Metasurfaces for High Numerical Aperture Optical Signal Processing

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Abstract: Metasurfaces constructed of subwavelength periodic arrays of metal particles have been shown to possess asymmetric optical transfer function with a relatively high numerical aperture of ~0.5 enabling phase imaging of diverse transparent objects.

Conventional phase imaging performed using traditional optical systems for spatial filtering or interferometry typically requires expensive and bulky components. Motivated by the miniaturization of electronic devices and the widespread use of spatial information, there has been an emerging recent interest in the use of compact nanophotonic devices for real-time phase imaging [1,2]. One challenge faced by meta-optics in this application has been the relatively low numerical aperture which limits the range of spatial frequencies that can be accessed by the device. This results in limiting the object details that can be seen and the introduction of various artefacts.

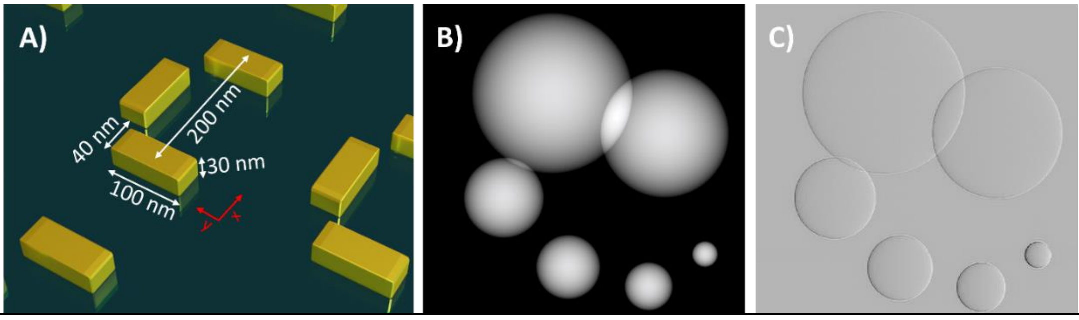

Fig.1: a) Visualization of the Wheatstone bridge periodic structure. The periodicity of the device is 400 nm in the x-axis and 300 nm in the y-axis. b) Phase object, with a maximum phase excursion of 2 π (Image size is 800 μm×800 μm). c) Pseudo-3D phase visualization when the optical transfer function of the Wheatstone bridge device is applied to the pure phase object. Incident light is polarized at 45°with respect to the x-axis indicated in a), while output analyzer is polarized parallel to the y-axis.

In this presentation we demonstrate phase imaging using an array of nanoparticles that under appropriate polarization has been theoretically [3] shown to exhibit a numerical aperture up to approximately 0.5. The device consists of a (subwavelength) periodic array with the unit cell formed by three identical 100 nm × 40 nm × 30 nm gold nanorods placed in a configuration that has been referred to as a “Wheatstone Bridge” in analogy with the electrical circuit (Fig. 1a). optical response of this device, calculated via the modal matching technique [4], shows that an asymmetric transfer function can be seen when incident light is polarized at 45° or 135° with respect to the orientation of the nanoparticles and that this produces a pseudo-3D intensity image (Fig. 1c) of a pure phase object (Fig. 1b) when observed through an output analyser polarized in the y-direction. This device can be used to image transparent cells, eliminating the need for bulky conventional phase imaging systems or time-consuming computational strategies.

[1] L. Wesemann, J. Rickett, J. Song, J. Lou, E. Hinde, T.J. Davis, and A. Roberts, *Light Sci Appl* **10**, 98 (2021)

[2] T. Zhu, J. Huang, Z. Ruan, *Advanced Photonics*, **2(1)**, 016001 (2020).

[3] T. J. Davis, F. Eftekhari, D. E. Gomez, and A. Roberts, *Phys. Rev. Lett.* **123**, 013901 (2019).

[4] A. Roberts, T. J. Davis, and D. E. Gomez, JOSA B **34**, D95-D100 (2017).