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Near-IR Wide Field-of-View Huygens Metalens for outdoor imaging applications

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Abstract: We present a Huygens nano-antenna based metalens, designed for outdoor photographic applications in the near-infrared. We show that good imaging quality can be obtained over a moderate ±15˚ field-of-view (FOV).
OCIS codes: 310.6628, 090.1970

1. Design

The topic of metasurfaces in general, and in particular the topic of metalenses, is an ongoing and flourishing area of research [1–4]. The main aspirations for metalenses are miniaturization and economical mass production of optical systems by replacement of conventional lenses with metalenses. In recent years, variety of metalenses have been demonstrated. However, almost all of them were designed for on-axis only operation. The few that were designed for a wide FOV [5] had a short focal length, preventing them from being directly coupled to a camera for outdoor imaging applications. Hereby we present the first Huygens-antenna based metalens capable of outdoor imaging.

The optical design of our metalens was performed using commercial optical design software (Zemax OpticStudio, Zemax LLC). The design concept is based on an aperture stop located at the front focal plane of the lens, which results in a telecentric design (chief ray exits parallel to optical axis), with good off-axis aberration correction [5,6]. The layout of the optical system is shown in fig.1(a). The metalens substrate is 1mm thick glass. The front aperture is 1.35mm in diameter, and the focal length of the metalens is 3.36mm (F/2.5). The design supports field angles of up to 40˚, with near diffraction limited performance, using a parabolic phase function. The modulation transfer function (MTF) of the nominal metalens design for monochromatic illumination at 850nm is shown in fig.1(b).

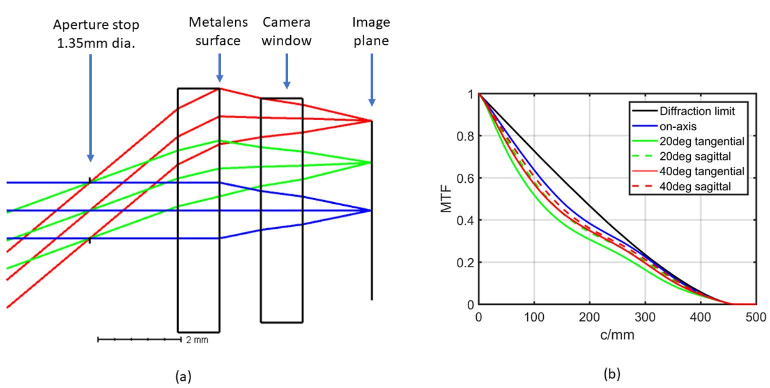

Fig. 1. (a) Metalens optical layout. (b) Nominal MTF for monochromatic 850nm illumination.

To implement the phase shifts required for the diffractive phase function we used Huygens nano-antennas. The advantage of Huygens-type nano-antennas over truncated-waveguide [2] and geometrical-phase [3-4] type nano-antennas is the low aspect-ratio (height to diameter/width) of the nano-antennas, which makes it easier to fabricate. This comes at the expense of higher sensitivity to wavelength and incidence angles. In this paper we explore what performance can be achieved by a Huygens metalens in the optical region, over different wavelength ranges and fields-of-view, and demonstrate the usefulness of our metalens for outdoor imaging applications.

The nano-antenna simulation was performed using commercial 3D FDTD software (Lumerical FDTD Solutions). The antennas are made of amorphous silicon on a glass substrate, covered with a thin layer of PMMA (~300nm thick). A hexagonal lattice with a period of 500nm, and antenna height of 140nm was used. The simulated transmission and phase response are shown in fig. 2. Eight discrete antenna radii were chosen, spanning a range of 100-164nm, such that the phase shifts are equally spaced over the 2π range.

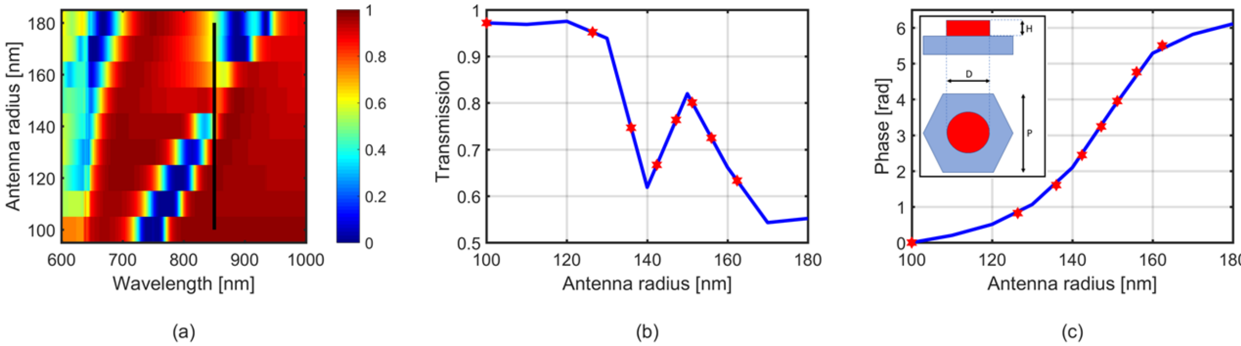

Fig. 2. Response of Huygens aSi antenna array on glass. (a) Transmission as a function of wavelength and antenna radius. Black vertical line is the section along which graphs b and c are drawn. (b, c) Transmission and phase at 850nm as a function of antenna radius, respectively. Red markers represent the 8 antenna radii that were actually used for the implementation of our metalens. Inset: Nano-antenna unit cell design. P=500nm, H=140nm, D is in the range of 200-328nm.

2. Results

Measured vs. simulated Modulation Transfer Function (MTF) results are shown in fig. 3 (a-f). To the best of our knowledge this is the first time metalens (or conventional diffractive lens) MTF has been measured a over broad spectral range. The MTF performance are affected most by axial and lateral chromatic aberration, and vignetting effects. The spectral weights used in our simulation are based on the measured spectrum of the light source used in our test setup with the different spectral filters, and spectral responsivity of the camera. In fig. 3(g) an outdoor photo of our Israeli research group, captured with our metalens is shown. The metalens was coupled to a Thorlabs DCC1545M monochrome camera, with a 10nm wide band-pass filter incorporated in front of the metalens.

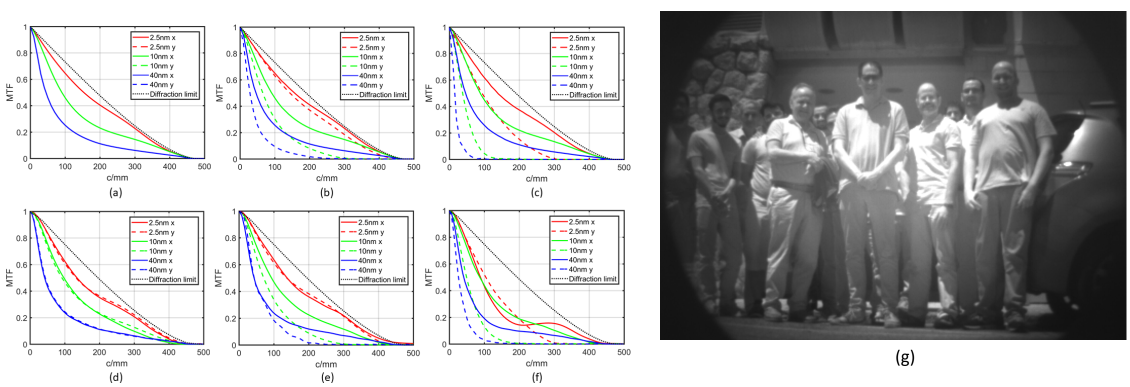

Fig. 3. Polychromatic MTF measured vs. simulated results. (a), (b) and (c) are simulated results for on-axis, 0.4mm off-axis, and 0.8mm off-axis (in the image plane), respectively. (d), (e), and (f) are the corresponding measured results. The y- axis is the tangential direction. (g) Outdoor image of some members of the nano-photonics group at Hebrew University

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