Hybrid Lens with Near Unitary Numerical Aperture in Transmissive Mode

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Lenses with large numerical apertures (NAs) are important for manipulation of electromagnetic waves, with widespread applications for focusing, imaging, and highly directive antennas. Planar and light-weight implementation of such lenses is of critical importance for many applications. Although recent advances in metasurfaces have shown opportunities for planarization and a high degree of phase control, the resulting efficiency drops as the refraction/reflection angle increases (V. S. Asadchy, et al., Phys. Rev. B, 94, 7, 075142). Metagratings can address these challenges in the large-angle limit (Y. Ra ' di, et al., Phys. Rev. Lett. 119, 6, 067404). Hence, the hybrid combination of metasurfaces and metagratings forms an ideal platform to realize a large NA lens. A few lenses have been proposed using this hybrid approach in a reflective mode (M. Kang et al. Phys. Rev. Applied 13, 4, 044016) and in a transmissive mode (Paniagua-Dominguez, R., et al. Nano Lett, 18, 3, 2124).

Here, we further extend this approach, studying the design and implementation of a transmissive hybrid metalens with near unitary NA and a focal length of one wavelength. In our design, the central region consists of a gradient metasurface, while the edges consist of metagrating cells that improve the aperture efficiency of the lens. In both regions, the hybrid lens consists of three stacked layers, each with metallic wires loaded with lumped capacitances and inductors to ensure impedance matching to free-space radiation. The designed metalens operates at 20 GHz.

Based on our full-wave simulations, we expect our design of hybrid lens to support 1.5-times focal intensity, twice focusing efficiency, and a similar size of the focal spot in comparison with a reference lens built with conventional approaches of the same NA and focal distance. We also explore the application of this large-NA lens as a highly directive antenna. A cylindrical-wave source is placed at the focal spot of the lens, and we evaluate the directivity. The hybrid lens enhances the directivity by 1.7 times compared to a lens made of only gradient metasurfaces. We envision opportunities to extend this approach to different frequency ranges and a wide range of applications.