Optics Fabrication and Metrology for Nanofocusing of Hard X-rays

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Introduction

Progress in the fabrication and metrology of both Multilayer Laue Lenses (MLLs) [1,2] and Kirkpatrick-Baez (K-B) mirrors [3,4] at the Advanced Photon Source (APS) is on-going as part of the world-wide race to achieve ever smaller focusing.

Successful MLLs require multilayer depositions consisting of many layers [1]. Focusing to 30 nm for 19.5 keV has been demonstrated at APS beamlines with a WSi_2/Si MLL having 728 layers made at the APS [2]. These same techniques were used to achieve a partial linear zone plate structure having a 5-nm outer most zone width and consisting of 1588 total layers as discussed below.

Achromatic focusing to 80 nm of x-rays in the range ~7 to 22 keV by an elliptically figured K-B mirror has been demonstrated at the APS with a mirror coated at the APS [4]. The mirror was made by profile coating a substrate with Au to achieve the elliptical surface shape [3]. The elliptical mirror was made starting from a flat substrate. To make further progress, non-x-ray-based metrology data for real mirrors [3,5] will need to be incorporated into simulations. This is being done using Fourier Optics methods as detailed below.

Multilayer Laue Lens with 5-nm outermost zone

A scanning electron micrograph of a cross section of a 5-nm MLL structure is shown in Fig.1, below. The bilayer structure was WSi_2/Si and a total of 1588 layers were sputter deposited at the APS. The micrograph was read to obtain the data plotted in Fig. 2. Here the d-spacing as a function of position in the lens is shown, where the d-spacing is twice the individual layer spacing A linear behavior in 1/d vs. position is needed to satisfy the zone plate law. (Owing to limited SEM resolution, the thinnest layers were subject to greater uncertainty.) This lens was used to obtain a linear focus of 19.3 nm at 19.5 keV at beamline 12-BM at the APS [6].

Kirkpatrick-Baez mirrors and Fourier Optics Simulations

Elliptically shaped mirrors have been made by profile coating at the APS. A program to simulate the performance of such mirrors by means of Fourier Optics [7] has recently been started. Mirror aberrations away from a perfect ellipse will be incorporated into a complex pupil function. In the absence of any aberrations, spherical waves emanating from a point source will be reflected to produce spherical waves directed to a focus. The resultant Fraunhofer diffraction pattern near the focal plane is shown in Fig. 3. Subsequent introduction of mirror aberrations will be simulated with this procedure.

References:

[1] C. Liu, R. Conley, A.T. Macrander, J. Maser, H.C. Kang, M. Zurbuchen, and G.B.Stephenson, J. Appl. Phys. **98**, 113519 (2005).
[2] H.C. Kang, J. Maser, G.B.Stephenson, C. Liu, R.Conley, A.T. Macrander, and S. Vogt, Phys. Rev. Lett. 96, 127401 (2006).
[3] C. Liu, L. Assoufid, R. Conley, A.T. Macrander, G.E. Ice, and J.Z. Tischler, Opt. Eng. **42**, 3622 (2003).
[4] W. Liu, G. E. Ice, J.Z. Tischler, A. Khounsary, C. Liu, L. Assoufid, and A.T. Macrander, Rev. Sci. Instrum. **76**, 113701 (2005).
[5] G. Ice, J.-S. Chung, J.Z. Tischler, A. Lunt, and L.Assoufid, Rev. Sci. Instrum. **71**, 2635 (2000).
[6] H.C. Kang, J. Maser, B. Stephenson, C. Liu, R.Conley, A. Macrander, S. Vogt, and H. Yan, unpublished.
[7] J.W. Goodman, *"Introduction to Fourier Optics"*, third edition, Roberts & Co., Englewood, Colorado (2005).

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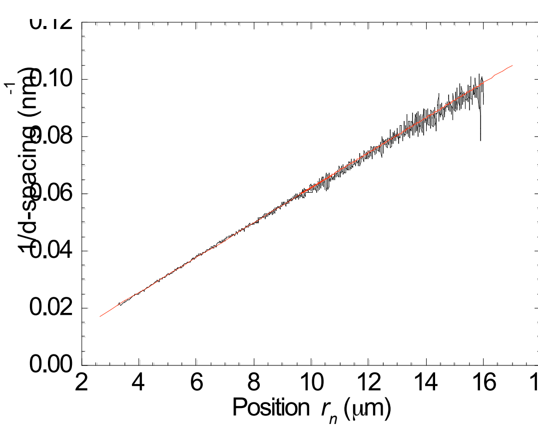

Fig. 2. Inverse bilayer thickness versus position in the MLL of Fig.1. Data showing noisy behavior is compared to a line for an ideal Fresnel zone plate.

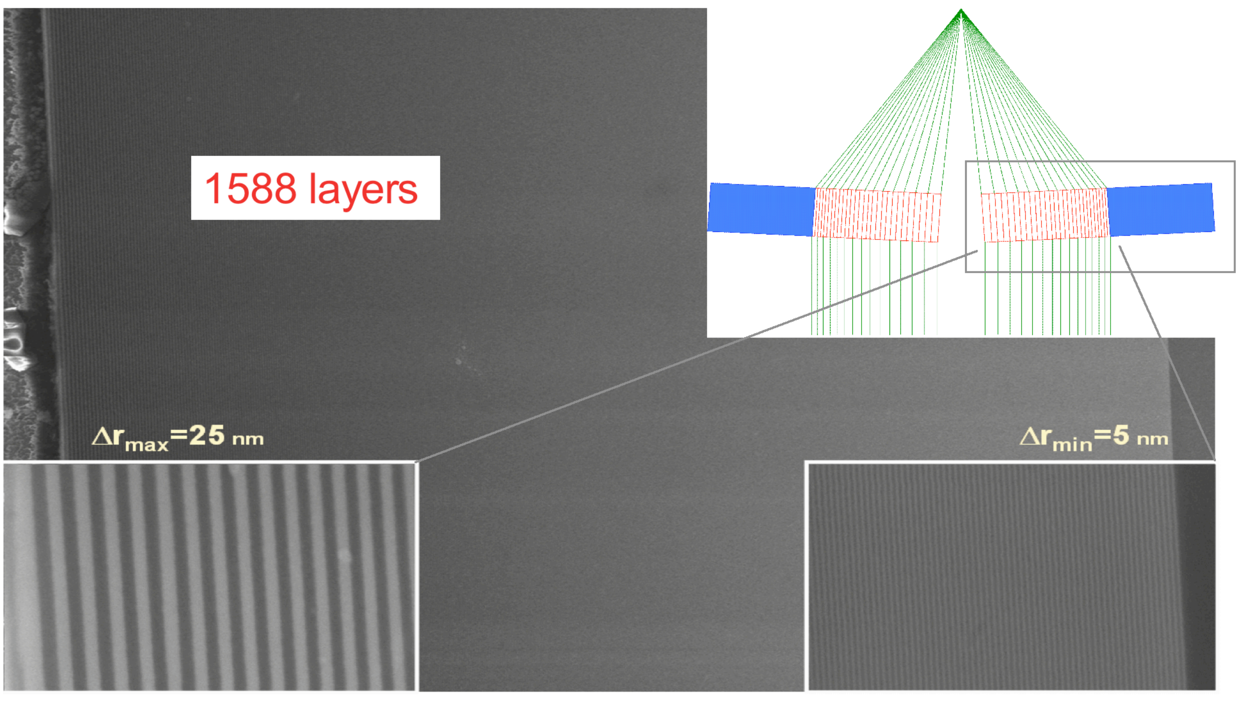

Fig.1. Cross section SEM micrograph of a MLL having a 5-nm outermost zone. The inset shows the focusing geometry employed to achieve a focus of 19.3 nm at 19. 5 keV.

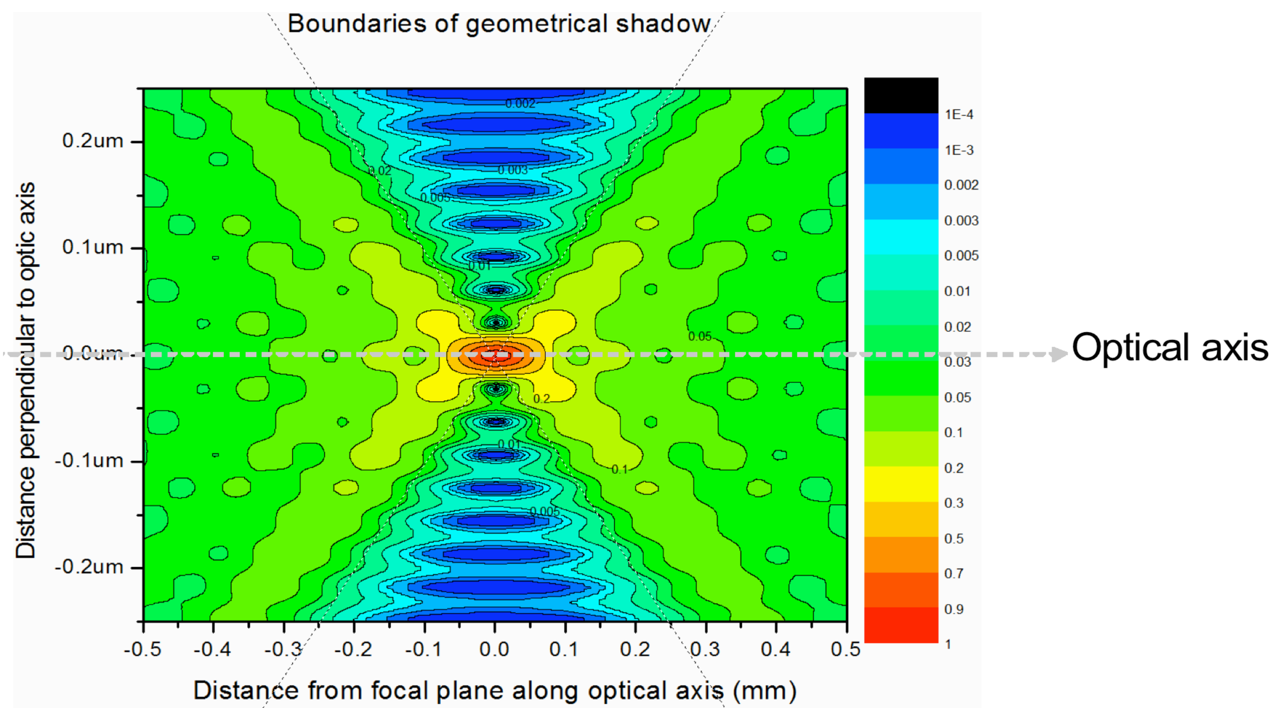

Fig.3. Equal intensity maps (isophotes) near the focus for a perfect elliptically shaped mirror simulated by Fourier Optics methods. A Fraunhofer pattern is shown in the focal plane.