Printed Flat Optical Component: Metasurface for Cylindrical Vector Beam Generation

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Metasurfaces are optical structures with sub-wavelength textured surfaces, and can be thought of as the two-dimensional equivalent of metamaterials. Recently, dielectric metasurfaces have been considered as promising alternatives to conventional bulky optical components, thanks to their low optical absorption as well as reduced impedance mismatch with the surrounding media. In this work, we present a low-cost, and highly reliable fabrication procedure for dielectric metasurfaces by taking the various advantages of nanoimprint lithography (NIL), such as high-fidelity, high-throughput, and compatibility with various substrates. We demonstrate high-performance dielectric metasurfaces for cylindrical vector beam generation.

The metasurface is made of Poly-Si, which has negligible light absorption at its working wavelength (1.5 µm). The unit cell consists of Si gratings on a fused silica substrate, and the grating has a height of 400 nm, width of 180 nm, and period of 800 nm (figure 1a). With such a design, the Si grating works as an efficient nano-size half wave-plate, where TE and TM light have a similar amplitude, but π phase difference upon transmission (figure 1c and 1d). To achieve a spatially-variant polarization vector of the transmitted beam, the wave-plate's orientation is rotated gradually over the plane (gradient metasurface). Consequently, the device converts a vertically polarized incident light to a radially polarized light, and at the same time, transforms a horizontally polarized incident light to an azimuthally polarized light. Thermal NIL was employed for fabricating the metasurface. The patterns were first created on the resist, and then transferred onto the Poly-Si layer beneath through an anisotropic Si etching. An SEM picture of the fabricated device is shown in figure 1b.

The performance of the printed metasurface is characterized by sending an incident light (either vertically or horizontally polarized) through the device, and analyzing the intensity as well as polarization state of the transmitted light. The metasurface exhibits an averaged transmittance of 86%. A linear polarization analyzer is placed after the metasurface, and it transmission axis is rotated over 180°, with a step size of 10°. At each rotation, the transmitted light intensity and beam profile are recorded (figure 2a and 2b). The intensity of transmitted light through the linear analyzer remains flat with the polarizer's rotation, which is a direct proof of the cylindrical polarization state of the transmitted light. At the same time, the transmitted beam profile evolves with the analyzer rotation angle, which further confirms our observation.

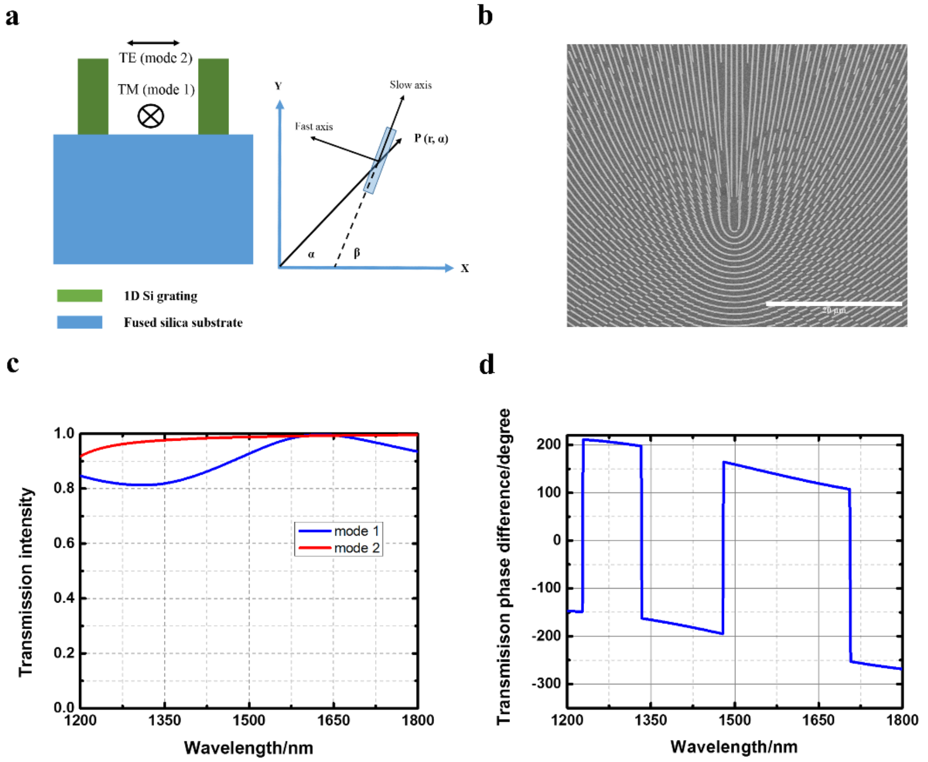

Figure 1: (a) Schematic drawing of the metasurface unit cell, which consists of Si gratings on a fused silica substrate, and the grating has a height of 400 nm, width of 180 nm, and period of 800 nm. The grating's orientation is rotated over the plane to achieve a spatially-variant polarization vector of the transmitted beam; (b) Scanning electron micrograph (SEM) of the fabricated device; (c-d) Simulated transmission intensity (c) and phase different (d) of TE and TM light. The Si grating works as an efficient nano-size half wave-plate, where TE and TM light have a similar amplitude, but π phase difference upon transmission at 1.5 μm.

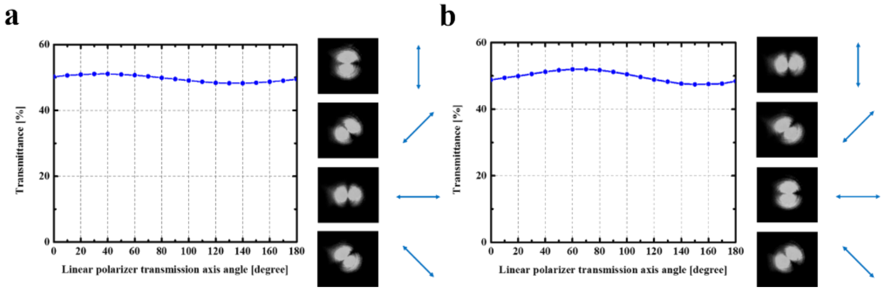

Figure 2: Measured transmission intensity and beam profile through the metasurface with respect to different orientations of the linear polarization analyzer. The incident light is polarized in the vertical direction in (a), and horizontal direction in (b). The intensity of transmitted light through the linear analyzer remains flat with the polarizer's rotation. At the same time, the transmitted beam profile evolves with the analyzer rotation angle. These observations prove the cylindrical polarization state of the transmitted light.