Fabrication of High-Aspect-Ratio Nanostructures to Characterize High-resolution Hard X-ray Nano-probe

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A hard x-ray nano-probe microscope based on Multilayer Laue lenses (MLLs) [1] is being developed at Advanced Photon Source in Argonne National Laboratory, which is expected to deliver a focused 2-D x-ray beam of 10x10 nm^2 operated at energy range of 10 - 20 keV at National Synchrotron Light Source II in Brookhaven National Laboratory in 2015. At the current stage, the microscope is operated in scanning fluorescence microscope mode. In order to feed back to the fabrication process for optics development, an efficient characterization of the MLL performance is crucial. For this purpose, a test pattern sample with a lateral feature size comparable to or smaller than the beam size (<20 nm) and a large thickness (>200 nm, for ample volume of atoms for strong fluoresce signals) is required. This is a challenging goal due to the high-aspect-ratio sample geometry.

The pattern layout, as illustrated in Fig. 1, includes both high-resolution features and low-resolution features. High-resolution feature has to be a small and isolated object to avoid a strong background signal from the direct beam and high orders (see Fig. 2) in case an order-sorting aperture is absent in the microscope.

Here we present a new fabrication method for such a test pattern, which is modified from that described in reference 2. A thin resist pattern with sub-20-nm critical dimension is defined by e-beam lithography and is transferred to a silicon substrate by a cryogenic deep reactive ion etch (RIE). An atomic layer deposition (ALD) process is followed to conformally coat a platinum (Pt) layer with a thickness comparable to the size of x-ray beam (10 - 25 nm). Another RIE step is then introduced to remove the horizontally coated Pt layer that will cause the background fluorescence. Pt is selected due to its high fluorescence yield and the availability of ALD and RIE recipes. ALD can precisely deposit thin Pt layer down to 5 nm or less, which makes the above test pattern fabrication technique feasible for future nano-probe development.

An example of the test sample is shown in Fig. 3, and an x-ray fluorescence mapping of the high-resolution pattern features is shown in Fig. 4.

[1] A.T. Macrander, H. Yan, H.C. Kang et al., "Nanofocusing of Hard X-Rays with Multilayer Laue Lenses," Chap. 42 in Handbook of Optics (McGraw-Hill Professional, 2009), Vol. V; H. Yan, V. Rose, D. Shu et al., "Two Dimensional Hard X-ray Nanofocusing with Crossed Multilayer Laue Lenses," submitted to Opt. Express.

[2] K. Jefimovs, J. Vila-Comamala, T. Pilvi et al., "Zone-Doubling Technique to Produce Ultrahigh-Resolution X-Ray Optics," Phys. Rev. Lett. 99, 264801 (2007).

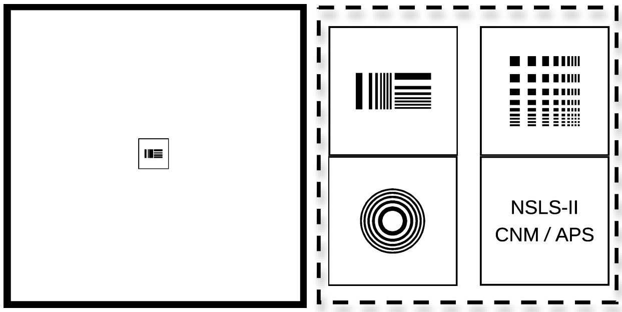


Fig. 1. Left: layout of a resolution test pattern. Outer frame is 40 μm x 40 μm with 1 μm line width for quick locating the pattern position. Inner frame is 4 μm x 4 μm with 60 nm line width, which is good for knife-edge scan. The actual resolution test pattern contains one of four patterns shown in the dash line frame at the right side.

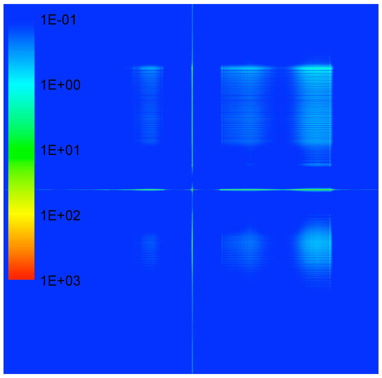
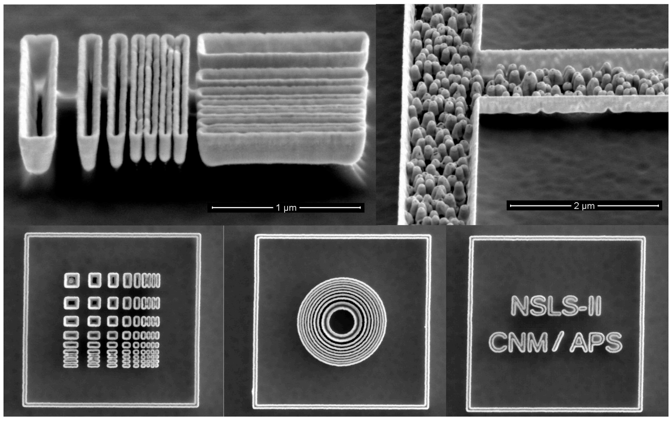


Fig. 2. Simulated x-ray intensity distribution at the focal plane of a pair of MLLs with the absence of an order-sorting aperture.

Fig. 3. SEM pictures of a fabricated test pattern. Upper left: grating pattern for line scan test. Upper right: low-resolution frame for quickly locating beam to the pattern. Scum left from under-dosed e-beam lithography exposure forms porous etching mask and results in high-density platinum zones with strong x-ray fluorescence signal.



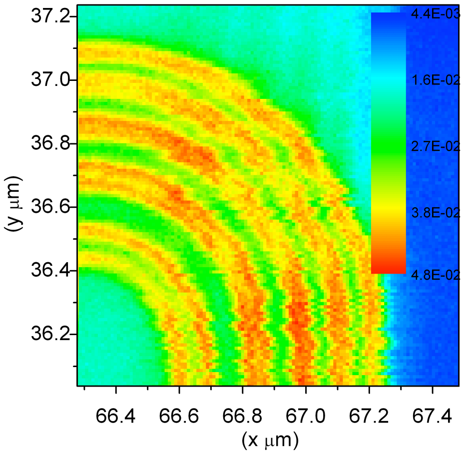


Fig. 4. Fluorescence image recorded from an x-ray scanning over a high-resolution test pattern.