A new method for measuring X-ray optics aberrations

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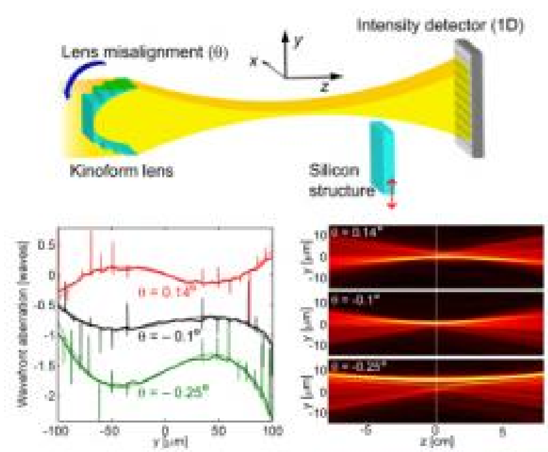

Top: Experimental setup. Bottom: Measured and simulated lens aberrations (left) and their corresponding through focus amplitude of reconstructions (right) for different lens angular misalignments. (From Manuel Guizar-Sicairos et al., Appl. Phys. Lett. 98, 111108 [2011]. © 2011 American Institute of Physics)

(PhysOrg.com) -- In a new report, scientists from the University of Rochester, Cornell University, and the Brookhaven and Argonne national laboratories carrying out research at national laboratories including the U.S. Department of Energy's Advanced Photon Source at Argonne describe phase retrieval methods to measure wavefront aberrations produced by imperfect hard x-ray optics. The authors demonstrate an accurate and easy-to-implement technique that allows both optimized positioning of existing optics and provides quantitative feedback that can guide improved fabrication procedures for future optics.

One application of existing and new high-brightness x-ray sources is to focus x-ray beams into small, nanosized spots. The small spots can then be used to make spatially resolved measurements of samples in order to better understand the unique properties of materials at the nanoscale. To create such small spots requires an x-ray optic to modify the phase profile of the x-ray beam in a specific way. Imperfections or aberrations in the realized optic will, however, prevent the user from obtaining the smallest spots possible.

Measuring the wavefront (a surface of points having the same phase) is a common method at optical wavelengths for testing the quality of surfaces and evaluating the overall performance and alignment of complicated imaging systems. If accurately measured, the deviation of the wavefront from an ideal sphere provides a quantitative map of the aberrations induced by manufacturing errors and/or misalignment.

Aberrations are deviations from the perfect phase profile and can distort and broaden the focused spot. They arise from either the misalignment of the optic or they can be "baked-in" as a result of imperfect fabrication of the optic or from these two effects combined. As desired spot sizes become smaller, the aberrations need to be made correspondingly smaller. Clearly, the ability to accurately measure these aberrations is critical to realizing the full potential of bright x-ray sources to investigate materials at the nanoscale.

Currently, the most widely used method of x-ray-optics performance characterization is a series of knife-edge scans at different distances from the optic. From such measurements, one can extract the best focal spot size and distance. This method, however, does not contain direct information on the aberrations and is slow. In a recent publication, the authors describe a new application of so-called phase retrieval methods to determine the aberrations of hard x-ray optics. The authors used a phase retrieval method called "transverse translational diversity" or TTD that has been very successfully used in X-ray imaging applications. In TTD, the x-ray field of the focusing optic is perturbed with a known object placed at a diversity of transverse positions. At each position, the corresponding diffraction intensity pattern is measured. The resulting data allows for a more robust resolution of the ambiguities typically present in phase retrieval data, with the ambiguities being especially severe for the one-dimensional case of conventional phase retrieval. The measured data is quickly processed using a computer algorithm to obtain the x-ray wavefront aberrations. This, in turn, can be used to optimize the alignment of the existing optic on-line or to improve the manufacture of future optics.

To test this new method, the researchers deliberately introduced an aberration into their focusing set-up by rotating a one-dimensional-focusing kinoform x-ray optic away from its optimal position. Since the aberrations created by the rotation can be accurately predicted, the authors had a tool to evaluate the accuracy of their wavefront measurement. As described in detail in their paper, the new method is found to be rapid, accurate, and robust.

As well as providing quantitative information on the wavefront aberrations produced by imperfect x-ray optics, the authors' approach has other key advantages. First, the measurements can be performed at arbitrary x-ray wavelengths. As such, the new method is a direct measurement of actual optics performance rather than the extrapolated performance often derived from other measurement techniques. Second, the new method facilitates the alignment of samples. Instead of making iterative measurements of the field profile at different distances from the focusing optic in order to find the optimum location for the sample, the phase retrieval measurement can be done at one distance. Computer-based propagation methods can them be used to predict the field at all other distances and, hence, predict the distance where the best focus occurs, and the size and profile of this best focus. A third advantage is that the known perturbing object can be located far from the focus. This allows optimization of the focusing optic without the need to disturb sensitive samples and sample environments located at the x-ray-beam focus.

More information: Manuel Guizar-Sicairos, Suresh Narayanan, Aaron Stein, Meredith Metzler, Alec R. Sandy, James R. Fienup, and Kenneth Evans-Lutterodt, "Measurement of hard x-ray lens wavefront aberrations using phase retrieval," *Appl. Phys. Lett.* 98, 111108 (2011). DOI:10.1063/1.3558914

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