Precision X-Ray Optics Development

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Building on achievements of the EUVL Program, we have begun developing a long-term vision for manufacturing reflective x-ray optics that may lead to diffraction-limited performance (~100 Å). The feasibility of building a Wolter mirror with this spatial resolution raises significant system-level questions about detectors, reconstruction algorithms, and alignment that will also require similar levels of investment.

Project Goals

In the first three years of this program we set out to meet important goals: development and implementation of a complete process flow for the construction of reflective x-ray optics, improvement of metrology techniques, and fabrication of a replicated optic with 1 μm spatial resolution over a millimeter field of view.

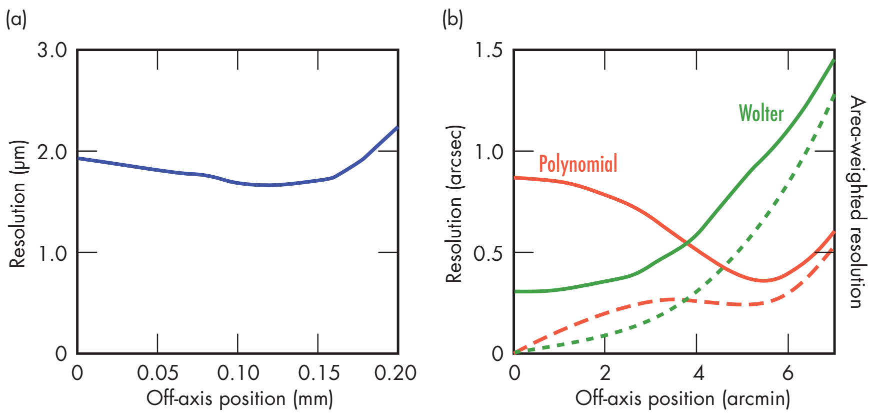

Figure 1. (a) Resolution vs. off-axis position for a standard Wolter optic designed to fulfill the imaging requirements for a 40-keV NIF backlighter experiment, assuming a figure error of 0.2 arcs. The field has been flattened by slightly shifting the position of the focal plane. (b) Comparison of a Wolter telescope with a design that incorporates additional polynomial terms to improve off-axis performance.

Relevance to LLNL Mission

Wolter systems fulfill demonstrated needs in a range of programmatic applications, including microscopy for high-Z NIF targets and imaging of NIF and EOS experiments. Figure 1 illustrates the combination of a Wolter optic with a 40-keV backlighter to perform a Ta foil experiment on NIF. Other applications include astronomical optics and manufacturing improvements that can be applied to synchrotron and LCLS beamline optics.

FY2004 Accomplishments and Results

Constructing an optical system that meets stringent resolution goals requires a detailed understanding of the process flow and an error budget that accurately captures limitations in manufacturing and metrology. As a test of key error sources in producing replicated optics, a flat test mandrel and replicated coupon are being fabricated. The process includes diamond turning a 2-in.-diameter flat; depositing electroless-nickel plating; diamond turning the nickel coating; polishing the diamond-turned nickel; and replicating the polished surface. Metrology is performed at each step to track the high (λ < 100 nm), mid (100 nm < λ < 1 mm), and low (λ > 1 mm) spatial frequency sources of error throughout the process. LLNL is performing all metrology and diamond turning. NASA MSFC is providing the polishing and replication.

Driving down the uncertainty in measurements will lead to more accurate maps of the surface, which can in turn be fed back into the process flow to improve the performance of the final optic. A major challenge in inspecting x-ray optics is the interrelation of noncontact scan data with the optic's coordinate system.

Two options are being considered to provide this new capability. The first is based on the Phase-Shifting Diffraction Interferometer (PSDI) developed during the EUV Lithography Program. It appears that current PSDI designs can be used in a grazing incidence configuration to measure Wolter-type shells—singly or nested—as well as the convex replication mandrels themselves. The basic concept is sketched in Fig. 2.

The second approach is an integration of an optical profiling instrument with a coordinate measuring machine (CMM) that would lead to the measurement of an entire surface from a discrete set of sub-aperture scans. Candidates for the optical profiler include the well-known "Takacs Long-Trace Profiler" and a sub-aperture version of the PSDI that would provide both figure and finish information. Combining the PSDI with LLNL's Large Optic Diamond Turning Machine (LODTM), used as a CMM, opens the possibility of normal-incidence surface measurements of more complex shells and mandrels, thus increasing our capability beyond standard conic-shaped optics.

One difficult challenge is simultaneously meeting the stringent figure and finish specifications, as polishing usually leads to the degradation of figure. A novel solution to this problem takes advantage of the magnetron sputtering capabilities developed for the EUVL Program, where the precision of the figure control of the deposited layers was maintained to less than 0.1 nm rms (see Fig. 3).

Related References

1. Martz Jr., H. E., and G. F. Albrecht, "Nondestructive Characterization Technologies for Metrology of Micro/Mesoscale Assemblies," *Proceedings of Machines and Processes for Microscale and Mesoscale Fabrication, Metrology, and Assembly,* ASPE Winter Topical Meeting, Gainesville, Florida, January 22-23, pp. 131-141, 2003.
2. Burrows, C. J., R. Burg, and R. Giacconi, "Optimal Grazing Incidence Optics and Its Application to Widefield X-Ray Imaging," *Astrophysics Journal,* **392**, p. 760, 1992.

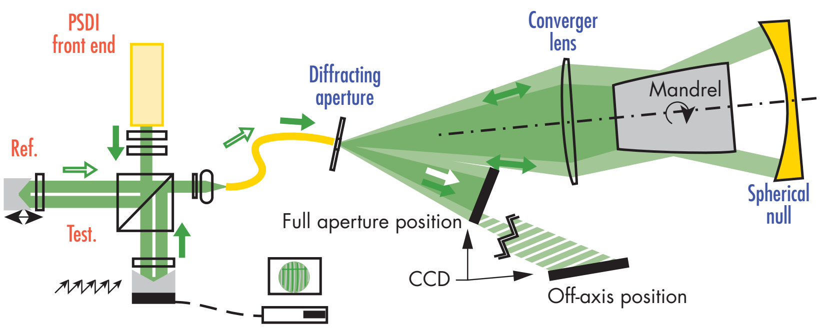

Figure 2. Sketch depicting the basic concepts of a PSDI design intended for grazing incidence metrology. The interferometer components are labeled in red, optical elements in purple, and detector elements in black.

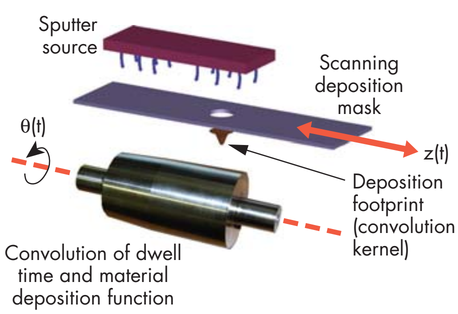

Figure 3. Extension of the EUV deposition technology envisioned for post-polishing figure correction. The mandrel rotates underneath a sputtering target configured with a small mask. Surface maps based on metrology techniques determine the rate the aperture mask moves across the mandrel face.

FY2005 Proposed Work

We propose to develop optical designs that meet the requirements of specific NIF/EOS diagnostics, and also of a target characterization microscope. A production process will be designed that can achieve optical surface errors consistent with sub-micron imaging resolution. Proof-of-principle developments will begin in optical fabrication and metrology for constructing and characterizing Wolter-type optics and mandrels.