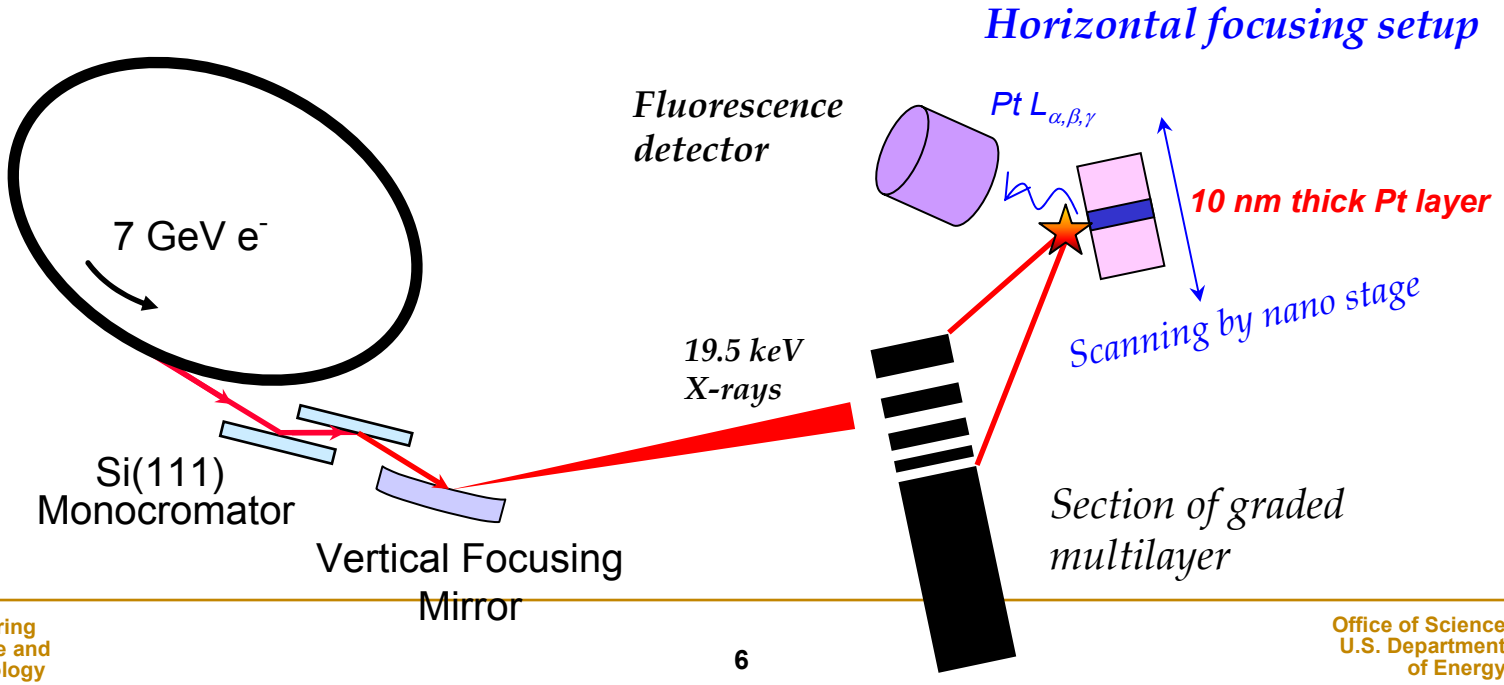
H. C. Kang, J. Maser, C. Liu, A. Macrander, G. B. Stephenson, unpublished (2005)

Transmission multilayers fabricated by deposition and sectioning

Measurement of Focal Spot Size



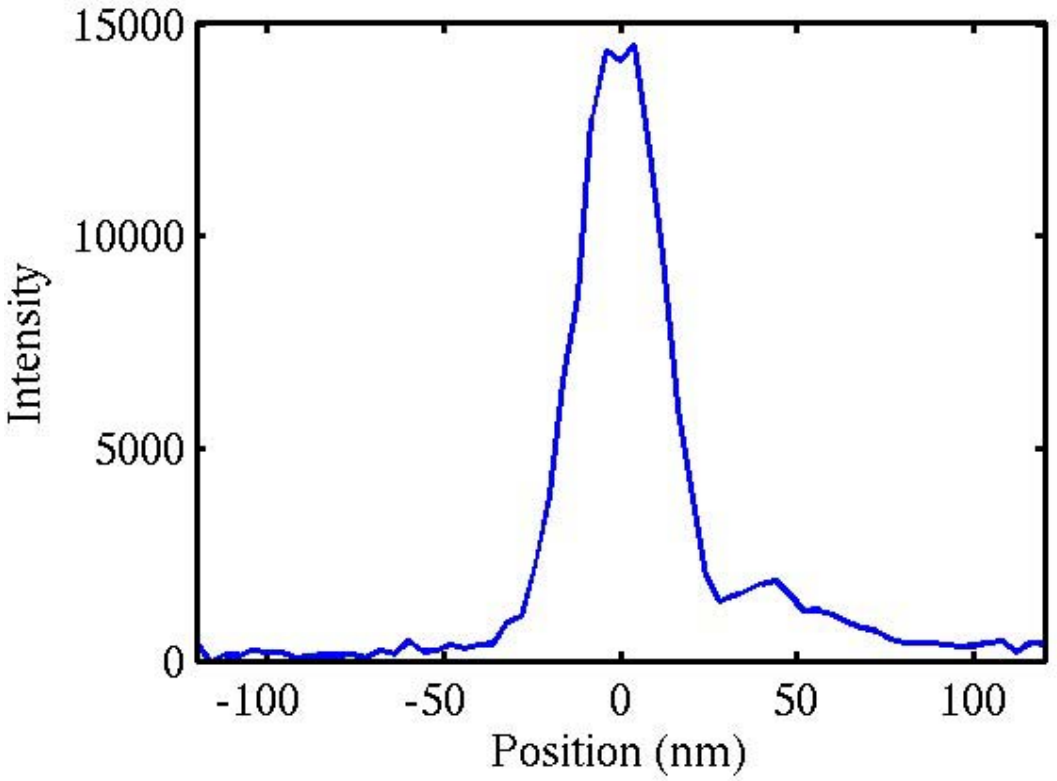




Recent Result: Transmission Multilayer Lens

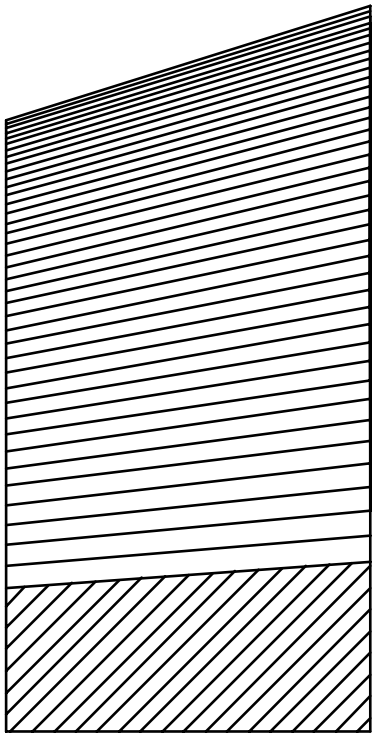
Using one half of lens structure (40% of full zone plate), 10 nm outermost zone width, 19 micron depth (aspect ratio 1900), we recently achieved:

29 nm FWHM line focus with 46% efficiency at 19.5 keV

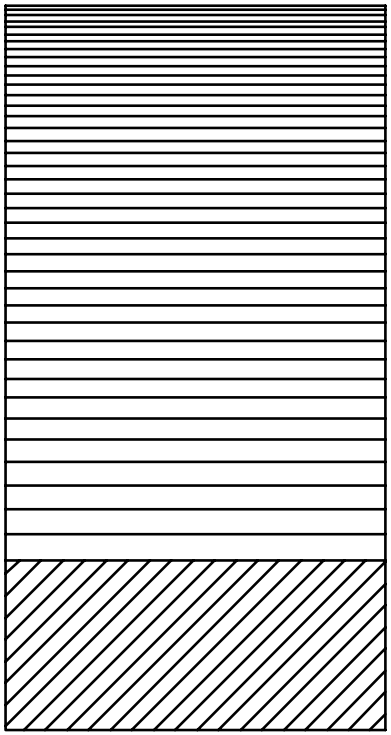


H. C. Kang, J. Maser, C. Liu, A. Macrander, G. B. Stephenson, unpublished (2005)

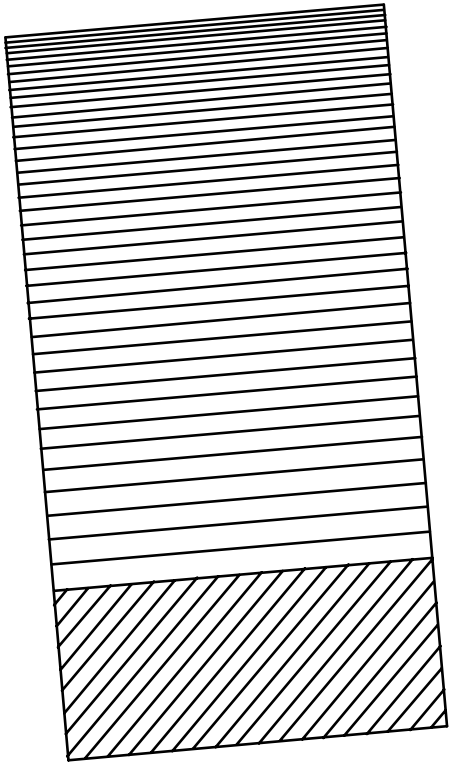
Optimum Zone Plate for Hard X-ray Nanofocus



Volume ZP



MLL (untilted)



MLL (tilted)

Outlook

- Demonstrated deposition and fabrication of thick transmission multilayers
- Demonstrated diffraction-limited performance at 29 nm FWHM; assembling full structure would give <15 nm FWHM
- Expect to achieve sub-10-nm focusing with thinner layers
- Calculations suggest tilting of layers within structure will be needed to approach 1 nm