This document provides supplementary information to “Polarization-Controlled Color-Tunable Holograms with Dielectric Metasurfaces,” Optica volume, first page (year). The numerical simulations, the metasurface fabrication, the optical setup, the designed spin-controlled full color holograms, the quantitative relation between the incident polarization and the generated colors, and the relative intensities of the dual images are presented in detail. © 2017 Optical Society of America

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**Numerical simulations.** Numerical simulations were carried out using commercial software COMSOL Multiphysics based on a finite element method. Periodic boundary conditions and periodic port boundary conditions were used for reflection coefficient calculation of the structure arrays. The refractive index of Si is based on the results of Vuye et al.1993; n, k 0.26-0.83μm,20℃ from website of RefractiveIndex.info. The refractive index of the oxide layer is taken as 1.46.

**Metasurface fabrication.** The demonstrated holograms were fabricated on an SOI substrate. First a ~200-nm-thick positive electron resist (ZEP-520 A) was spin-coated on a clean substrate and baked at 180 °C on a hotplate for 2 min. Then the metasurface patterns were exposed using electron-beam lithography (Vistec EBPG 5000+ES). After the development of the resist, the cryogenic dry etching was performed in a mixture of SF₆ and O₂ plasmas using an inductively coupled plasma etching system (Plasmalab System 100 ICP180). The residual resist was finally removed an ultrasonic bath of butanone solvent.

**Optical Setup.** In our demonstrated experiments, three laser sources centered at wavelengths of 473nm, 532nm and 632.8nm are collimated as a mixed laser beam. The mixed beam passes through a Glan-Prism and an achromatic quarter-wave plate (Thorlabs, AQWP05M-600). After that, the beam is focused by a lens (focal length f = 120mm). The metasurface sample is located near the focal spot, and the reconstructed holographic images in the reflection are projected to a screen and captured by a camera (SONY α6300).

Fig. S1. The experiment setup. Polarization is tuned by rotating the quarter waveplate. The corresponding polarization
states are exemplarily illustrated by the dots on the Poincare sphere.

The designed spin-controlled full color holograms. Figure S2 presents a proposed color hologram of three alphabets with distinct multiple colors for RCP and LCP incidences, respectively. The whole image is designed symmetrically and only its half (the right side in this work) is the target for the spin-controlled color changes. For arbitrary incident polarizations, the resultant colors of the image are the weighted color mixing of those for RCP and LCP incidences and can be locally controlled. As any colorful images can be divided into three RGB sub-images, the phase distribution for each sub-image is independently retrieved using the GS algorithm. Then, it is converted to the distribution of $S_{rs}$ or $S_{gs}$ or $S_{bs}$. Finally, the $S_{rs}$, $S_{gs}$ and $S_{bs}$ are multiplexed in subwavelength scale to form the desired metasurface.

Figure S2 presents the efficiencies of the nanoblocks as functions of their sizes ($l_x$ and $l_y$) at the three laser wavelengths. Based on the principle that each nanoblock works with relatively high efficiency at the specified wavelength but with negligible efficiencies at the other two wavelengths (which ensures high extinction ratio and low crosstalk), we choose the sizes of $S_b$, $S_g$ and $S_r$ marked as circles in Fig.S3(a). Their efficiency spectra are shown in Fig.S3(b).

The relation between incident polarization and generated colors. The color gamut is determined by the wavelengths of the lasers we use, as shown in Fig.S4. In order to investigate the relation between the generated color for a certain part of the hologram and the incident polarization, we first need define a reference white point. This actually is a normalization of the maximum powers of the three lasers. The reference white point can be chosen at will, and accordingly it also alters the relative powers among the three lasers. Since any color within a certain color gamut can be represented by arbitrary RGB values between 0 and 1, the color of a selected part of the holographic image under arbitrary polarization illumination can be expressed as,

$$R = R E^r_r + R E^l_r, \quad G = G E^r_g + G E^l_g, \quad B = B E^r_b + B E^l_b.$$  \hfill (S1)
Here the RGB values without subscript correspond to the color generated by arbitrary incident polarization \((E_r, E_l)\), where \(E_r\) and \(E_l\) are the relative complex electric field in helical basis for RCP and LCP; the RGB with subscript \(r\) and \(l\) are colors artificially designed for the RCP and LCP incidences, respectively. Equation (S1) is the guide for designing the colors of spin-controlled full-color holograms and it determines the color path for a series certain polarization changes. Note that the RGB relates the XYZ coordinates by a matrix transformation \([1]\), it helps us to observe the path the color goes through for a certain polarization change on the CIE color space. As depicted in Fig.S1, the incident polarization is determined by a polarizer and a quarter wave plate. The polarization state after P is set as \(\hat{E} = 1/\sqrt{2}\begin{bmatrix} 1 & 1 \end{bmatrix}^T\), and the Jones matrix of the quarter wave plate is \(J(\theta)\), where \(\theta\) is the rotating angle. The \(E_r\) and \(E_l\) after the quarter wave plate can then be expressed as \(E_r = \hat{R} J(\theta) \hat{E}, \quad E_l = \hat{L} J(\theta) \hat{E}\), with \(\hat{R} = 1/\sqrt{2}\begin{bmatrix} 1 & 1 \end{bmatrix}^T, \quad \hat{L} = 1/\sqrt{2}\begin{bmatrix} 1 & -1 \end{bmatrix}^T\). By rotating the quarter waveplate, the polarization changes following a path depicted as dots on the Poincare sphere in Fig.S1, and the color follows a line on the CIE color space, depicted in Fig.S4 (a). The numbers 1 to 6 denotes the six letters, and the marks are experimentally measured colors for these letters upon rotating the quarter waveplate from 0 to 90 degrees every 10 degrees (from RCP to LCP). Fig.S4 (b) depicts the theoretical colors of the six letters at four specific polarization states, which shows the abundant colors it creates by mixing the RGB lasers with various ratios.

**The relative intensities of the dual images.** The intensity change of one image upon changing the incident polarization from RCP to LCP or vice versa is always symmetrically reversed for its conjugate image. This is why only half of the far field is considered here. Fig.S5 gives the far field image of the dual-color hologram shown in Fig.5 in main text. We design a green chameleon for RCP incidence and red for LCP incidence. Accordingly, there will be a chameleon symmetrically located in the far field which is red for RCP incidence and green for LCP incidence, as shown in rectangular frames. The intensities of the red and green colors vary as a function of the polarization state as shown in Figs. S5(b) and S5(c). On the CIE color space, the dual chameleon images will both go through the colors on the line 2 in Fig.S3 (a), but with opposite directions. This is also the reason how the color changes in Fig.3 and Fig.4 in the main text. Additionally, there is a special case without color change as depicted in the two circles. The branch remains green with the same intensity upon changing the incident polarization, since we only design this image for green light.

![Fig. S5](image-url) The intensity changes between dual images for two primary colors. (a) The hologram is captured in the far field for \(\theta = 70^\circ\). The white rectangles and circles denote the area within which the intensities are measured. (b) The relative intensity changes for Red and Green light upon rotating the quarter waveplate, the intensity is measured in the rectangles marked (b) in (a). (c) The relative intensity changes for Red and

**References**

1. Y. Shi, et al. "Practical color matching approach for color computer-generated holography." J. Display Technol. 9, 638-643 (2013).