A Metasurface-based Scalar Vortex Phase Mask Design

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The technique best suited for direct imaging of exoplanets is high contrast direct imaging using a coronagraph. In particular, the vortex coronagraph has proven to be one of the most promising approaches for imaging Earth-like planets with future space-based optical/infrared telescopes. However, differential polarization aberrations become difficult to control at the high contrasts required for this goal, requiring careful wavefront control in both polarizations independently. While the well-established vector vortex coronagraph is polarization-sensitive, a polarization-independent (scalar) vortex coronagraph circumvents this issue since it imprints the same phase ramp regardless of polarization [1]. Metasurfaces provide a promising approach for implementing a scalar vortex with relatively simple microfabrication techniques. The freedom introduced by different design topologies makes them a prime candidate for achieving achromatic performance.

We present a metasurface framework capable of implementing the helical phase ramp of a scalar vortex phase mask across a large bandwidth. We start by creating a library of square metasurface building blocks (nanoposts) of different size and height and simulate their phase and transmission response to an incident plane wave using rigorous coupled-wave analysis [2] (Fig. 1). We then choose an optimal set of nanopost sizes providing broadband 2π phase coverage at a given nanopost height and arrange them in a design providing a helical phase ramp (Fig. 2). We finally propagate the phase and transmission provided by the mask through a wavefront propagation software [3] and obtain contrast curves at several wavelengths (Fig. 3). We note that the results presented here are optimized for the astronomical L band (3.4-4.2μm), but can be generalized to other wavelength ranges due to the scale invariance of the problem.

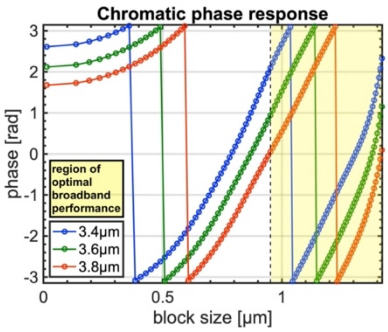

Fig. 1 Nanopost phase response

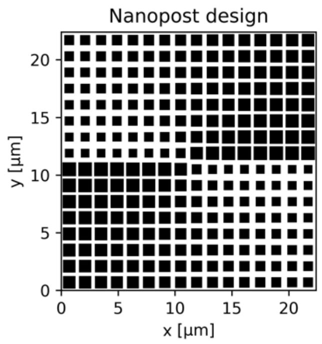

Fig. 2 Nanopost design of a scalar vortex

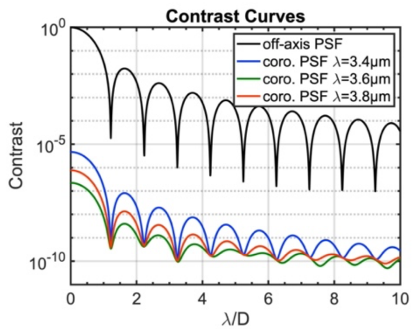

Fig. 3 Contrast Curves for several wavelengths

We conclude that the proposed metasurface framework is well suited to achromatize scalar vortex phase masks and that our design can be implemented using standard microfabrication techniques. We are currently testing a method based on diamond etching, which was used in the past to manufacture achromatic vector vortex phase masks for the L-band [4]. In this context, we find that a deviation of the nanopost size of up to 10% from the design value still provides contrasts below 10^{-3}. We also note that a height gradient due to the microloading effect in dry etching [5] could be at least partly compensated for by increasing the range of nanopost sizes in the optimization.

References

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