

**Supplementary Information for**  
**Broadband spin and angle co-multiplexed waveguide-based**  
**metasurface for six-channel crosstalk-free holographic projection**

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This Supplementary Information includes:

**Part 1.** Translation distance of spatial frequency pattern for oblique light illumination

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## 1. Translation distance of spatial frequency pattern for oblique light illumination

For a far-field-projection metahologram working in the Fraunhofer diffraction region, the light field on the image plane is the Fourier transform of the modulated light field on the metahologram plane. Compared to the modulated light field on the metahologram under normal light illumination  $U_h$ , the modulated light field under oblique light illumination  $U'_h$  has been imparted an in-plane phase gradient and can be expressed as

$$U'_h(x, y) = U_h(x, y)e^{ip_g(x\cos(\theta_x) + y\cos(\theta_y))}, \quad (\text{S1})$$

where  $p_g = nk_0 \sin \alpha$  is the in-plane phase gradient,  $\alpha$  is the angle of incidence of the illumination light with respect to the metahologram's normal direction,  $n$  is the refractive index of the surrounding medium, and  $k_0$  is the free-space wave vector.  $\theta_x$  ( $\theta_y$ ) is the angle made by the direction of in-plane phase gradient and the coordinate axis,  $x$  ( $y$ ), on the metahologram plane. Consequently, the relation between the light fields on the image plane under normal light illumination and oblique light illumination, respectively denoted as  $U_i$  and  $U'_i$ , can be expressed as

$$\begin{aligned} U'_i(f_x, f_y) &= F(U'_h(x, y)) = \iint_{-\infty}^{\infty} U_h(x, y)e^{ip_g(x\cos(\theta_x) + y\cos(\theta_y))}e^{-i2\pi(f_x x + f_y y)}dx dy \\ &= \iint_{-\infty}^{\infty} U_h(x, y)e^{-i2\pi((f_x - p_g \cos(\theta_x)/2\pi)x + (f_y - p_g \cos(\theta_y)/2\pi)y)}dx dy \\ &= U_i(f_x - p_g \cos(\theta_x)/2\pi, f_y - p_g \cos(\theta_y)/2\pi) \\ &= U_i\left(\frac{1}{\lambda_0}\left(\frac{k_x}{k_0} - \frac{p_g}{k_0} \cos(\theta_x)\right), \frac{1}{\lambda_0}\left(\frac{k_y}{k_0} - \frac{p_g}{k_0} \cos(\theta_y)\right)\right), \end{aligned} \quad (\text{S2})$$

where  $p_g \cos(\theta_x)/k_0$  and  $p_g \cos(\theta_y)/k_0$  determine the translation distances in the normalized  $k$ -space along the two perpendicular main axes  $k_x/k_0$  and  $k_y/k_0$ , respectively.

## 2. Structural parameter optimization of the meta-atom

In our design, the meta-atom comprises a poly-Si nanopillar of rectangular cross-section on a SiO<sub>2</sub> substrate to form a square lattice. Meta-atom performs polarization conversion between two spin states of the guided incident light and imparts phase modulation on the converted cross-circularly-polarized light [1-3]. To maximize the cross-polarization conversion efficiency, commercial software Lumerical FDTD Solutions is employed to implement the optimization of the structural parameters (length  $D_1$ , width  $D_2$ , and height  $H$ ) of nanopillar in the meta-atom.

The meta-atoms are designed to have a fixed pitch of 177 nm and the incident light of visible wavelength propagates inside the glass slab waveguide with a total internal reflection (TIR) angle  $\alpha = 55.3^\circ$ . According to the grating equation [4,5], the guided light illuminating on such periodic meta-atom array (which can be considered as a two-dimensional grating consisting of meta-atoms with identical size and orientation angle) cannot be diffracted and out-coupled from the glass slab waveguide. Consequently, the polarization-converted component cannot be directly evaluated. Therefore, we here choose to optimize the meta-atom's structural parameters according to the cross-polarization conversion efficiency of meta-atom under normal light illumination (Fig. S1).

In simulation, the nanopillar is set to have a fixed rotation angle ( $\theta = 0^\circ$ ) while its structural parameters,  $D_1$ ,  $D_2$ , and  $H$ , vary within specific ranges: 90 nm to 160 nm, 20 nm to 90 nm, and 200 nm to 300 nm, respectively, with an interval of 10 nm. Periodic boundary condition is applied along the x and y axes and perfectly matched layer (PML) boundary condition is applied along the z axis. Averaged cross-polarization conversion efficiency across the visible region under study (450 nm - 650 nm) is recorded for different combinations of these structural

parameters (Fig. S2). The maximum averaged efficiency reaches 38% (denoted by a black solid-line square in Fig. S2) and the associated structural parameter combination ( $D_1 = 120$  nm,  $D_2 = 50$  nm,  $H = 280$  nm) is selected for constructing the meta-atom.

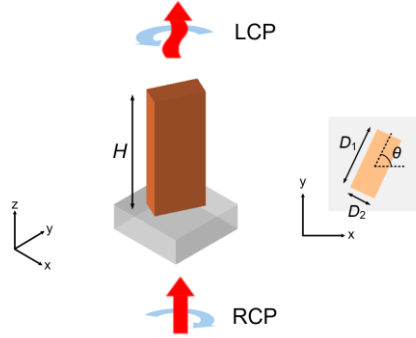


**Figure S1.** Schematic of a meta-atom performing polarization conversion between two spin states for normal light illumination. RCP: right circular polarization. LCP: left circular polarization.

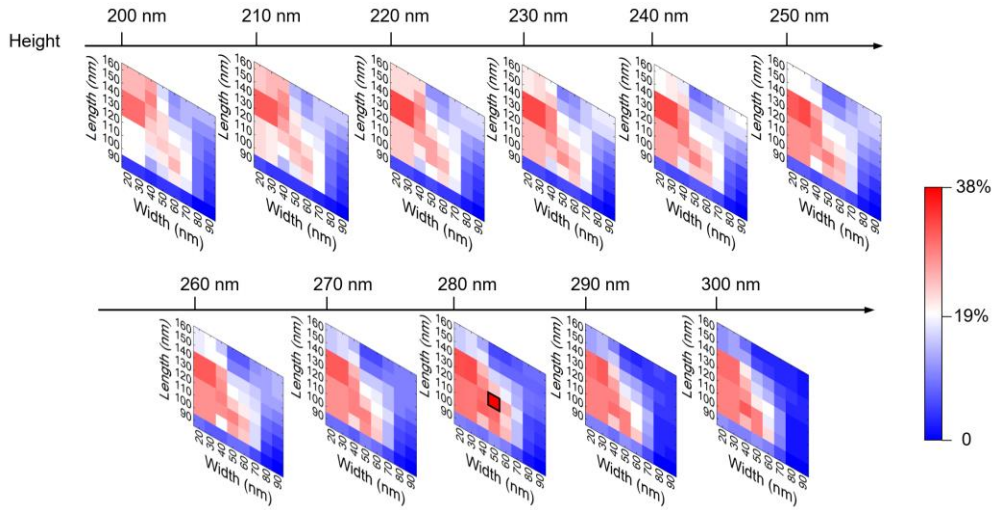


**Figure S2.** Simulated averaged cross-polarization conversion efficiency across the visible wavelength region under study (450 nm - 650 nm) for a meta-atom having a fix orientation angle  $\theta = 0^\circ$  and different structural parameters (length  $D_1$ , width  $D_2$ , and height  $H$ ). The maximum value reaches 38% (denoted by a black solid-line square) and the associated structural parameters  $D_1 = 120$  nm,  $D_2 = 50$  nm, and  $H = 280$  nm, are selected for constructing the meta-atom.

### 3. Holographic imaging simulation of the six-channel metahologram

For the ease of device modeling and simulation,  $200 \times 200$  meta-atoms with the optimized structural parameters and spatially-varying rotation angles are built in the simulation region. The simulation region is set to have a side length of  $40 \mu\text{m}$ , slightly larger than the meta-atom array (with a side length of  $35.2 \mu\text{m}$ ). The rotation angle of each meta-atom is determined according to the phase distribution generated by the Gerchberg–Saxton (G-S) algorithm. PML boundary condition is applied along all x, y, and z axes. To project different target images, incident light is set successively to have different circular polarizations (LCP and RCP) and propagate along each of the designed directions  $V_1 (\alpha = 55^\circ, \beta = 0^\circ)$ ,  $V_2 (\alpha = 55^\circ, \beta = 60^\circ)$ , and  $V_3 (\alpha = 55^\circ, \beta = 120^\circ)$  within the glass substrate beneath the meta-atom array. A two-dimensional monitor parallel to the device plane is placed  $100 \text{ nm}$  above the metahologram to collect the modulated light field data and the “farfieldexact3d” function in the Lumerical FDTD Solutions software is employed to calculate the intensity distribution of the cross-circularly-polarized light on the image plane, which is located  $1 \text{ cm}$  above the metahologram device.

### 4. The Gerchberg–Saxton algorithm used in the metahologram design

We adopt the commonly-used Gerchberg–Saxton (G-S) algorithm to calculate the phase distribution on the metahologram [6]. In the G-S algorithm, the light field is set to propagate forward and backward between the hologram plane and image plane iteratively to generate an optimized phase distribution on the hologram plane. As shown in the flow chart in Fig. S3, the algorithm starts by creating a light field on the image plane  $U_t$ , whose amplitude is obtained by taking the square root of the target image intensity and phase is randomly generated. The

light field on the hologram plane,  $U_h$ , is then obtained by implementing an inverse Fourier transform of  $U_t$ . After that,  $U_h$  is fed into the loop where Fourier transform and inverse Fourier transform are successively performed to calculate the light fields on the hologram and image plane,  $U_h$  and  $U_i$ , respectively. Between the two transforms, the amplitudes of  $U_h$  and  $U_i$  are replaced by unity amplitude and the square root of the target image intensity, respectively, while their phase distributions are preserved. Typically, the phase distribution of  $U_h$  converges within tens of iterations, at which point the convergent phase distribution is output.

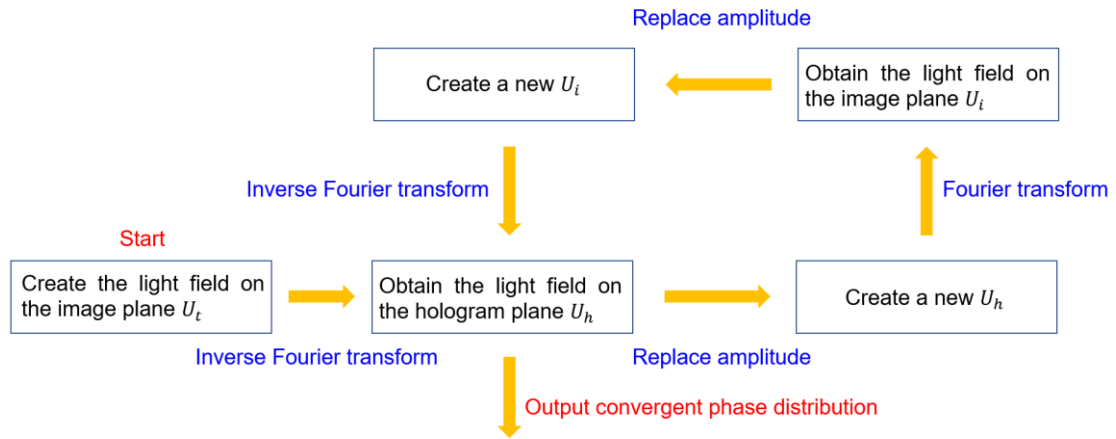


**Figure S3.** Flow chart of the G-S algorithm used in the metahologram design.

## 5. Simulated operational efficiency of the waveguide-based metahologram

As rigorously measuring the final efficiency of our device is difficult in experiment, we attempt to evaluate the value through numerical simulation. In the simulation, the metahologram is set to consist of  $200 \times 200$  meta-atoms and occupy a square area with a side length of  $35.2 \mu\text{m}$ . Red illumination light (of free space wavelength  $\lambda_0 = 637 \text{ nm}$ ) is set to have different circular polarizations and propagate along the six designed azimuthal angles inside the glass slab. The

final working efficiency, defined as the ratio of the intensity of projected holographic image to the intensity of incident illumination light, is calculated to be in the range from 1.2 % to 2.3 % for different combinations of circular polarization and azimuthal angle (Table 1).

**Table 1** Simulated operational efficiency of the waveguide-based metahologram for different combinations of circular polarization and azimuthal angle.

| Azimuthal angle $\beta$<br>Circular polarization state | $\beta = 0^\circ$ | $\beta = 60^\circ$ | $\beta = 120^\circ$ |
|--------------------------------------------------------|-------------------|--------------------|---------------------|
|                                                        |                   |                    |                     |
| RCP                                                    | 1.5 %             | 1.8 %              | 2.3 %               |
| LCP                                                    | 1.8 %             | 1.2 %              | 1.6 %               |

We note that the efficiency is lower than recently reported values ( $\sim 9\%$ ) in the literature [7, 8]. We attribute the reasons as follows:

(1) The employed flat glass waveguide slab in our study has a millimeter-scale thickness, which is far greater than the size of the metahologram. Therefore, the device only interacts with the guided incident light once. However, a majority of waveguide-based metahologram studies [9], including those afore-mentioned ones in efficiency comparison [7, 8], utilities waveguides that are typically hundreds of nanometers in thickness. In such case, the guided incident light can repeatedly interact with meta-atoms along the TIR propagation path and get out-coupled each time and therefore, the device efficiency is enhanced. By reducing the thickness of the waveguide slab and increasing the size of the device, a more sufficient interaction between the guided light and metahologram can be achieved and the device efficiency will then be remarkably improved.

(2) The meta-atoms in this study are made of poly-Si, which exhibits certain absorption over the visible region. Using visible-transparent materials (e.g., a-Si:H, TiO<sub>2</sub>, Ta<sub>2</sub>O<sub>5</sub>, SiN<sub>x</sub>, etc.) to construct the meta-atoms, or further optimizing the meta-atom's structural parameters for implementing geometric phase on guided incident light, could further promote the working efficiency of the device.

## 6. Phase changes of P- and S-polarized light upon total internal reflection

Light reflection at a planar interface between two semi-infinite homogeneous, isotropic media is governed by the Fresnel Formula. When both media are transparent, the phase shift in partial external or internal reflection equals 0 or  $\pi$ . In the case of total internal reflection (TIR) where the angle of incidence  $\alpha$  is greater than the critical angle of TIR, the phase changes of P- and S-polarized light after each TIR,  $\delta_p$  and  $\delta_s$ , respectively satisfy the following relations [10]

$$\tan(\delta_p/2) = r\sqrt{r^2 \sin^2 \alpha - 1} / \cos \alpha, \quad (\text{S3})$$

and

$$\tan(\delta_s/2) = \sqrt{r^2 \sin^2 \alpha - 1} / r \cos \alpha, \quad (\text{S4})$$

where  $r$  is the ratio between the refractive indices of the two media. The difference between  $\delta_p$  and  $\delta_s$ , denoted by  $\Delta$ , is nontrivial and can be expressed by

$$\tan(\Delta/2) = \sqrt{r^2 \sin^2 \alpha - 1} / r \sin \alpha \cos \alpha. \quad (\text{S5})$$

Figure S4 shows the relations of  $\delta_p$ ,  $\delta_s$ , and  $\Delta$  versus the TIR angle  $\alpha$  at a glass-air interface for an incident light with free-space wavelength  $\lambda_0 = 637$  nm. For the proposed waveguide-based metahologram, guided incident light has a TIR angle  $\alpha = 55.3^\circ$  and thus, the difference  $\Delta$  between the phase changes of P- and S-polarized components after each TIR

is approximately  $42^\circ$  (denoted by the green dot in Fig. S4).

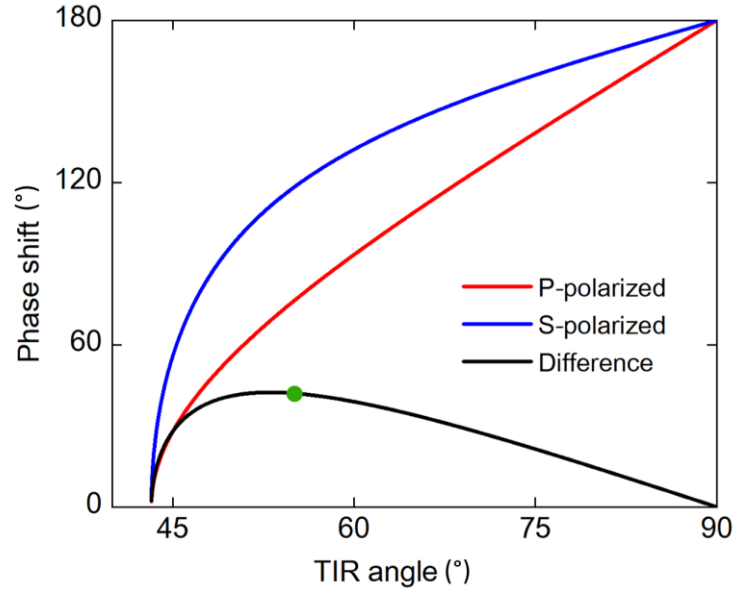


**Figure S4.** Phase changes of P- and S-polarized light ( $\lambda_0 = 637$  nm) upon each total internal reflection at the glass-air interface.

## 7. State of polarization of free-space incident light in the six-channel holographic imaging experiment

For the geometric phase modulation, when the incident light has a proper circular state of polarization, the output light contains the highest amount of cross-circularly-polarized component in the opposite spin with the target phase modulation. Due to this fact, the polarization of free-space incident light can be modified to maximize the brightness of the projected image. Under this condition, the guided incident light illuminating the metahologram region will possess the proper circular polarization.

In the holographic imaging experiment, the paired linear polarizer and quarter-wave plate located between the object lens and the tube lens are first adjusted to allow light in the circular polarization of the target image pass through. This is verified using a polarimeter. In this way,

the CMOS camera will capture the projected target image without crosstalk of the image in the opposite spin state. Then, the paired linear polarizer and quarter-wave plate located between the laser and the glass waveguide are gradually adjusted to modify the polarization of the free-space incident light until the brightness of the captured holographic image reaches its highest value. The polarization of the free-space incident light is then recorded using the polarimeter. As displayed in Fig. S5, the measured states of polarization for the projection of two sets of polarization-multiplexed images (“A”, “B”, “C” and “D”, “E”, “F”) are slightly elliptical.

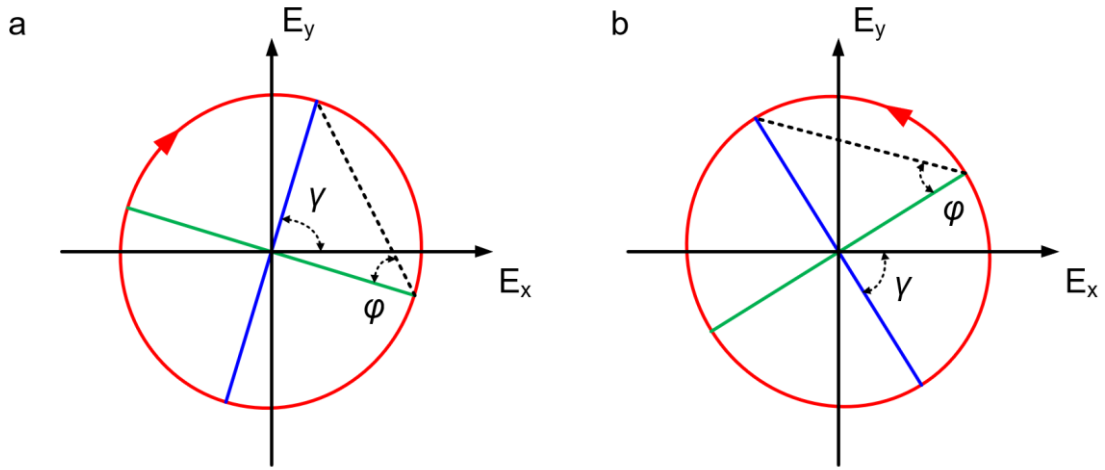


**Figure S5.** States of polarization of the free-space incident light for the projection of two sets of polarization-multiplexed images. The azimuth angle and ellipticity angle ( $\gamma$ ,  $\phi$ ) equal  $(73.07^\circ, 43.69^\circ)$  and  $(-58.11^\circ, -43.58^\circ)$  for the polarization ellipses in (a) and (b), respectively. The state of polarization in (a) and (b) has right and left handedness and corresponds to the projection of images of capital letters “A”, “B”, “C”, and “D”, “E”, “F”, respectively. Blue solid line and green solid line denote the major axis and minor axis of the polarization ellipse, respectively.

## 8. Experimental procedure of obtaining the projected holographic images by the three-channel polarization-independent metahologram

In the experiment of obtaining the projected holographic images by the three-channel polarization-independent metahologram, the paired linear polarizer and quarter-wave plate

located between the object lens and the tube lens are removed from the custom-built imaging setup, such that the projected image by the metahologram can be recorded by the camera without any polarization filtering (Fig. S6). Incident light is set successively to have four typical states of polarization, namely, RCP, LCP, P-polarization (electric field vector parallel to the plane of incidence), and S-polarization (electric field vector perpendicular to the plane of incidence), by adjusting the paired linear polarizer and quarter-wave plate located between the laser and the glass waveguide. The state of polarization of incident light is verified using a polarimeter. The intensities of incident light having different polarizations are set to be the same and verified using a power meter.

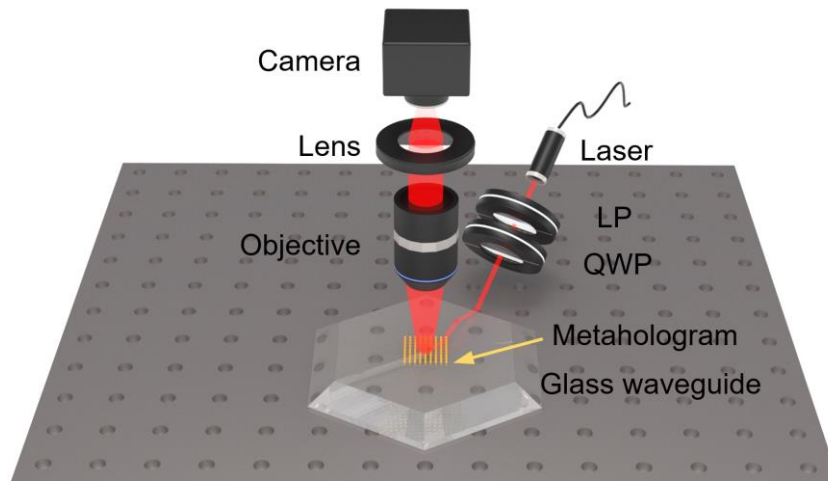


**Figure S6.** Schematic of the custom-built imaging setup for obtaining the projected holographic images by the three-channel polarization-independent metahologram. QWP: quarter-wave plate. LP: linear polarizer.

## 9. Spatial frequency pattern encoded on the dual-channel full-color metahologram

Figure S7 displays the spatial frequency pattern encoded on the dual-channel full-color metahologram. The individual red, green, and blue components of two colored images, flowers “lilac” and “rose”, are encoded into the two distinct sets of angle-multiplexed channels.  $r_r$ ,  $r_g$ ,

and  $r_b$  denote the radii of the red, green, and blue dashed-line circular areas containing the corresponding color components, respectively.  $d_r$ ,  $d_g$ , and  $d_b$  denote the distances from the centers of red, green, and blue color components to the  $k$ -space center (origin), respectively. Although far-field-projection metaholograms designed using the geometric phase modulation method have a broadband response, the size of projected holographic image as well as the range of central-period  $k$ -space is indeed proportional to the wavelength of illumination. Therefore, to compensate for such chromatic dispersion, the sizes of different color components in the  $k$ -space and their distances to the  $k$ -space center are accordingly adjusted to be inversely proportional to the wavelengths of illumination ( $\lambda_0 = 637$  nm, 532 nm, and 473 nm for red, green, and blue color lasers, respectively). Their ratio can be expressed by Eq. S6. Therefore, with the scale change of  $k$ -space induced by different illumination wavelength,  $r_r$ ,  $r_g$ , and  $r_b$  will become identical (equal to 0.2), and  $d_r$ ,  $d_g$ , and  $d_b$  will also become identical (equal to 1.2) in their corresponding normalized  $k$ -space when the metahologram is under the illumination of red, green, and blue light, respectively. In this way, different color components can be seamlessly overlapped to form the designed colored images when they are projected into free space.

$$r_r: r_g: r_b = d_r: d_g: d_b = 1/637: 1/532: 1/473. \quad (\text{S6})$$

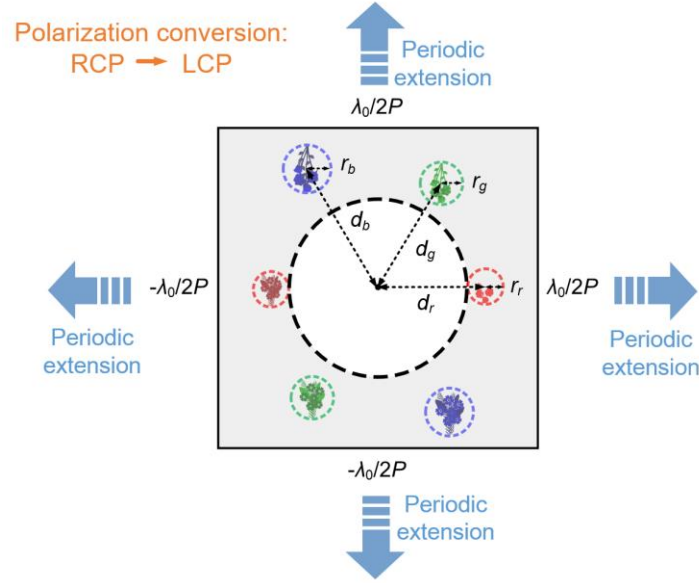


**Figure S7.** Central-period spatial frequency pattern encoded on the dual-channel full-color metahologram under normal light illumination for polarization conversion from RCP to LCP. The spatial frequency pattern in the case of polarization conversion from LCP to RCP can be obtained by in-plane rotating the spatial frequency pattern shown in this figure by  $180^\circ$  with respect to the  $k$ -space center.  $r_r$ ,  $r_g$ , and  $r_b$  denote the radii of the red, green, and blue dashed-line circular areas containing the corresponding color components, respectively.  $d_r$ ,  $d_g$ , and  $d_b$  denote the distances from the centers of red, green, and blue color components to the  $k$ -space center, respectively. The black dashed-line circle, defined by  $(k_x/k_0)^2 + (k_y/k_0)^2 = 1$ , has a radius of 1 and denotes the boundary of the propagation-wave region. As an illustration, in the case of red-light illumination ( $\lambda_0 = 637$  nm), the central-period region of the spatial frequency distribution pattern in this figure ranges from -1.8 to 1.8 ( $\lambda_0/2P = 1.8$ ) along the two perpendicular coordinate axes. The red color component is exactly outside the boundary of the propagation-wave region while the other two color components are located further away from the boundary.

## 10. Design of the eight-channel metahologram

For the eight-channel metahologram, the spatial frequency pattern contains eight different target images (capital letters from “A” to “H”). The letters are located on the vertices of a regular octagon that is centered at the origin of the normalized  $k$ -space coordinate system (Fig.

S8a). Each target image has the same size as the ones in the six-channel metahologram and is also located inside a circular area with a radius of 0.2. The side length of the regular octagon is set to be 1.2, such that when a given target image (take the capital letter “A” as an example) is moved to the  $k$ -space center, its adjacent two target images (“H” and “B”) are exactly outside the propagation-wave region (Fig. S8b). For such regular octagon, the distance from each vertex to its center is approximately 1.57, which equals the translation distance to move each target image to the  $k$ -space center. For the target images that are translated out of the central-period region partially (“F”, “G”, and “C”) or entirely (“D” and “E”), the same images in the adjoint-period regions will be moved into the central-period region from the opposite side. To ensure these target images are still outside the propagation-wave region after translation, the central-period  $k$ -space is set to range from -2.05 to 2.05 along the two coordinate axes ( $k_x/k_0$  and  $k_y/k_0$ ), such that the closest image to the propagation-wave region (“D”) will appear exactly beside the boundary.

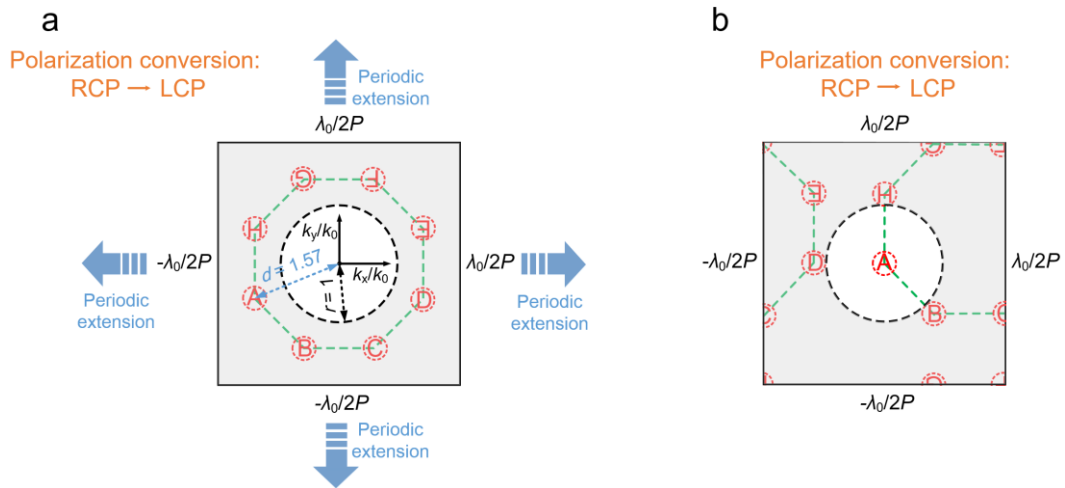


**Figure S8.** Central-period spatial frequency pattern of the eight-channel metahologram. (a) Central-period spatial frequency pattern encoded on the eight-channel metahologram under normal light illumination for polarization conversion from RCP to LCP. (b) Central-period spatial frequency pattern after a directional translation to move letter “A” to the  $k$ -space center. The translation direction makes an angle of 22.5° with

the horizontal coordinate axis ( $k_x/k_0$ ). The translation distance is 1.57 in the normalized  $k$ -space coordinate system.

Under the condition of red-light illumination ( $\lambda_0 = 637$  nm), the pitch of meta-atoms  $P$  is set as  $P = \lambda_0/4.1 \approx 155$  nm according to the designed range of the central-period  $k$ -space. The structural parameters (length  $D_1$ , width  $D_2$ , and height  $H$ ) of the rectangular poly-Si nanopillar of each meta-atom are optimized to be  $D_1 = 110$  nm,  $D_2 = 40$  nm, and  $H = 280$  nm. The meta-atom shows an acceptable cross-polarization conversion efficiency between two opposite spin states across the visible range under study (450 nm to 650 nm) for normal light illumination, with an averaged efficiency of 31.3% (Fig. S9). In the device simulation,  $200 \times 200$  meta-atoms with the optimized structural parameters and spatially-varying rotation angles are built in the simulation region. The simulation region is set to have a side length of 35  $\mu\text{m}$ , slightly larger than the meta-atom array (with a side length of 31  $\mu\text{m}$ ). Incident light is set successively to have different circular polarizations (LCP or RCP) and propagate along each of the designed directions  $V_1$  ( $\alpha = 56.3^\circ, \beta = 22.5^\circ$ ),  $V_2$  ( $\alpha = 56.3^\circ, \beta = 67.5^\circ$ ),  $V_3$  ( $\alpha = 56.3^\circ, \beta = 112.5^\circ$ ), and  $V_4$  ( $\alpha = 56.3^\circ, \beta = 157.5^\circ$ ) within the glass substrate beneath the meta-atom array for the projection of eight different images. The boundary conditions, monitor settings, and image intensity calculation process are the same as the simulation of the six-channel metahologram in Part 3.

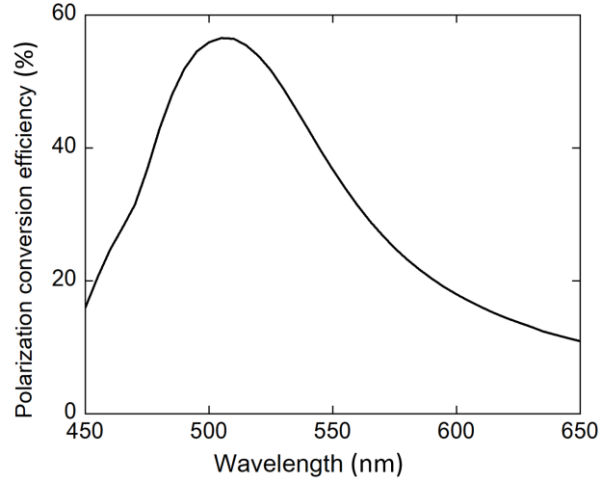


**Figure S9.** Simulated cross-polarization conversion efficiency between two opposite spin states across the visible range under study (450 nm to 650 nm) by the designed meta-atom for normal light illumination. The averaged efficiency across the region is 31.3%.

## 11. Extended number of display channels by orbital angular momentum multiplexing

Combining the proposed  $k$ -space translation strategy with the orbital angular momentum (OAM) multiplexing technique [11,12] can significantly extend the number of display channels, realizing a metahologram simultaneously multiplexed by angle of incidence, state of polarization, and OAM.

The design flow of such metahologram is shown in Fig. S10, where three topological charges ( $l = 1, 2$ , and  $3$ ) are employed in this work. Three sets of spatial frequency patterns, each of which contains six different target images centered on the vertices of a regular hexagon with a side length of 1.2 in the normalized  $k$ -space coordinate system, are first spatially sampled using a filtering array to avoid spatial overlap of the helical wavefront and preserve the OAM property of each pixel of the holographic image. The filtering array consists of periodic circular apertures. The spacing between two adjacent apertures is determined by the largest size of the donut-shaped OAM beams (associated topological charge  $l = 3$ ) on the image plane. Then, the

phase distributions (matrix dimension:  $5001 \times 5001$ ) corresponding to the sampled patterns are obtained using the G-S algorithm. The calculation results of phase distributions are subsequently added with the helical phase distributions corresponding to different topological charges of the OAM beams. After that, these three OAM-imparted phase distributions are superposed together and encoded on the metasurface using the geometric phase modulation method. The design is numerically verified (Fig. S11), where eighteen different holographic images (capital letters from “A” to “R”) can be projected when the guided incident OAM light has different state parameter combinations of circular polarization (LCP or RCP), azimuthal angle ( $\beta = 0^\circ, 60^\circ, \text{ or } 120^\circ$ ), and topological charge ( $l = -1, -2, \text{ or } -3$ ). The light intensity distribution on the image plane is spatially filtered using the same filtering array to select pixels without OAM. Because OAM as a degree of freedom has an unbounded set of orthogonal helical modes, incorporating additional topological charges in the design flow can further enable the implementation of more display channels.

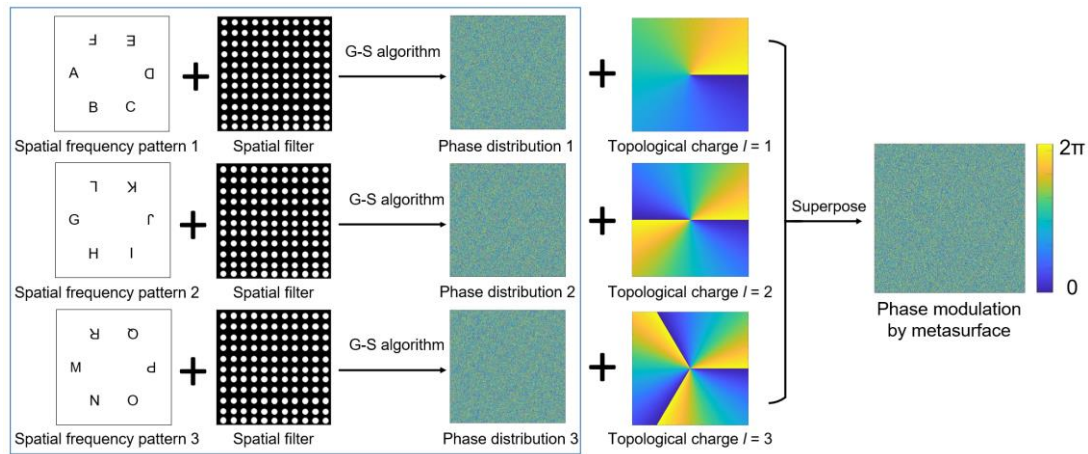


**Figure S10.** Design flow of the metahologram simultaneously multiplexed by state of polarization, angle of incidence, and OAM simultaneously.

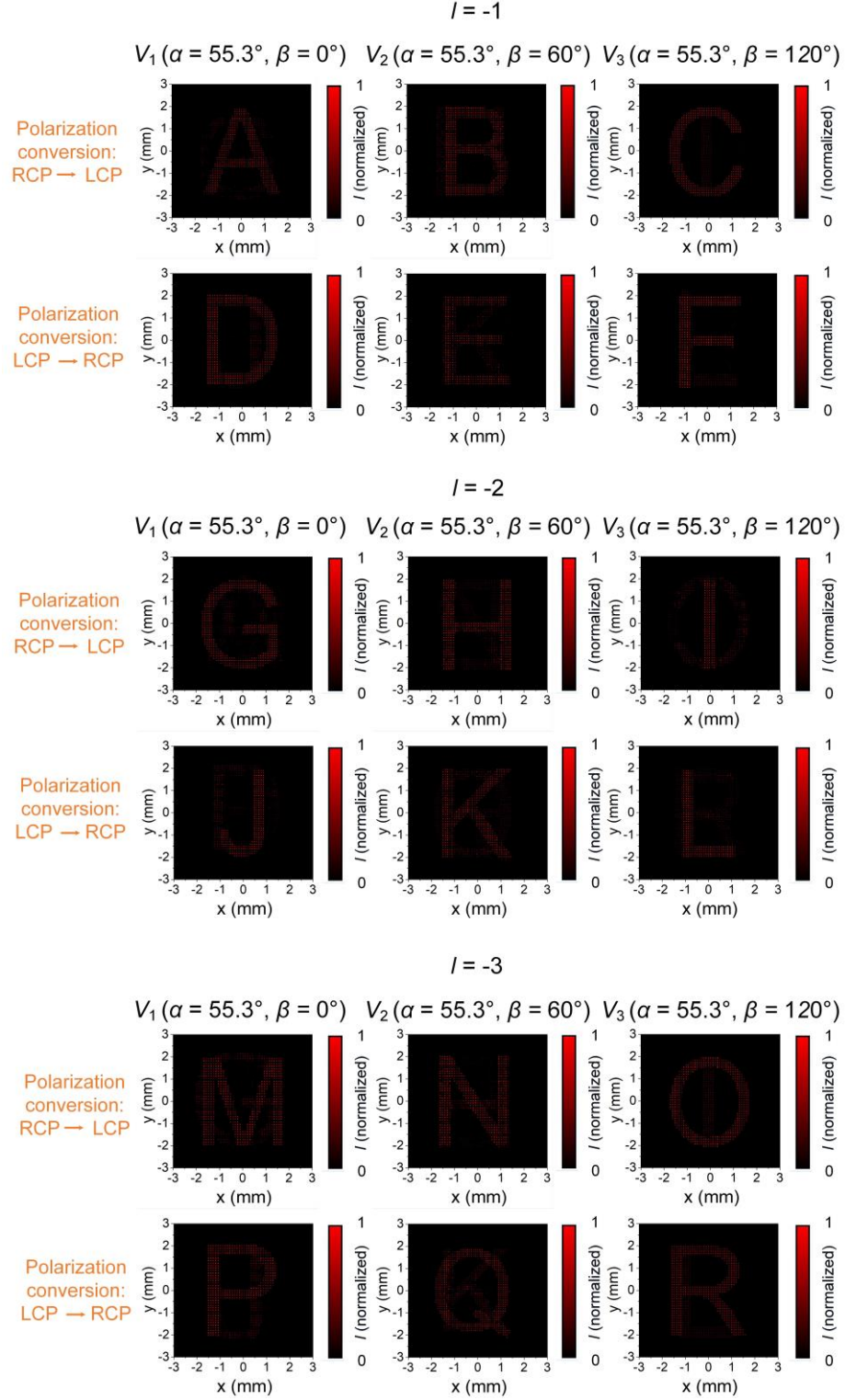


**Figure S11.** Simulated imaging results of an eighteen-channel metahologram simultaneously multiplexed by angle of incidence, state of polarization, and OAM. Eighteen different holographic images of capital letters from “A” to “R” can be selectively projected when the guided incident OAM light with a fixed TIR  $\alpha = 55.3^\circ$  has different state parameter combinations of circular polarization (LCP or RCP), azimuthal angle ( $\beta = 0^\circ, 60^\circ$ , or  $120^\circ$ ), and topological charge ( $l = -1, -2$ , or  $-3$ ).

## 12. Influence of the residual hydrogen silesquioxane resist layer on meta-atom's cross-polarization conversion efficiency

In the metasurface fabrication, the developed hydrogen silesquioxane resist (HSQ) layer is used as the etch mask to transfer the metasurface pattern into the poly-Si layer (Left panel, Fig. S12). After the inductively coupled-plasma (ICP) reactive ion etching process, the residual HSQ layer on top of the nanopillar is estimated to be less than 20 nm in thickness. Due to its low refractive index ( $\sim 1.4$ ) [13], the thin HSQ layer possesses minimal influence over the metasurface performance. Right panel of Figure S12 shows the two curves of the simulated cross-polarization conversion efficiency of the designed nanopillar with and without the 20-nm-thick residual HSQ capping layer. The difference in cross-polarization conversion efficiency between the two curves are less than 5% across the visible region under study.

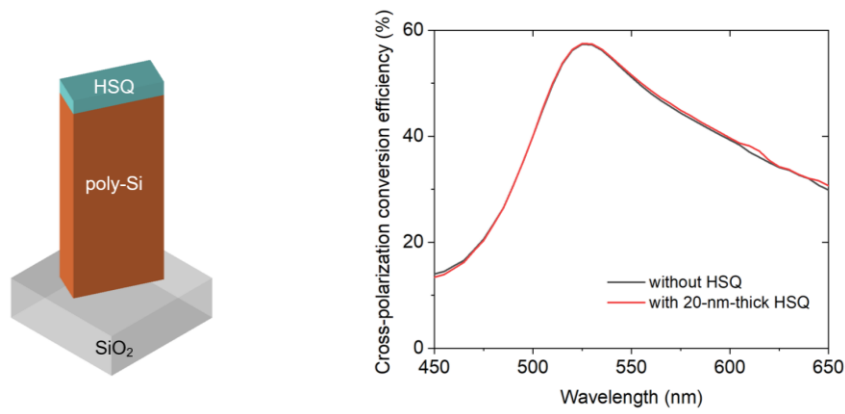


**Figure S12.** Comparison of cross-polarization conversion efficiency of the designed nanopillar with and without of the 20-nm-thick residual HSQ capping layer. Cross-polarization conversion efficiencies over the visible region in these two cases are very close to each other.

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