Fabrication of High Resolution Zone Plates with High Aspect Ratio using Metal-assisted Chemical Etching

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Metal-assisted chemical etching (MACE) has been shown to be a promising method for the fabrication of Fresnel zone plates for imaging and nanofocusing with multi-keV x-ray beams[1]. Fresnel zone plates require narrow zones (up to a finest value of dr_N for the outermost zone, with 10 nm as a goal in many research application areas) transverse to the x-ray beam direction, and micrometer-scale thickness along the beam direction so as to maximize diffraction efficiency. This leads to a requirement for high aspect ratio zones on a substrate with minimal absorption.

MACE allows the realization of a single zone plate with very high aspect ratio. However, while previous MACE zone plates[1] have demonstrated that one can use zone-doubling and atomic layer deposition[2] to achieve narrow, high aspect ratio zones, these zones have been etched into an un-thinned silicon wafer, greatly reducing the absolute focusing efficiency. It is desirable instead to have the MACE-fabricated zone plate located on a thin substrate; a substrate of 15 μm Si membrane would have a transmission of more than 90% for 10 keV x-rays.

We describe here a modified MACE process for fabricating Fresnel zone plates with high absolute efficiency and fine spatial resolution for x-ray nanofocusing applications. We used a multi-step process which first involves high resolution e-beam lithography, metal deposition and lift-off to produce the metal precursor pattern for MACE. With this process, we have fabricated a Si zone plate with an outermost zone width dr_N of 26 nm in zones that are more than 2 μm thick, thus achieving a very high aspect ratio up to 80:1 (MACE-produced zones with a 60:1 aspect ratio are shown in Fig. 1). We then followed this process with deep reactive ion etching (RIE) in order to thin the wafer substrate under the zone plate region to about 15 μm. We are now adding atomic layer deposition to our process so as to combine the spatial resolution and focusing efficiency of narrow Iridum or Platinum zones with the reduced loss of our back-etched silicon wafers. We will describe our progress on meeting this goal.

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[1] Chang and Sakdinawat, *Nature Communications* **5**, 4243 (2014).
[2] Jefimovs *et al.*, *Phys. Rev. Lett.* **99**, 264801 (2007).

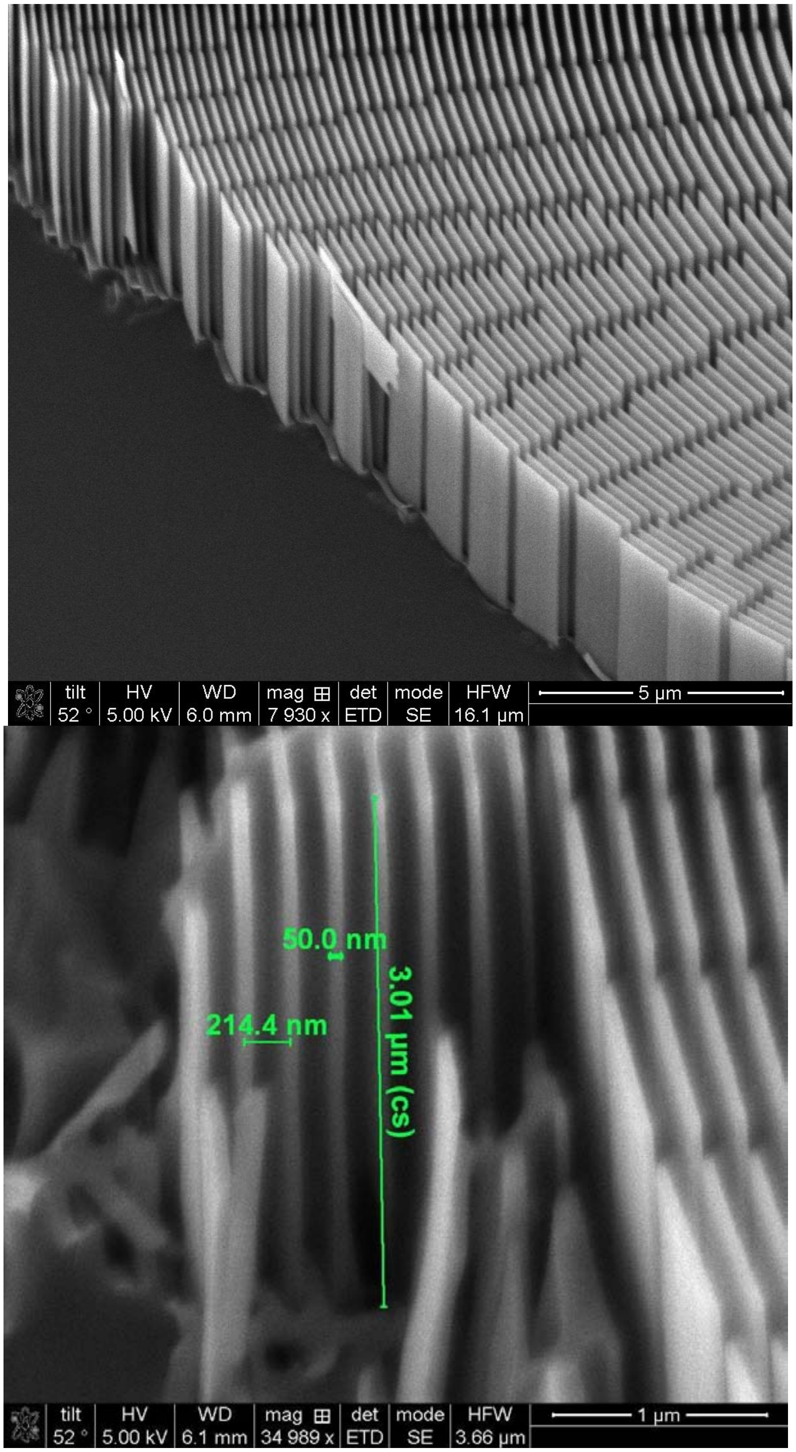

Figure 1 & 2: Silicon zone plate fabricated using Metal-assisted Chemical Etching (MACE). Top: SEM images of the cross-section of a zone plate with 50 nm zone width on 200 nm period, and a total height of 3 µm. The corresponding maximum aspect ratio reaches up to 60:1. The 1:3 line:space ratio is as desired for the zone doubling process[2].