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Supplementary materials for

Zixin CAI, Xin HE, Xin LIU, Shijie TU, Xinjie SUN, Paul BECKETT, Aditya DUBEY, Arnan MITCHELL, Guanghui REN, Xu LIU, Xiang HAO, 2023. Wavelength-selective wavefront shaping by metasurface. *Front Inform Technol Electron Eng*, 24(4):617-625. https://doi.org/10.1631/FITEE.2200510

1 Fabrication of the metasurface

The fabrication of the metasurface was carried out with electron beam lithography (EBL). First, using standard procedure, a 400-nm-thick ZEP 520A resist was spin-coated onto the crystalline silicon (c-Si). Then, the pattern was exposed using Raith Vistec EBPG-5000 PLUS. After exposure, 50-nm-thick Cr was deposited using Kurt J. Lesker PRO Line PVD Series followed by a lift-off process. The pattern was transferred to the Cr mask. Finally, the sample was etched using a reactive ion etch (Oxford PlasmaLab System 100) and the residual Cr layer was removed in solvent.

2 Phase characterization with Mach–Zehnder interferometer

To characterize the spiral phase modulation at 785 nm, we used a purpose-built Mach–Zehnder interferometer as shown in Fig. S1. In this configuration, the laser beam (Pigtailed Laser Diodes, LPS-PM785-FC, 785 nm) was collimated and passed through a linear polarizer (LP1). Subsequently, the linearly polarized beam was divided into two beams using a 50/50 beam splitter (BS1). Both object beam and reference beam passed through quarter-wave plates (QWP1, QWP2) with different rotation angles. After passing the array of silicon nanofins, a vortex beam was generated and overlapped with the reference beam. A 4f lens system (f_1: 100 mm; f_2: 200 mm) was used to magnify the interference fringe to accommodate the pixel size of the camera (CS165MU, Thorlabs), which may otherwise degrade the resolution of the image and affect the phase retrieval of the metasurface. The lens also imaged the sample on the camera and made the fringing pattern clearer, thereby enhancing the precision of phase restoration.

3 Point spread function characterization system

The point spread function (PSF) characterization system is shown in Fig. S2. A white laser beam is collimated and passes through a tunable filter (YSL Photonics' VLF wavelength selection system) to select the illumination wavelength. Two refractive mirrors are set to ensure that the beam is perpendicular and to avoid introducing extra aberrations. LP and QWP are used to generate an elliptically polarized beam in the same way as the elements in the interferometer. After passing through the metasurface, the beam is modulated depending on the incident wavelength. An aperture is set to filter the unmodulated beam outside the bounds of the metasurface, which would otherwise appear as a background level in the PSF, potentially swamping the modulated PSF signal, as shown in Figs. S3b–S3g. The smallest aperture diameter is ~1 mm, which does not match the size of our design (~500 μm). Thus, a 4f lens system (f_1: 50 mm; f_2: 100 mm) is used to magnify the sample. Finally, the modulated beam passes through the camera lens (L3) and is focused on the image sensor. Notably, the L3 should have a long focal length to guarantee that the PSF magnitude is sufficient to be captured by the camera, as determined by the Rayleigh criterion for resolution, $0.61\lambda/\mathrm{NA}$ (where NA is the numerical aperture). Thus, the diameter of the Airy disc is given by

$$d_{\mathrm{Airy}}=0.61\frac{\lambda}{\mathrm{NA}}=1.22\frac{\lambda f}{D}, \quad \text{(S1)}$$

where f and D are the focal length and the diameter of the lens, respectively. Therefore, if the focal length is too short, the size of the focus would be too small and would not be distinguishable by the camera.

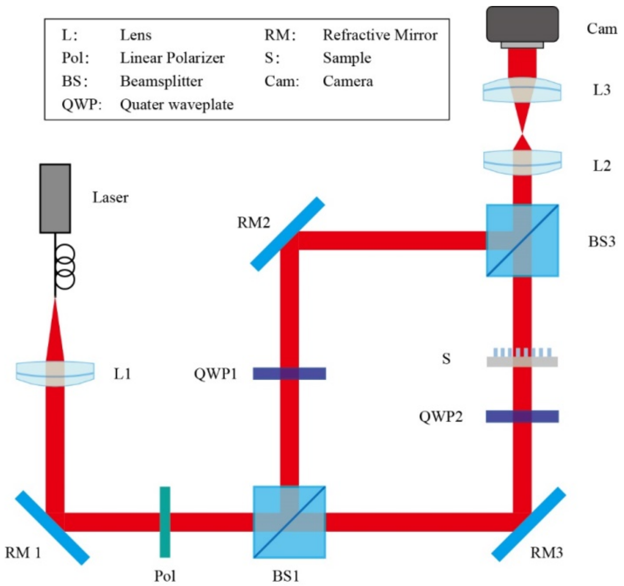

Fig. S1 Scheme of the interferometric setup used to characterize the phase distribution of the modulated beam

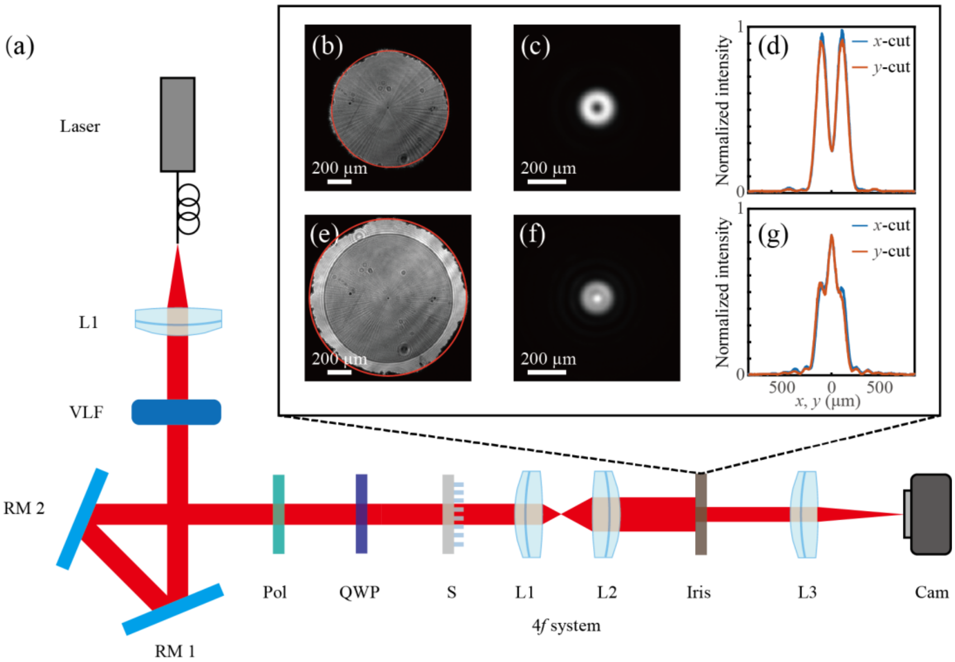

Fig. S2 Scheme of the point spread function characterization system

(a) is the setup of the systems; (b–d) show that when the size of the aperture matches the size of the metasurface, the PSF presents an annual-shaped spot (red line: the size of the aperture); (e–g) show that if the aperture is larger than the area of the metasurface, a bright solid spot will appear at the center of the doughnut-shaped PSF. Inset: the corresponding measured PSF results with different sizes of aperture