Supplementary Material

Title Dual-polarized multiplexed meta-holograms utilizing coding metasurface

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**Section S1 Periodicity *p* and its affect on the imaging performance**

When the operating frequency is determined, the periodicity is associated with the resonance of the meta-atom. In our design, the periodicity is optimized to be around 8 mm (which is about 0.4λ) so that the selected double-layered SR apertures can be resonant at 15 GHz. A smaller periodicity can provide higher resolution of the hotspots, since it can improve the spatial resolution of the phase profile on the metasurface [S1]. Similarly, a larger periodicity will deteriorate the resolution. The mender-line design can help to miniaturize the periodicity [S2], but it also results in complicated design, fabrication challenges and undesired resonances. In our design, the periodicity *p*, which is below the half a wavelength, is small enough to provide a deep subwavelength spatial resolution for the phase profile.

The perfect periodic condition will be affected in the real implementation, and it will have impact on the imaging performance. However, since the geometric structure of these elements is similar, and just the size or orientation has little difference, the influence of the non-perfect periodic conditions is acceptable. In order to improve the periodic condition, 2\*2 periodic arrangement can be adopted [S3], where a pixel of hologram can be represented by four same elements. For such arrangement, every element is surrounded by at least two same neighbors. For illustrative comparison, a metasurface constructed by 2\*2 periodic elements with same dimensions of the metasurface presented in the manuscript is designed and simulated. The simulated results are presented in Figure S1. It can be observed from Figure S1 and Figure 3 that the image quality of our proposed metasurface in the manuscript is better than metasurface constructed by 2\*2 periodic element with the same dimensions. In fact, although the 2\*2 arrangement improves the periodic condition, it reduces the number and resolution of the pixel of the hologram. Thus for most metasurface design, the 1\*1 element is adopted to construct the metasurface despite the small impact of the non-perfect periodic condition.

If the periodicity *p* increases, the coupling effect among adjacent elements will be weakened, which will help to reduce the influence of the adjacent elements with different size. However, as discussed above, a larger periodicity will deteriorate the resolution of the hologram. Considering the tradeoff between the small influence of non-perfect periodic conditions and spatial resolution of the phase profile, we think the periodicity of 8 mm is a good choice.



Figure S1. Simulated results of metasurface constructed by 2\*2 periodic element. (a) and (b) Simulated images of cross- and co-polarized channels under *x*-polarized incidence, respectively. (c) and (d) Simulated images of cross- and co-polarized channels under *y*-polarized incidence, respectively.

**Section S2 Longitudinal polarization component in the radiative near field**

Since the imaging plane is in the radiative near-field region, the longitudinal polarized (*E*z) component also exists. As it can be seen from Figure S2, the energy of the longitudinal polarization is mainly distributed near the hotspots of *x*- and *y*-polarized components. Form the simulated results, the energy stored in *z*-polarized component is calculated to be 15.0% and 14.8% of the total incident energy under *x*- and *y*-polarized incidences, respectively. The energy of *Ez* component at the positions of hotpots in the two image (Figure S2a and S2b or Figure S2d and S2e) is calculated to obtain the overlap energy, and the energy in the overlap area of Figure S2c and S2f is also calculated, as shown in Figure S3. For *x*-polarized incidence, the energy of *Ez* component at the positions of hotpots shown in Figure S2a and S2b is calculated to be 2.4% and 2.8% of the incident energy, respectively, as shown in Figure S3a and S3b. For *y*-polarized incidence, the energy of *Ez* component at the positions of hotpots shown in Figure S2d and S2e is calculated to be 2.6% and 3.1% of the incident energy, respectively, as shown in Figure S3d and S3e. The energy in the overlap area of Figure S2c and S2f is also calculated here, which corresponds to be 6.6% and 7.0% of the incident energy, respectively, as shown in Figure S3c and S3f. Except energy in the *z*-polarized component, there are other reasons causing losses of the incident wave, including reflection and absorption losses. The reflected energy ratio is simulated to be 47.6% and 48.0% of the total incident energy under *x*- and *y*-polarized incidence, respectively. Absorbed energy ratio is 5.4% and 5.1% under *x*- and *y*-polarized incidence, respectively. For *x*-polarized incidence, the transmission efficiency is found to be 47.0%, in which *Ex* accounts for 18.2%, *Ey* 13.8% and *Ez* 15.0%. For *y*-polarized incidence, the transmission efficiency is simulated to be 46.9%, in which *Ex*accounts for 14.6%, *Ey* 17.5% and *Ez* 14.8%.



Figure S2. Simulated electric intensity distributions of different polarizations. (a), (b) and (c) *Ex, Ey and Ez* components under *x*-polarized incidence. (d), (e) and (f) *Ey*, *Ex* and *Ez* components under *y*-polarized incidence.

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Figure S3. (a), (b) and (c) Intensity of Ez component under x-polarized incidence at positions of hotspots shown in Figure S2a, S2b and S2f, respectively. (d), (e) and (f) Intensity of Ez component under y-polarized incidence at positions of hotspots shown in Figure S2d, S2e and S2c, respectively.

**Section S3 Directivity enhancement for lens antenna functionality**

To further validate the directivity enhancement for lens antenna functionality, Figure S4 presents the simulated far-field radiation patterns when transmitters are placed at the hotspots generated for *x*-polarized incidence, while the situation is similar for *y*-polarized incidence. As shown in Figure S4a and S4b, when *x*-polarized transmitters are placed at hotspots shown in Figure 3h and *y*-polarized transmitters are placed at hotspots shown in Figure 3d respectively, by reciprocity the *x*-polarized component transmitted through the metasurface is a directive beam (similar to the excitation used to create the hotspots in the former configuration) while the transmitted *y*-polarized component is a random beam without obvious directivity. When both *x*-polarized and *y*-polarized transmitters are placed at corresponding hotspots in Figure 3h and 3d, the transmitted wave is transformed to *x*-polarized plane wave with *y*-polarized component eliminated, as shown in Figure S4c. The generated far-field radiation patterns therefore agree well with the reciprocity principle, and validate the directivity enhancement function of our proposed metasurface as lens antenna.

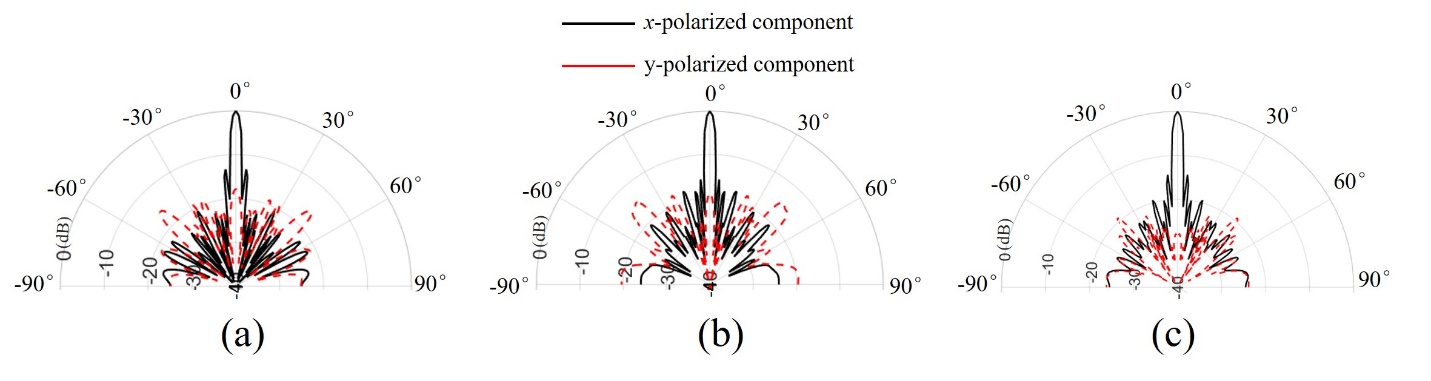
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Figure S4. Normalized far-field radiation patterns produced when transmitters with different polarization state are placed at the different hotspots location. (a) *x*-polarized transmitters placed at hotspots shown in Figure 3h. (b) *y*-polarized transmitters placed at hotspots shown in Figure 3d. (c) *x*-polarized transmitters placed at hotspots in Figure 3h and *y*-polarized transmitters placed at hotspots in Figure 3d.

**Reference**

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