Metasurface: Multi-Element Optical System Design

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***Abstract*—Metasurfaces that control the amplitude, phase and polarization of light are two-dimensional ultra-thin optical components consisting of nanoscatterers. In this paper, we demonstrate a triplet zoom system by using three different planar lenses (metalenses) working at 600 nm. The movement of metalenses provide three f# values: 1, 1.25, 1.5 and three focal length values: 20, 25, 30 μm, while total thickness does not change. Our design of triplet zoom system shows that zoom systems could be realized with metasurface applications.**

I. Introduction

With the further downsizing of electronic and optical systems as a result of widespread usage of smaller components, the prominence of metasurfaces is increasing [1]–[3]. In contrast to conventional optical materials, metamaterials are getting cheaper and more efficient for modern optical systems. Metalenses can also fabricated without using complex methods. Metasurfaces have better focal power than traditional glass lenses; they are thinner and lighter therefore they could be used in microscopes, cameras, and displays in place of traditional lenses in the future. The ability to work on different spectra such as visible and infrared is the one of the most important advantages of using metasurfaces. In traditional optics, zoom lens systems are formed via varying the focal length by changing distances between lenses. Today there are many execution areas of using zoom lens systems, which are heavy and take up space. Therefore, as the use of metalenses increases, they are expected to manifest throughout these areas. This work shows that metalens applications could be used in such systems. The design is operated at 600 nm wavelength with focal lengths of 20 μm, 25 μm, 30 μm and numerical aperture values of 0.5, 0.4, 0.33.

II. Methodology

A. Design Approach and Material Parameters

Optical metasurface is an optical element that acts as a phase shifter and is formed by the arrangement of nanoparticles on a flat surface. The wavelength is shifted to the incoming wave to focus the light by periodically aligning the nanoparticles. In other words, an ultra thin lenses can be made by using this technique. The design is made through phase shift. Phase profile of the wavefront as a function of position x along the metasurface is given by [4] :

$$\phi(x) = \frac{2\pi}{\lambda}\left(f - \sqrt{x^2 + f^2}\right) \quad (1)$$

Where f is focal length and λ is wavelength. The phase profile of each metasurface is executed by arranging the diameter of nanopillars. Other parameters of nanopillars such as height and period are optimized to obtain high efficiency. The height of the nanopillars should be constant (600 nm) to obtain 2π phase coverage through a range of diameters. In our optimized design of single metalens, the diameters of nanopillars are varied between 100 nm and 220 nm. The size of each nanopillar is changed by phase shift. The smallest achievable diameter is limited by fabrication constraints, while the largest diameter is equal to unit cell size. Unit cell size must satisfy the Nyquist sampling criterion ($U < \frac{\lambda}{2NA}$) [5].

In general, metalenses have been designed by building TiO_2 (n=2.60 at 600 nm) blocks on a single side of the glass substrate (n=1.46 at 600 nm) [5]. In our design, we initially tested a single-sided metalens with TiO_2 nanopillars on glass substrate, however effective beam focus could not be achieved. Therefore, in this design, the materials of the substrate and the nanopillars are interchanged. For increasing the light transmittance, the nanopillars were aligned symmetrically to both sides of metalenses and it was shown that transmission efficiency was increased.

B. Triplet Design

While designing the triplet lens, to make a comparison with a conventional design, we used commercial optical design software (Zemax OpticStudio, Zemax LLC) for optimizing the paraxial design. In this design, we optimized the triplet design which has three different focal lengths by using paraxial lenses. The design is optimized just for calculating the thick-

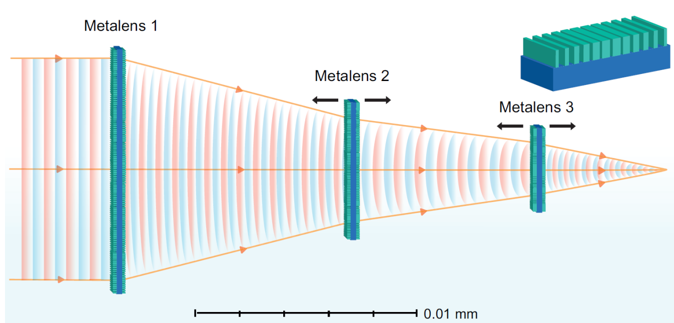

Fig. 1: The schematic view of triplet zoom system and (inset) general view of metalens surface.

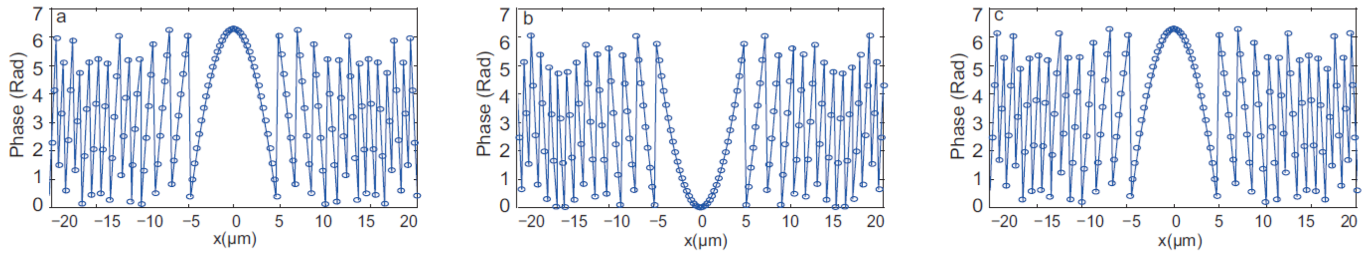

Fig. 2: Phase maps for (a) Metalens 1, (b) Metalens 2 and (c) Metalens 3; focal lengths are 19.742 μm, -20.256 μm and 19.802 μm, respectively.

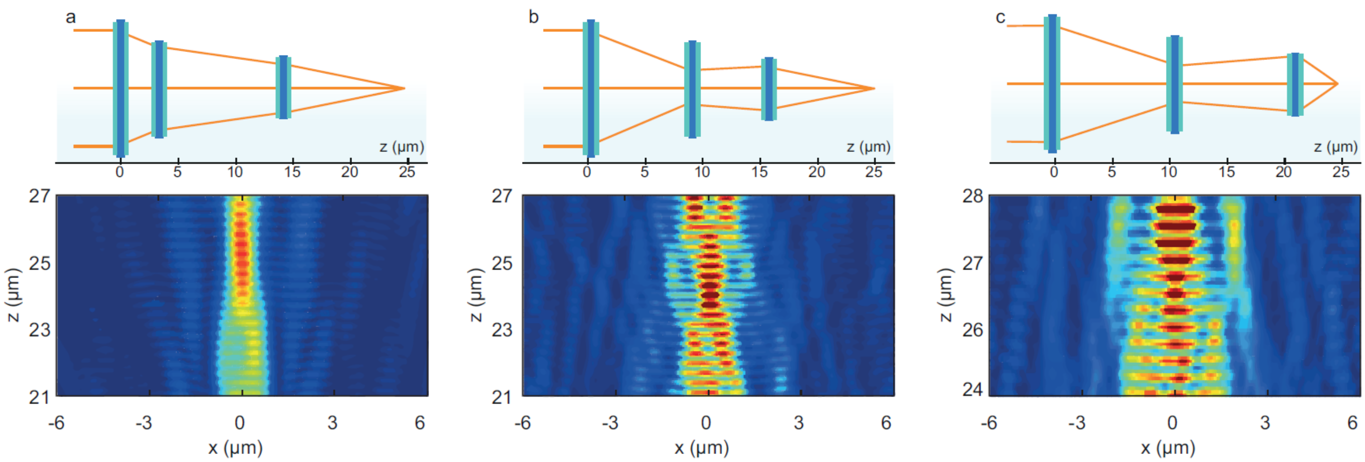

Fig. 3: The position of the metalenses for each focal length and corresponding intensity profile simulations for (a) 20 μm, (b) 25 μm and (c) 30 μm in the focal region.

ness of air gaps and the focal lengths of the flat lenses. The triplet design includes three different focal lengths of 20 μm, 25 μm and 30 μm at wavelength of 600 nm. The movement of Metalens 2 and Metalens 3, shown in Fig. 1, provide different focal lengths.

After optimization of the paraxial zoom lens, we calculated phase shifts of every individual metalens from focal length data and used the required air thickness data from Zemax design. After total phase shift $\phi(x)$ is found, it is divided by zones through 2π and the multiples of 2π and each zone is combined so that it is not more than 2π. Phase shift plot for each meta-lens is shown on Fig. 2. The required diameters of nanopillars are easily calculated to satisfy required phase shifts of each individual metasurface. Three different metasurface doublet lenses were designed in this manner.

After all configurations of the zoom system are designed in FDTD tools [Lumerical Solutions, Inc. http://www.lumerical.com/tcad-products/fdtd/], we measured the focusing efficiency of the system. Fig. 3 shows the intensity distribution of the metalens zoom system in the focal region. The ratio of the power at focused spot to the incident optical power gives the efficiency. Efficiencies of each configuration as high as 61.2%, 53.1% and 69.8% are achieved, respectively; with focal spot sizes of < 2 μm are measured, which is well beyond the requirements of modern detectors used in imaging systems.

III. Conclusion

A metalens structure is proposed to obtain a zoom system. The proposed structure includes three different metalenses and the zoom system is formed by varying the distance between metalens, with nanopillars symmetrically placed on both sides of the metalens. The design was initially optimized with Zemax and analyses were conducted using FDTD.

Acknowledgment

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