Waveguide-Based Metasurfaces for Light Focusing and Beam Deflection

Siyu Chen [a], Milan M. Milosevic [b], Jianzhi Huang [a], Harold M. H. Chong [a] and Xu Fang [a,*]
[a] *School of Electronics and Computer Science, University of Southampton, Southampton SO17 1BJ, UK*
[b] *Zepler Institute for Photonics and Nanoelectronics, University of Southampton, Southampton SO17 1BJ, UK*
* Corresponding author: x.fang@soton.ac.uk

We numerically demonstrate wavefront manipulation in silicon metasurfaces driven by input light from underlying silicon waveguides. The nanostructures provide the full 2π phase coverage in radiation, enabling functionalities such as light focusing and beam deflection.

Metasurfaces provide a high level of wavefront control within a subwavelength device thickness, bringing novel solutions to applications ranging from tunable imaging lenses to phased array LiDAR. Nevertheless, most existing metasurfaces work under the illumination of plane waves (e.g. our recent work on tunable beam deflectors [1], tunable metalenses [2], and stretchable THz wave converters [3]). This configuration is too bulky for many photonic integrated circuit applications (e.g. integration of metasurfaces with photonic integrated circuits to facilitate novel sensing). To address this challenge, a new design strategy has been proposed and tested recently [4], where the illumination has been changed to guided modes inside the waveguides. In this design strategy, the output light beam remains in free space, offering a plethora of applications such as imaging and beam steering, while the input light beam is confined inside on-chip silicon waveguides.

Utilizing this design strategy, we present a new type of waveguide mode-driven metasurfaces. A key novelty of our work is in its use of all-dielectric metasurfaces, as opposed to metallic ones published in the literature. These all-dielectric metasurfaces use silicon as the constituent material, the same material used for waveguides. This choice of material can simplify device fabrication and speed up the development of integrated metasurfaces.

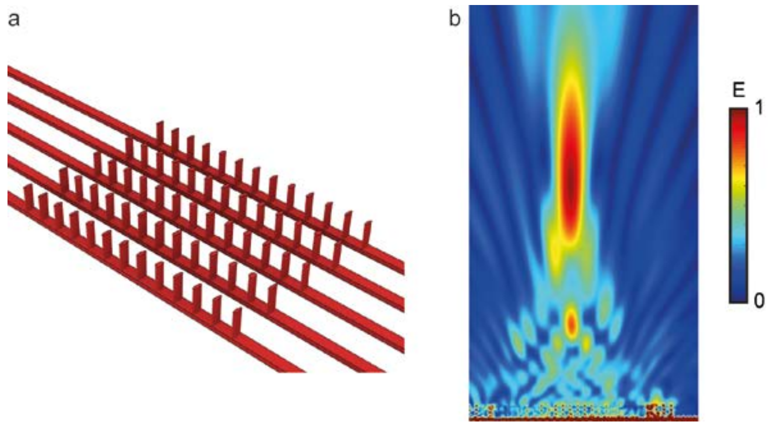

Fig. 1: Device schematic and light focusing. (a) A schematic of silicon metasurface comprising an array of silicon pillars located on top of parallel silicon waveguides. (b) A specific pillar configuration can focus light at a specific spot in the free space. The electric field profile corresponds to an area of 20 μm (width) × 40 μm (height).

Figure 1 shows device schematic and an optical function achieved using such devices: light focusing. The silicon metasurface is a rectangular array of elliptical nano-pillars. The pillars have a uniform height of 1250 nm, while the pillar cross sectional profile is tuned to produce the desired optical phase profile in free-space light scattering. The pillars are excited through a set of parallel, 500 nm wide and 220 nm thick, single-mode silicon waveguides at 1550 nm wavelength. By selecting pillars based on a target phase profile, we can tailor the output wavefront to obtain the light focusing functionality (Fig. 1b). In addition to the light focusing shown here, we have also demonstrated in numerical simulation a new type of beam deflection, in which the output beam deflection angle is independent of propagation direction of the input waveguide mode.

References

[1] F. He, K. F. MacDonald and X. Fang, Opt. Exp. **28**, 30107 (2020).
[2] S. Yin, F. He, W. Kubo, Q. Wang, J. Frame, N. G. Green and X. Fang, Opt. Exp. **28**, 38949 (2020).
[3] J. Liu, X. Fang, F. He, S. Yin, W. Lyu, H. Geng, X. Deng and X. Zheng, Opt. Exp. **29**, 21749 (2021).
[4] X. Guo, Y. Ding, X. Chen, Y. Duan and X. Ni, Sci. Adv. **6**, eabb4142 (2020).