The Advanced Photon Source

A New Multilayer-Based Grating for Hard X-ray Interferometry

A new x-ray multilayer grating that could open a pathway for high-sensitivity, hard x-ray phase contrast full-field imaging of large samples has been developed by researchers at the National Institutes of Health, the U.S. Department of Energy Office of Science's (DOE-SC's) Argonne National Laboratory, and Penn State University. In tests at the DOE-SC's Advanced Photon Source (APS) at Argonne, the device produced phase-contrast images of vascular structures in a mouse kidney specimen that rival those obtained with magnetic resonance imaging [1]. Such soft-tissue structures were previously invisible to conventional, attenuation-based x-ray imaging.

The grating (Fig. 1), with an ultra-small period and theoretically unlimited depth-to-period ratios, is based on a multilayer thin-film-deposition technique utilizing an anisotropic wet-etched staircase on an off-cut silicon (Si) wafer as the substrate. The grating consists of an array of micro-gratings of multilayer sitting on the floor of steps of the staircase Si substrate. Details of the fabrication processes were published in the *Journal of Micromechanics and Microengineering* [2].

Grating-based interferometry for x-ray phase-contrast imaging has advanced rapidly thanks to its potential for better image contrast and lower radiation dose over conventional absorption radiography and computed tomography. Phase-contrast imaging is hundreds of times more sensitive than conventional x-ray imaging techniques based solely on absorption contrast. It is especially useful for imaging soft tissue with hard x-rays from synchrotron light sources like the Advanced Photon Source.

A small grating period, which splits and diffracts light into several beams travelling in different directions, will lead to a larger separation between the diffracted beams and thus higher interferometer sensitivity.

Traditional hard x-ray gratings are fabricated using lithography processes; the grating period is relatively large, and the attainable aspect ratio of the grating is limited.

Multilayer gratings can overcome the aspect ratio problem. The layers can be as thin as a few nanometers, and the grating can be sliced to many millimeters. However, if a flat substrate is used, the limited height of a single multilayer stack (<50 μm) precludes full-field imaging of large samples. The new grating with multilayers grown on a staircase substrate, on the other hand, promises both large- area detection and small, dense periods, thus enabling large-area imaging with unprecedented resolution.

Slit diffraction patterns and contact radiography images obtained at the Argonne X-ray Science Division beamline 2-BM-B of the APS demonstrated successful intensity modulation by the new grating of a 25-keV x-ray beam. The slit diffraction pattern showed 69% of the beam energy diffracted into the ±1 and higher diffraction orders. For comparison, a perfect absorption grating diffracts 50% of the beam energy, while an ideal π phase shift grating with no absorption loss diffracts 100% of the beam energy.

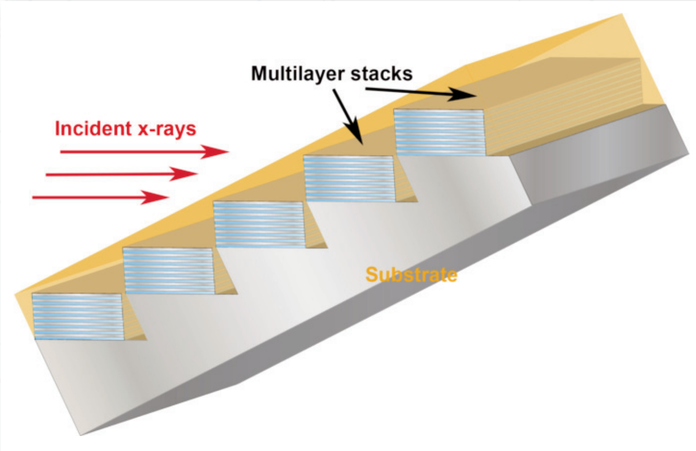

Fig. 1: The multilayer grating consists of an array of multilayers sitting on the floor of steps of a staircase Si substrate. The grating period equals the bilayer thickness, and the grating area covers the whole staircase with thousands of steps.

This method opens a path for compact x-ray end-station systems to deliver the full benefit of phase contrast to a broad range of applications, such as high-sensitivity x-ray microscopy of pathology specimens that are opaque to optical microscopes, pre-clinical imaging of animal disease models, and non-invasive detection in industrial and materials science areas.

— Chian Liu (Argonne), Han Wen (National Institutes of Health), Lahsen Assoufid (Argonne)

[1] Han Wen, Andrew A. Gomella, Ajay Patel, Susanna K. Lynch, Nicole Y. Morgan, Stasia A. Anderson, Eric E. Bennett, Xianghui Xiao, Chian Liu, and Douglas E. Wolfe, "Subnanoradian X-Ray Phase-Contrast Imaging Using a Far-Field Interferometer of Nanometric Phase Gratings," Nat. Commun. **4**, 2659, (November 5, 2013). DOI:10.1038/ncomms3659

[2] Susanna K. Lynch, Chian Liu, Nicole Y. Morgan, Xianghui Xiao, Andrew A. Gomella, Dumitru Mazilu, Eric E. Bennett, Lahsen Assoufid, Francesco de Carlo, and Han Wen, "Fabrication of 200 Nanometer Period Centimeter Area Hard X-Ray Absorption Gratings by Multilayer Deposition," J. Micromech. Microeng. **22**, 105007 (2012). DOI:10.1088/0960-1317/22/10/105007

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Call for APS General-User Proposals

The Advanced Photon Source is open to experimenters who can benefit from the facility's high-brightness hard x-ray beams.

General-user proposals for beam time during Run 2014-2 are due by Friday, March 7, 2014.

Information on access to beam time at the APS is at http://www.aps.anl.gov/Users/apply_for_beamtime.html or contact Dr. Dennis Mills, DMM@aps.anl.gov, 630/252-5680.

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Argonne National Laboratory
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Advanced Photon Source
Bldg. 401/Rm A4115
Argonne National Laboratory
9700 S. Cass Ave.
Argonne, IL 60439 USA

U.S. Department of Energy
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