Fabrication of hard x-ray zone plates with high aspect ratio using metal-assisted chemical etching and electroless plating

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Fresnel zone plates are key elements in x-ray focusing optics and are widely used in x-ray microscopes. Higher spatial resolution and higher focusing efficiency zone plates require narrower and thicker zone structures which lead to very high aspect ratio. Metal-assisted chemical etching (MACE) has been developed to create very high aspect ratio silicon structures that has been successfully used in fabricating x-ray zone plates[1][2]. Atomic layer deposition (ALD) has been used to deposit a high-density material such as platinum as the phase-shifting material to form a zone-doubled zone plate[3]. However, because the ALD process leads to all zones having the same width, the inner zones have reduced diffraction efficiency. Combining a process whereby the inner zones are filled using metal plating and the outer zones are metalized using ALD can theoretically create a high efficiency zone plate.

Here we developed an electroless plating process to fill in the zones between silicon zones with palladium (Pd). Our zone plates were designed to be 150 μm in diameter with an outermost zone width of 30 nm. After MACE and Pd electroless plating, we obtained an etched and plated thickness of up to 4.2 μm, which is equivalent to an aspect ratio of ~140, as is shown in Fig. 1(A). The diffraction efficiencies of the zone plates were measured at Argonne National Lab. Preliminary results show a 6.2% efficiency at 8 keV. Reduction in overplating, application of new polishing processes, and new zone plate patterns are expected to improve the efficiency. The resolution/imaging property of the zone plates were measured at Brookhaven National Lab. The measurement used the fabricated zone plates as an objective lens to image a Siemen star test pattern using TXM. The results reveal that it performed equally with commercial 30 nm zone plates and is able to resolve 40-50 nm features.

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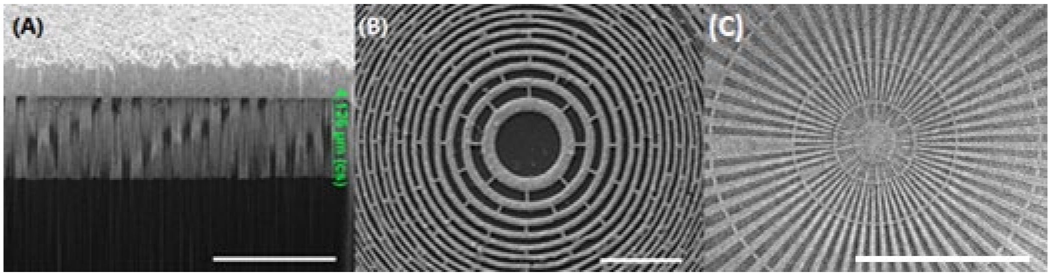

Figure 1: Zone plate fabricated using metal-assisted chemical etching and palladium electroless plating. (A) FIB cross sectional view of the outer finest zones of an overplated zone plate, showing a very high aspect ratio (B) zoom-in view of the inner zones of an overplated and polished zone plate (C) TXM image of Siemen star resolution pattern using fabricated zone plate as the objective lens, showing expected imaging resolution. Scale bars are 5 µm.