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Wavelength-selective wavefront shaping by metasurface

Key words: Metasurface; Wavelength-selective; Vortex; Wavefront shaping

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Motivation

Precise, wavelength-dependent phase retarding is essential in many fields, such as superresolution imaging, full-color holography, nanomanufacturing, and optical communications. This demand can be achieved by a combination of multiple optical devices but is challenging to implement using a single element. Metasurfaces, comprising surface-patterned nanostructures with subwavelength geometries, have attracted much attention in recent years due to their excellent light modulation capability.

Main idea

1. We employ a combination of wavelength-dependent polarization conversion and geometric phase to design a metasurface-based, wavelength-selective phase modulator that can exhibit unique wavefront responses at different illumination wavelengths.

2. Specifically, we design a metasurface that focuses the beam to an annular ring at 785 nm and a solid spot at 590 nm. For those systems that need to selectively modulate one wavelength wavefront and leave another unaffected, our design can break the inherent efficiency limit since every element simultaneously contributes at both target wavelengths in contrast to the spatial multiplexing approaches. Furthermore, brute-force searching of the unit cell in a large meta-atom library is not required so that the optimization process is less time-consuming.

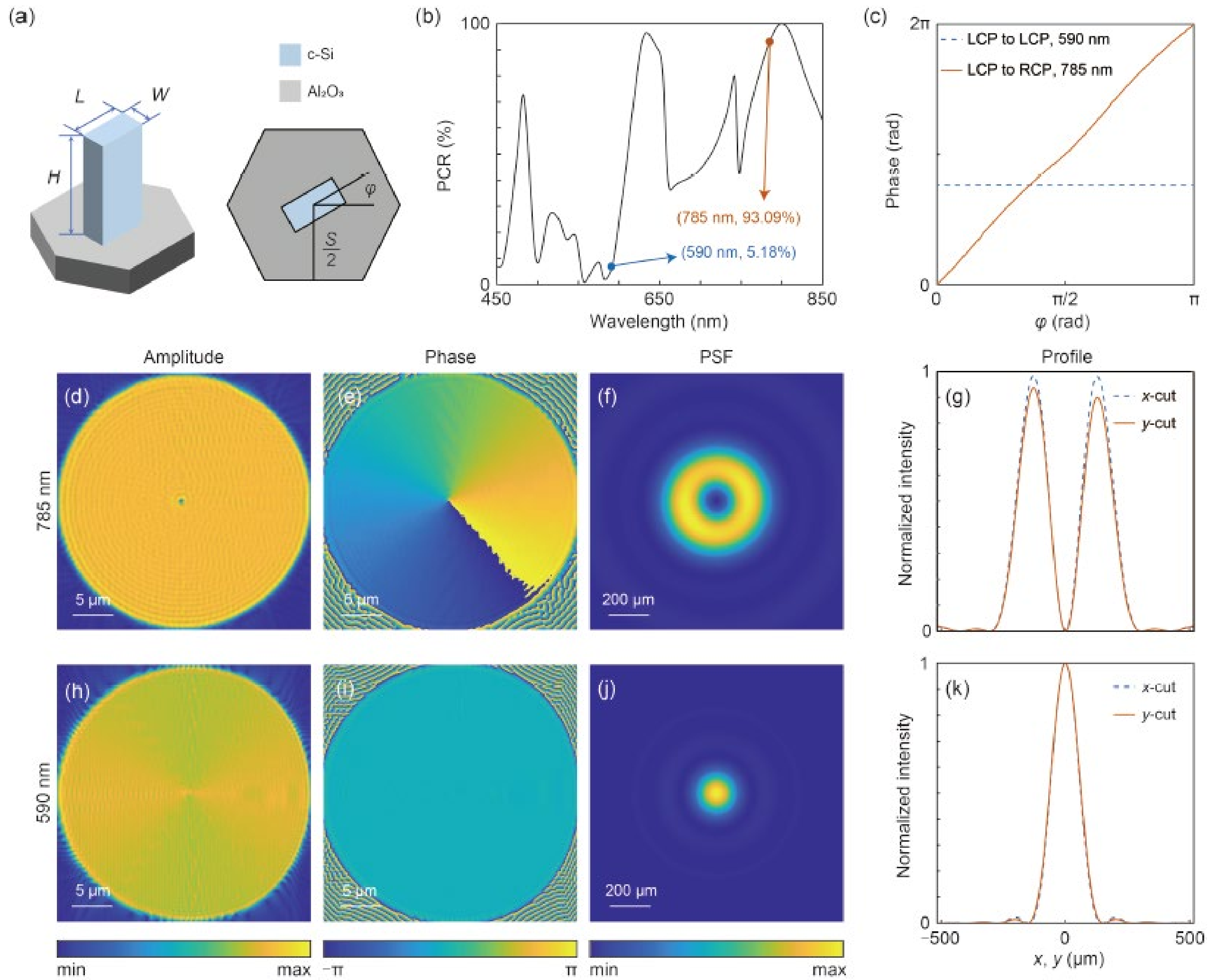
Method

1. Our design consists of c-Si rectangular nanofin. By suitably designing the size, a low polarization conversion rate (PCR) (mainly copolarization part with only propagation phase) at the desired wavelength and a high PCR (mainly cross-polarization part with propagation phase and Pancharatnam–Berry (PB) phase) at another specified wavelength can be obtained. The spiral phase can be achieved by rotating the nanofin to set the PB phase.

2. To physically verify our design, a circular metasurface with a diameter of 500 μm was fabricated on a crystalline silicon-on-sapphire (SOS) wafer. We used a custom-built Mach–Zehnder interferometer to characterize the phase distribution of the metasurface and directly characterize the point spread functions (PSFs) at different wavelengths.

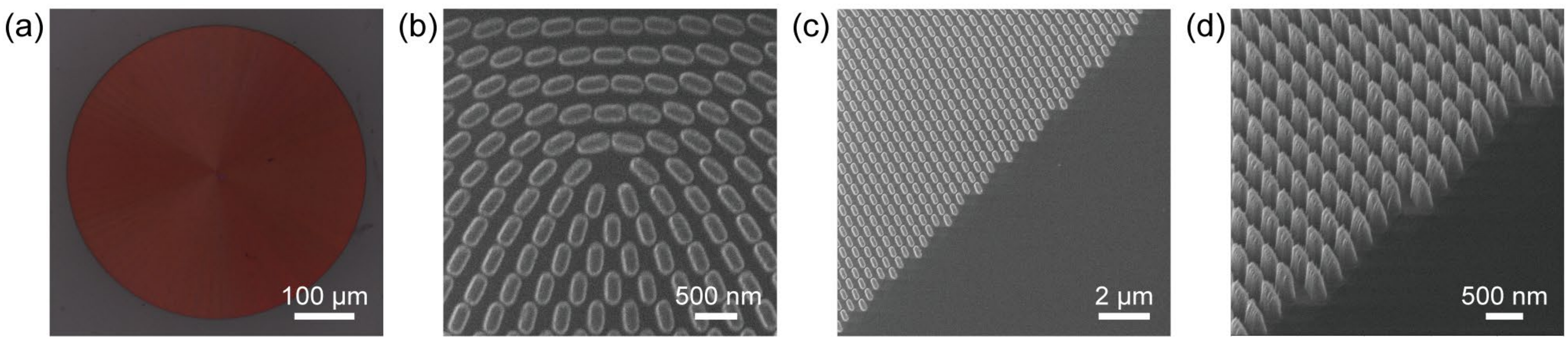
Major results

1. Metasurface design and simulation validation.



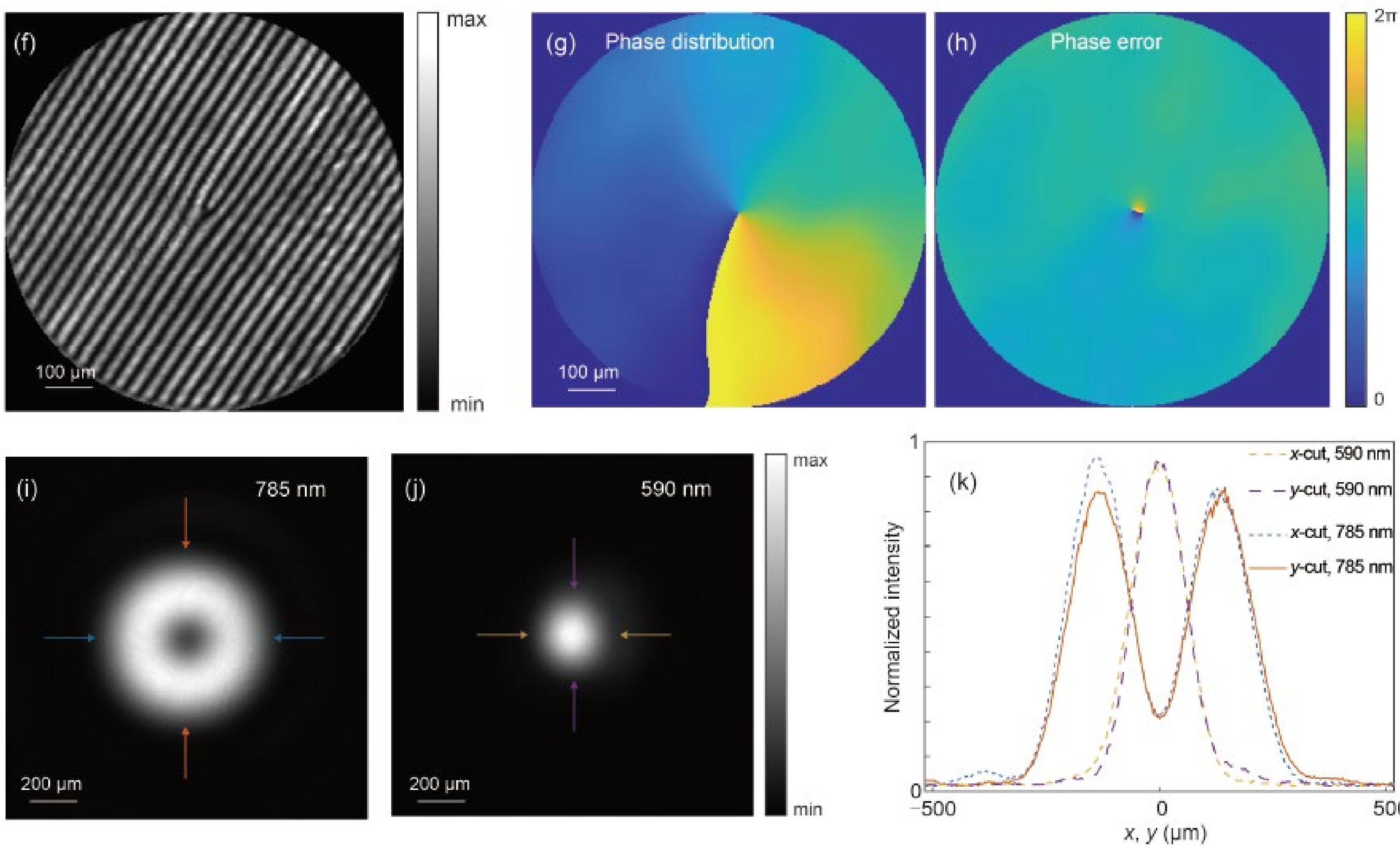
Major results

2. Optical image and scanning electron microscopy (SEM) image of the fabricated metasurface, comprising c-Si nanofins on an Al_2O_3 substrate.



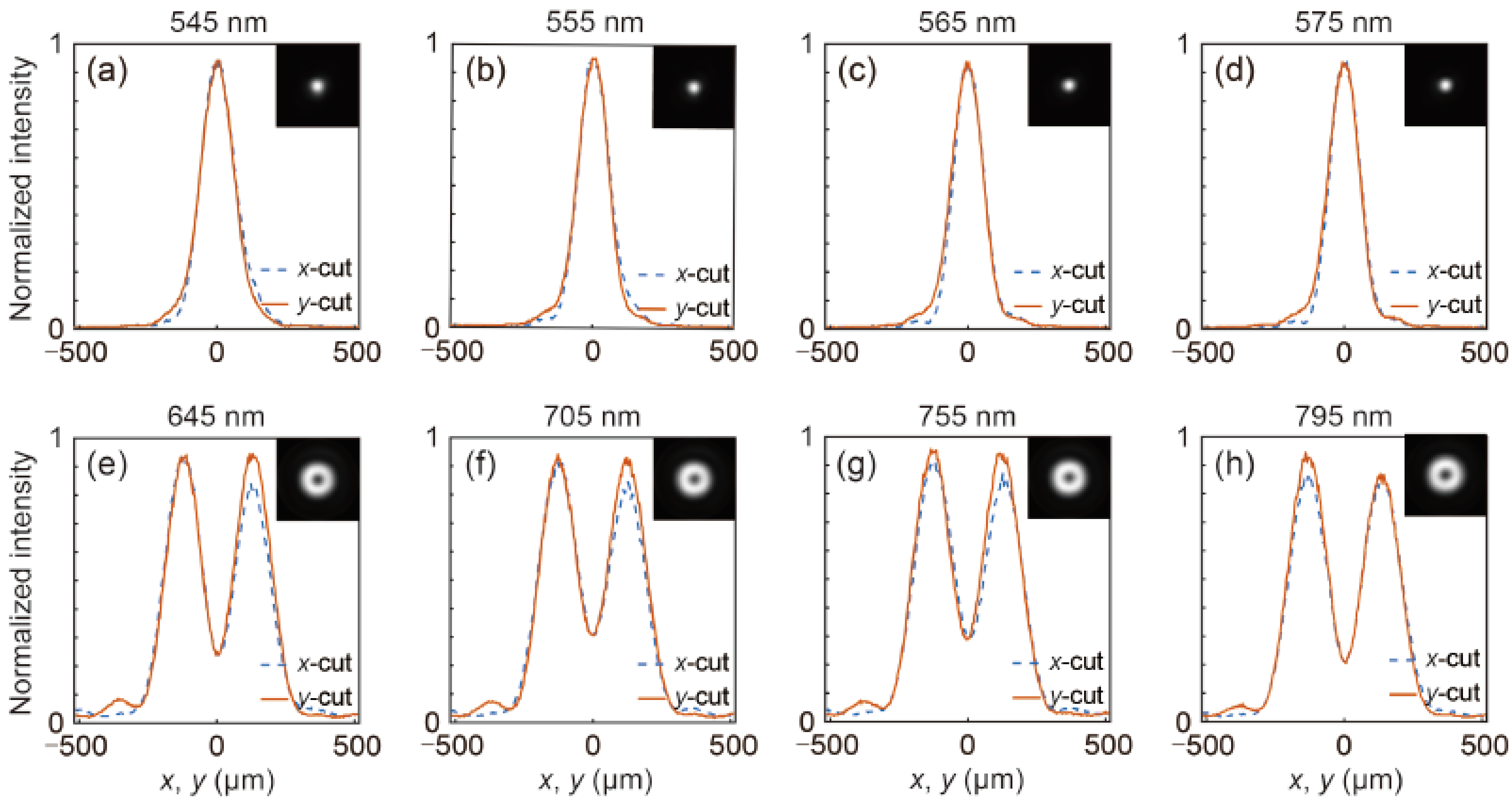
Major results

3. Characterization of the fabricated metasurface, including the interference fringe of the modulated beam and the PSF at different wavelengths.



Major results

4. Measured PSFs and the intensity profile across horizontal and vertical transects at different wavelengths.



Conclusions

1. In summary, we have proposed a wavelength-selective shaping metasurface based on a combination of wavelength-dependent polarization conversion and geometric phase modulation.

2. To verify the theory, we designed and fabricated a metasurface that can modulate an incident beam with a spiral phase at 785 nm and another with a relatively flat phase at 590 nm. The beams can then be focused into either an annular or a solid PSF depending on the wavelength.

3. This scheme can also be expanded to any other combination of wavelengths or multiwavelength configurations.