Higher-Efficiency Microlenses for Zone-Plate-Array Lithography

By

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Abstract

To date, Zone-plate-array lithography (ZPAL), has employed an array of binary-pi-phase zone plates, each 135μm in diameter, operating at 405 nm wavelength, in conjunction with a spatial-light modulator and a moving stage, to expose large-area patterns in photoresist without a mask[1]. Although the high background (~70%) of such zone plates can be mitigated via proximity-effect correction (PEC), lowering the background would enable higher quality patterning (e.g., lower k1 values). To that end, we've designed flat, diffractive-optical "metalenses." Each is first divided into Fresnel zones, across which the effective index-of-refraction is modulated by forming appropriate pillars or holes such that diffracted beams interfere constructively at the focal spot, located 100 μm in front of the lens plane.

The diffraction efficiency of each zone is evaluated using Rigorous-Coupled-Wave Analysis (RCWA)[2]. A genetic algorithm is then used to determine if higher efficiency can be achieved by repositioning of the pillars or their widths. MEEP software[3] is used to predict focal efficiency of the complete metalens. Scanning-electron-beam lithography was used to fabricate effective-index-modulated metalenses in CSAR-62 e-beam resist. Focal efficiencies up to 54% were achieved, a significant increase over zone plates. However, problems with stability and dimensional control led us to use reactive-ion etching rather than direct exposure. In a dielectric of 1.9 index, the maximum height-to-width ratios is about 10-to-1. Theoretical models and experimental results indicate that extreme precision in fabrication, on the order of 10 nm, well below the 213 nm wavelength within the dielectric, is needed to achieve theoretical expectations.

Figure 1 shows hole-based effective-index modulation of a microlens. Figure 2 illustrates the small adjustments in pillar size and location that can yield a 14% increase in simulated diffraction efficiency.

References:

[1] H. I. Smith, R. Menon, A. Patel, D. Chao, M. Walsh, G. Barbastathis, "Zone-plate-array lithography: a low-cost complement or competitor to scanning-electron-beam lithography,"Microelectronic Engineering, **vol 83**, pp.956-961 (2006).

[2] G solver: https://www.gsolver.com.

[3] Meep, a free and open-source software package for electromagnetic simulation via the finite-difference time-domain (FDTD) method. https://meep.readthedocs.io.

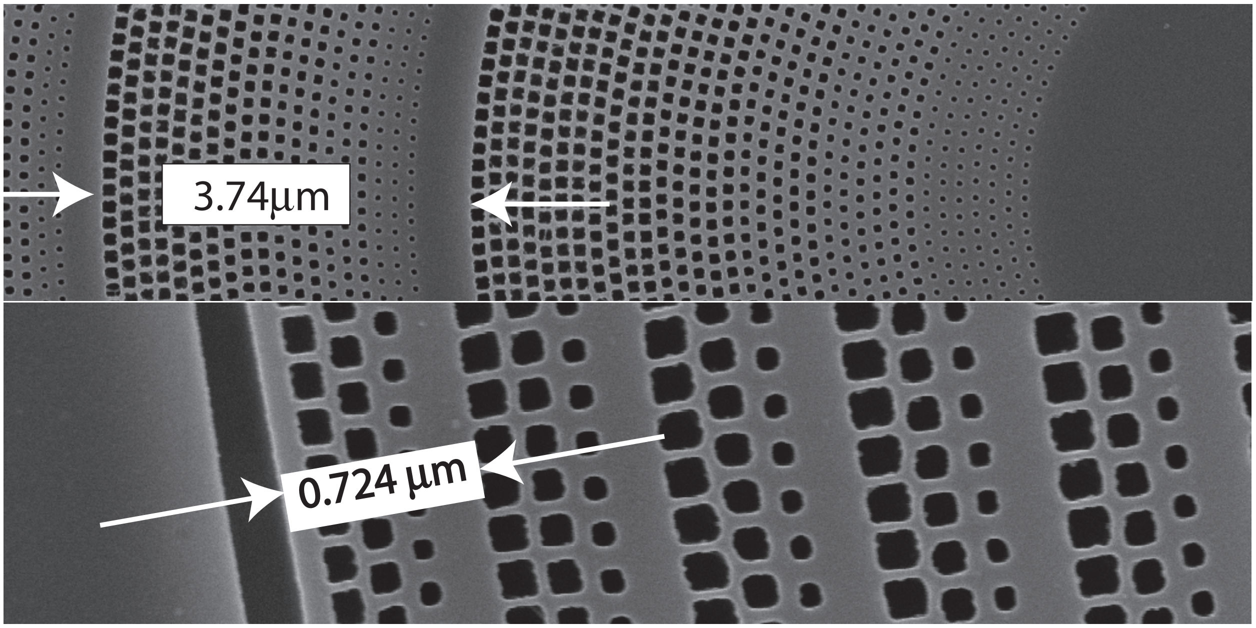

Figure 1: *Scanning-electron micrograph illustrating hole-based effective-index modulation:* ***(upper)*** *the central zone (9 µm radius) and the next zone (3.74 µm width).* ***(lower)*** *outer 5 zones. The electron beam resist (CSAR-62) with a refractive index of 1.59 was itself used as the dielectric. A maximum focal efficiency of 54% was measured..*

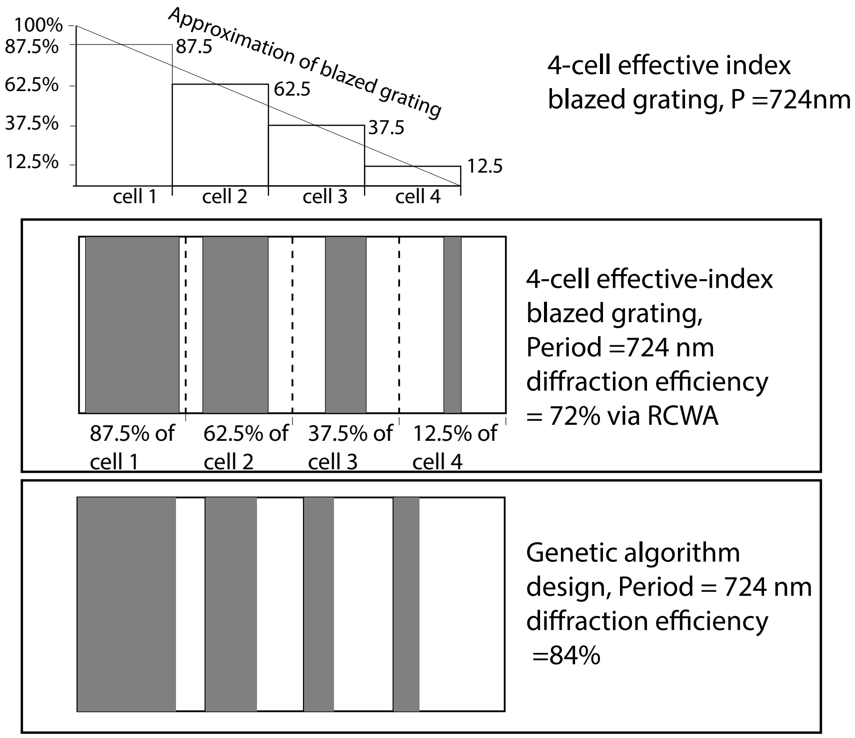

Figure 2: ***(upper and middle)*** *Schematics approximating a linearly varying refractive index (i.e., a blazed grating) by effective-index modulation across 4 sub-wavelength cells.* ***(lower)*** *A genetic algorithm maximizes diffraction efficiency by making small adjustments to the widths and locations of the pillars that the effective-index model specified, illustrating the necessity of precision control of dimensions and lateral position to achieve maximum efficiency and lowest background.*