Efficient Packaged Zoneplates for EUV Instruments

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Diffractive optical elements such as Fresnel zoneplate lenses have many uses at EUV such as at-wavelength mask inspection tools to image the mask at high-magnification onto a detector or in probe forming tools to focus the source to a small spot. However, the diffraction efficiency of a pure amplitude diffractive structure, consisting of alternating transparent lines with completely opaque lines, has a limit of about 10% and there is additional loss through the membrane support material. Although this compares unfavorably to two bounce reflective optics, zone plates are still useful for short focal length, high resolution applications.

We developed two approaches to improving the zoneplate efficiency. First we use the phase shifting property of Si_3N_4. At an etched depth of 244 nm, we measured a diffraction efficiency of 18% in the first order and 18% in the zero order, which compares to an amplitude grating of 10% and 25% respectively. Figure 1 shows the measured efficiency as a function of etch depth and matches scalar theory quite well using the measured EUV index of refraction 0.9790 + 0.0066i at the wavelength of 13.5 nm. While applying vector Electromagnetic grating calculations to these structures, we discovered that there is both amplitude and phase shifting introduced as a function of pitch, which, in theory, could be overcome by changing the linewidth to pitch ratio and zone placement across a zoneplate. However in practice this places a limit on the applicability for high resolution applications which is about half pitch of 50 nm. Fortunately, we developed a second approach, in which we improved our freestanding etching to produce zone plates in which the support membrane is completely removed as shown in the SEM micrographs of Figure 2. Although the diffraction efficiency is not improved, the membrane material can absorb up to 50% of the EUV so the final efficiency is similar to that of an optimized phase shifting zoneplate on a convential absorber.

Finally, a properly engineered package is needed for inserting and removing from an EUV instrument. We have exploited the kinematic approach using balls and grooves to produce a robust accurate package. The grooves are etched in the Si using anisotropic KOH etching. The angle is 54 degrees and the placement is done in the lithography steps so that the registration of the zoneplate features and the grooves can be made to sub-micron tolerances. We used ruby balls of diameters between 250 um and 1 mm which are commercially available with tight tolerances and reasonably priced. The balls are secured in the grooves using a low viscosity epoxy applied under a stereo microscope. Typical errors are in the few micron range for the smaller balls and the 10 um range for the larger balls. The completed package can be loaded and unloaded for ease of optics replacement with excellent repeatability and interchangeability.

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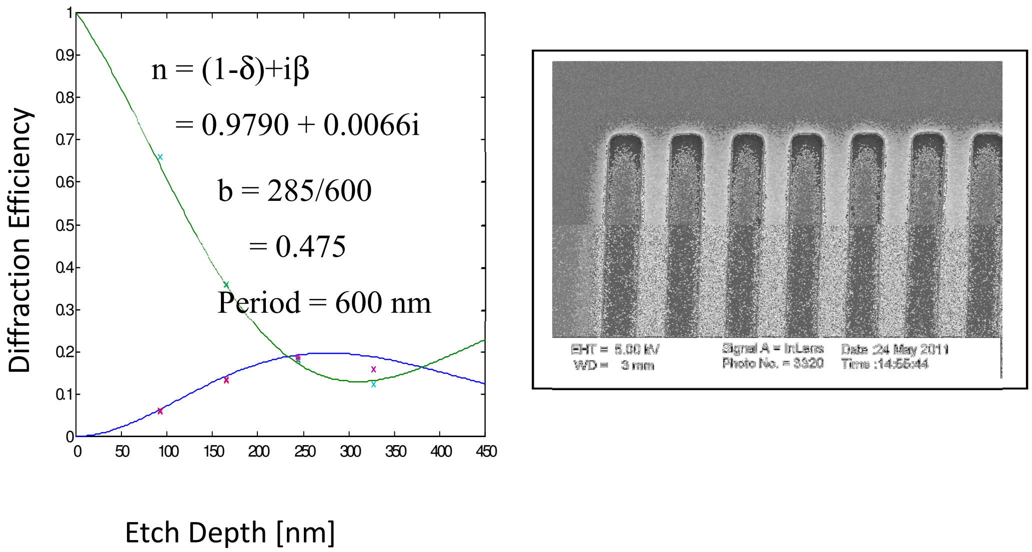
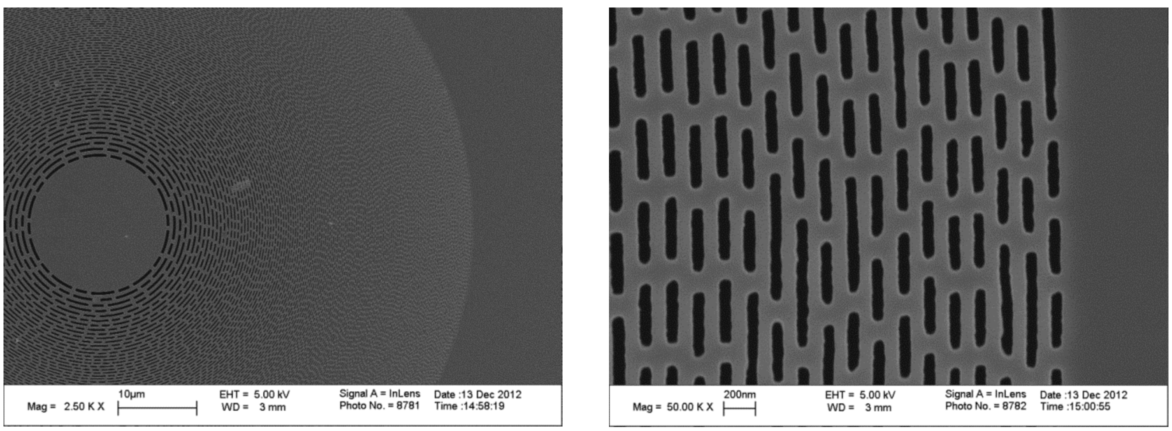


Figure 1. Measured Diffraction Efficiency of a 600 nm period Si_3N_4 grating etched to different depths. The highest diffraction efficiency of 18% in both the zero order and first order is achieved at a depth of 244 nm.



Figrue 2. SEM micrographs of freestanding zoneplate are fabricated in Si_3N_4 by etching completely through a 100 nm membrane and coating with 40 nm of Au or Ni. Diffraction efficiency is less than the amplitude limit of 10% but almost a factor of 2 is gained by not having a supporting membrane. Limitations of size due to stress in the membrane and absorber favor zoneplates of 100 um or less.

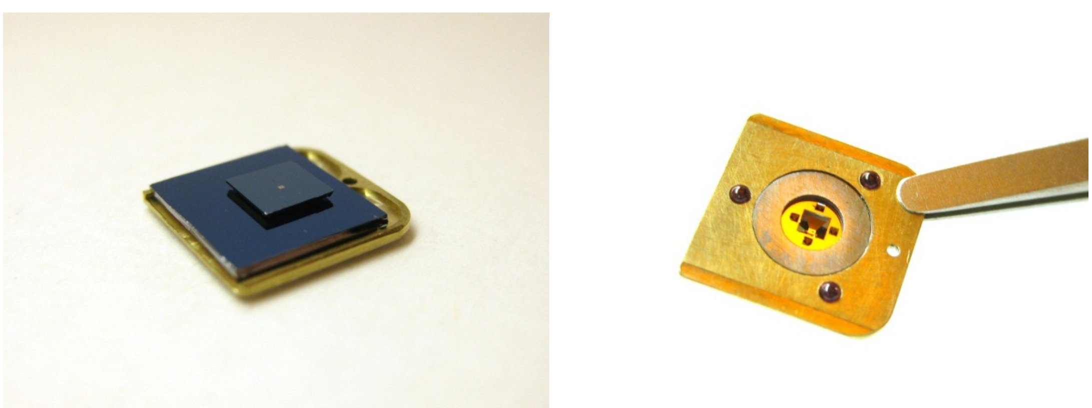


Figure 3. The left photo shows the front view with the larger zoneplate chip and smaller aperture chip attached to the machined holder. The bottom photo shows the back of the holder with the 1 mm ruby balls and the etched area for the window zoneplate is visible in the center. The kinematic ball in grove method is used to produce an accurate, reproducible package.