The Optical Vortex Lens

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Abstract—**The project seeks to fabricate a vortex lens (phase shift device) using optical lithography with a future goal of using it for astronomy purposes. Initially the goal is to create a lens tuned to a HeNe laser (632.8 nm wavelength) with eight photoresist steps, which causes the light to undergo a phase shift. It is this shift that allows the vortex lens to suppress starlight in the vicinity of extra solar planets; it diffracts the light of the star while preserving the image of the nearby planet.**

Index Terms—**Vortex Lens, HPR504, extrasolar**

I. Introduction

Photolithography has been applied to create a helical relief in photoresist on a fused silica substrate resulting in an optical vortex lens. The goal is to be able to transform a beam of light into a vortex; vortex lenses are important in high contrast imaging systems. They have recently been used to aide in the search for extrasolar planets. The fabricated vortex lens contains eight steps in photoresist; it is a discrete version of a continuous surface (Fig. 1).

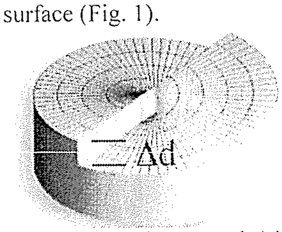

Fig. 1. Ideal vortex lens; smooth continuous step heights [1].

Exposure will be done on the RIT SMFL GCA6700 g-line stepper with HPR504 broadband photoresist. The following will be used to measure photoresist thickness: NanoSpec, Prometrix FT-500/SM-300 and Tencor P2.

The vortex lens is designed for use at the HeNe wavelength (632.8 nm). The HPR504 index of refraction may be calculated using the Cauchy coefficients:

$$N_g(\lambda) = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4} \quad (1)$$

Where a = 16112, $b = 5.68E - 3\ \mu^2$, $c = 1.99E - 3\ \mu^4$

At 632.8 nm wavelengths, HPR504 has a calculated index of 1.61. The photoresist thickness required for a given phase shift can be determined, from the relation [2].

$$\Phi = \frac{2*\pi}{\lambda}(n_1 - 1) * t \quad (2)$$

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Although there are eight steps in the lens, only a $\frac{7}{8}\pi$ phase shift is desired – going to a full 2π phase shift would cause the light to be in-phase at two neighboring sectors, which is undesirable.

Knowing the desired phase change and photoresist indices, the required step heights can be calculated (Table 1).

TABLE I
PHASE SHIFT VS. REQUIRED STEP HEIGHTS

Step	Phase Shift (π)	Step Height (nm)
0	0	0
1	0.25	129.67
2	0.5	259.34
3	0.75	389.01
4	1	518.68
5	1.25	648.36
6	1.5	778.03
7	1.75	907.70

Using some algebra, a truth table, and a dose curve vs. thickness curve (Fig. 2), the theorized doses for the required resist thickness can be calculated.

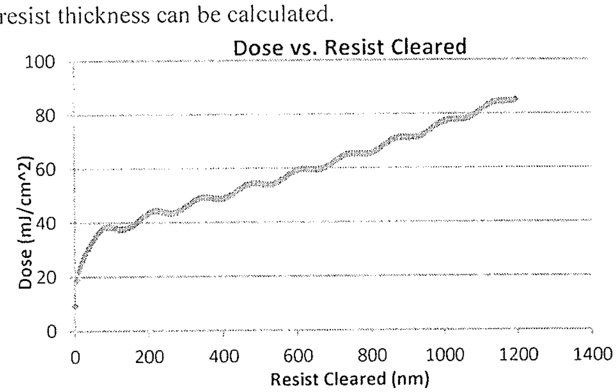

Fig. 2. Dose vs. Photoresist Cleared from ProLith v.11

These exposure doses were derived from data exported from Prolith (physical exposure matrix is still in progress) and were photoresist minimums or maximums from the swing curve; this was an attempt to have the greatest process latitude possible.

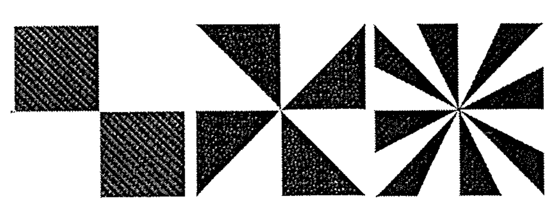

Fig. 3. Vortex Masking Levels: normalized pre-expose = 0.46, first level = 0.30, second level =0.15, third level = 0.07

The first product was a blank wafer; the dose to clear was overshot by a factor of 2.5; examining an actual exposure matrix on fused silica, the actual dose to clear was found and the rest of the doses recalculated. The second attempt was better but only exhibited seven steps instead of the proposed eight. As a result the assumed dose to clear was reduced by 10% and the wafer re-worked (Fig. 4).

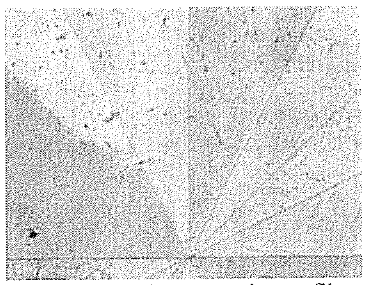

Fig. 4. Vortex Lens: second run - resist profile needs some work.

Because fused silica is clear, the wafer was viewed on top of a cleanroom wipe; many of the apparent defects are from the fibers that comprise the wipe.

The vortex lens was tested in the Chester F. Carlson Center for Imaging Science and initial results are promising. There is still a step missing, but the lens overall performance well (Fig. 5).

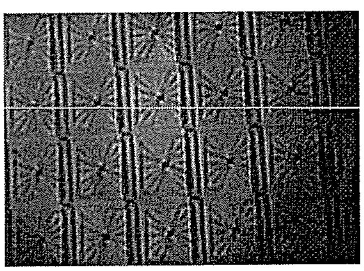

Fig. 5. Vortex Lens Demonstration; exhibits the properties of a vortex lens, but is still missing a step.

In an attempt to remedy the missing 8^{th} step, the resist coater spin speed was reduced and the theorized dose to clear increased back to the original 85 mJ/cm^2.

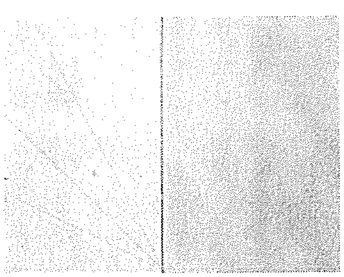

Fig. 6: Vortex Lens: third run – eighth step appears to be present, but is very faint.

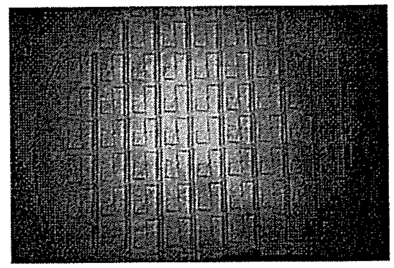

Fig. 7: Vortex Lens Demonstration: the diffraction pattern does not show the eighth step

Even though the micrograph shows the lens as having eight steps, the thickness may be so thin that there it is not doing anything to the light ray. However, the black spot is more uniform in this iteration. Work needs to be done to further optimize the coat and exposure process with the goal of a symmetric center black hole.

II. Conclusion

A working vortex lens was demonstrated at designed wavelength. Through the use of exposure matrices as well as swing curves, the required does for each lens step height was calculated. The resist was exposed four times before being developed to produce the eight photoresist steps. Initial results look good however more work needs to be done measuring resist thicknesses and optimizing the process for lens fabrication.

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References

[1] Swartzlander, Grover. "The Optical Vortex Lens". *Optics & Photonics News*, pp.37-41, November 2006.
[2] Suzuki, Kazuaki, and Bruce Smith. Microlithography Systems. New York: CRC Press, 2007