Low Contrast Dielectric Metasurface Optics

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Abstract: We demonstrate low contrast dielectric metasurface optical elements for operation at visible frequencies. Our devices show transmission efficiencies as high as 90% and focal spots on the order of the design wavelength.

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Metasurfaces, two-dimensional quasiperiodic arrays of sub-wavelength structures present a novel method for both miniaturizing traditional optical elements and also designing arbitrary spatial phase profiles. Rather than relying on gradual phase accumulation along an optical path, each structure imparts an abrupt phase upon incident light. Significant advancements have been realized in metasurface optics using silicon based and metallic nanostructures [1,2], leveraging their high dielectric constants. However, these materials are lossy at visible frequencies, limiting their achievable efficiencies.

Materials with low dielectric constants, such as silicon dioxide and silicon nitride have wide bandgaps and therefore do not have a material based limit on their achievable efficiency at the visible frequencies. Despite the rapidly increasing interest in metasurface optics, little work has been done with these low contrast materials. In our work, we have demonstrated both silicon nitride based metasurface lenses and vortex beam generators designed for operation in the visible frequency range. We report that our lenses achieve focal spots with a full width half max (FWHM) as small as 1 µm and a numerical aperture as high as 0.75 for our 50 µm focal length lens (Figure 2a). Transmission efficiencies as high as 90% and focusing efficiencies as high as 40% were measured for our 0.5 mm and 1 mm focal length lenses (Figure 2b). In addition, we demonstrate vortex beam generators with transmission efficiencies of near 80% and focusing efficiencies of 10%.

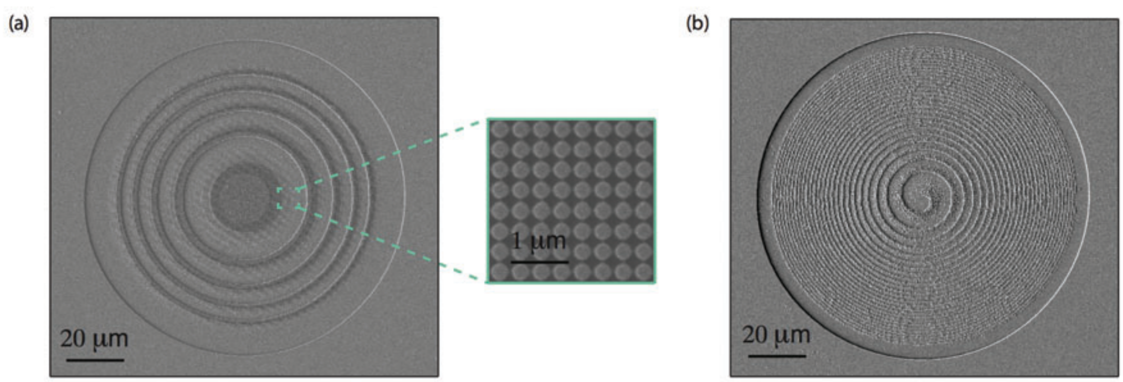

Figure 1: Scanning electron micrographs of a (a) metasurface lens designed with a focal length of 0.5 mm, and a (b) vortex beam generator designed to generate a $\ell = 1$ Laguerre-Gaussian beam.

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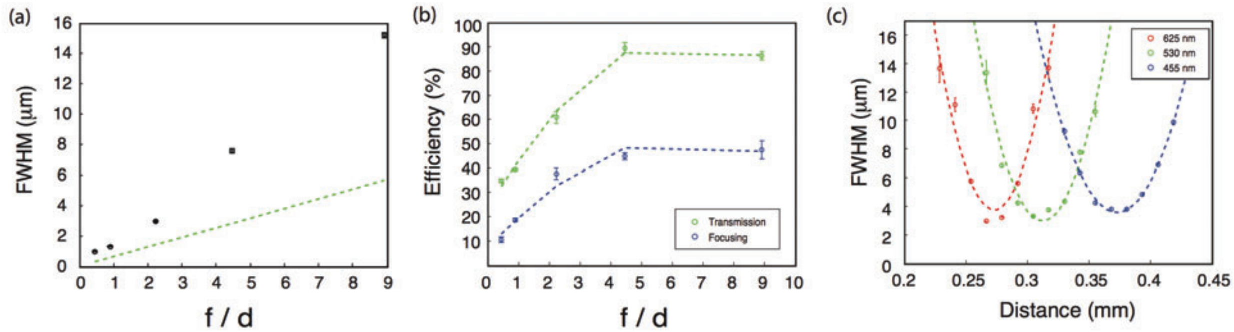

Figure 2: Metasurface optical element performance. (a) FWHM of lens focal spots for five fabricated lenses. The green line is the full width half max of a diffraction limited focal spot. (b) Measured transmission (green) and focusing (blue) efficiencies for the lenses. (c) Chromatic behavior of a lens designed for a focal length of 250 μm.

Lastly, we investigated the chromatic performance of the metasurface lens. The focal length strongly depends upon the frequency of the light, while the focal spot size is weakly affected by illumination by different wavelengths (Figure 2c).

In conclusion, we have demonstrated high performance low contrast dielectric metasurface optical elements for operation at visible wavelengths. We believe this work will enable the extension of metasurface optics into different low contrast materials such as transparent polymers, and transparent conducting oxides. These materials offer low cost scalable production, and avenues to explore tunability of individual elements using their stronger electro-optic properties or free carrier dispersion.

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