Supporting Information for:

Broadband and polarization-independent complex amplitude modulation using a single layer dielectric metasurface

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1. Operational Bandwidth Analysis

For a dielectric metasurface with a design wavelength of λ_0, the phase delay can be described using the equivalent refractive index, i.e., $\varphi=\frac{2\pi}{\lambda_0}n_{eff}H$. where H is the height of the dielectric pillar, n_{eff} is the effective refractive index, which is positively correlated with the width of the dielectric pillar. Let the width of the dielectric pillar be $w\in[w_{min},w_{max}]$. Full-space phase modulation can be achieved when $n_{eff}(w_{max})-n_{eff}(w_{min})=\lambda_0/H$, In this case, for any two meta-atoms, the difference in the effective refractive index satisfies $n^1_{eff}-n^2_{eff}\leq\lambda_0/H$. Since exchanging the positions of the two meta-atoms does not change the electromagnetic response, we can always have $n^1_{eff}-n^2_{eff}\geq0$. Hence, $0\leq n^1_{eff}-n^2_{eff}\leq\lambda_0/H$. Now, consider the case of dual meta-atoms interference. At positions far from resonance, the dispersion of n_{eff} can be neglected. According to equation (3) in the main text, the amplitude of dual meta-atoms interference can be expressed as:

$$A(\lambda)=\cos\left[\frac{\varphi_1-\varphi_2}{2}\right]=\cos\left[\frac{\pi}{\lambda}(n_{eff}^1-n_{eff}^2)H\right]$$

The amplitude error deviating from the design wavelength is equal to:

$$J(\Delta\lambda)=A(\lambda_1)-A(\lambda_0)=\cos\left[\frac{\pi}{\lambda_1}(n_{eff}^1-n_{eff}^2)H\right]-\cos\left[\frac{\pi}{\lambda_0}(n_{eff}^1-n_{eff}^2)H\right]$$

Assuming

$$x=\frac{\pi}{\lambda_0}(n_{eff}^1-n_{eff}^2)H$$

one can obtain:

$$J(\Delta\lambda)=\cos\left(\frac{\lambda_0}{\lambda_1}x\right)-\cos(x)\ ;\ x\in[0,\pi]$$

The average value of amplitude error $J(\Delta\lambda)$ is equal to:

$$c=\frac{1}{\pi}\int_0^{\pi}\cos\left(\frac{\lambda_0}{\lambda_1}x\right)-\cos(x)\,dx=\frac{\lambda_1}{\lambda_0\pi}\sin\left(\frac{\lambda_0\pi}{\lambda_1}\right)$$

Define a small quantity ϵ. When $|c|<\epsilon$, it is assumed that the amplitude responses of the two wavelengths are identical. Here, we let $\epsilon=0.1$, which gives:

$$\left|\frac{\lambda_1}{\lambda_0\pi}\sin\left(\frac{\lambda_0\pi}{\lambda_1}\right)\right|<0.1$$

Simplifying the equation, we obtain:

$$0.9\lambda_0<\lambda_1<1.1\lambda_0$$

Similarly, for phase error analysis, one can get the same result. The bandwidth is $\Delta\lambda\approx0.2\lambda_0$. When λ_0 =532nm, the bandwidth is approximately 110 nm. It is important to note that since the above derivation involves some approximations and the selection of ϵ is subjective, the above result is an approximation. However, compared to resonant metasurfaces, the bandwidth is significantly increased.

2. Theoretical and Simulation Results of Dual Meta-Atoms

Theoretically, according to the interference formula, it is sufficient to scan only the width of a single meta-atom to create a complete database, which can significantly reduce the computational load. Fig. S1(a) and Fig. S1(b) are the amplitude and phase response for meta-atoms of different widths. The simulated meta-atoms have a periodicity of 400 nm in both the x and y directions. Using the superposition principle, the amplitude and phase responses of the superlattice composed of dual meta-atoms are shown in Fig. S1(d) and Fig. S1(e). To verify the theoretical predictions, a thorough parametric scan of the dual meta-atoms structure in the superlattice was performed, yielding the electromagnetic responses for x-polarization and y-polarization as shown in Fig. S1(f) to (i). The results indicate that the theoretical predictions are almost consistent with the simulation results, confirming the accuracy of the interference process. Notable discrepancies occur at positions where the resonance of a single meta-atom is particularly strong. Slight differences in response between x-polarization and y-polarization are attributed to minor anisotropies in the superlattice along the two polarization directions.

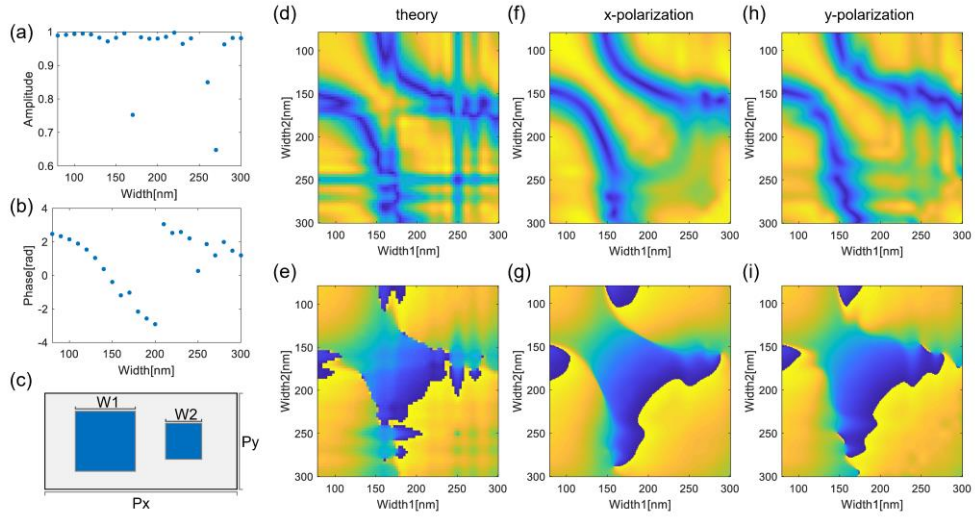

Fig. S1 (a,b) Amplitude and phase response of a single meta-atom. (c) Schematic diagram of the superlattice structure. (d,e) Amplitude and phase responses of the superlattice based on the interference formula. (f-i) Amplitude and phase simulation results of the superlattice for TE and TM polarization, using CST Studio software.

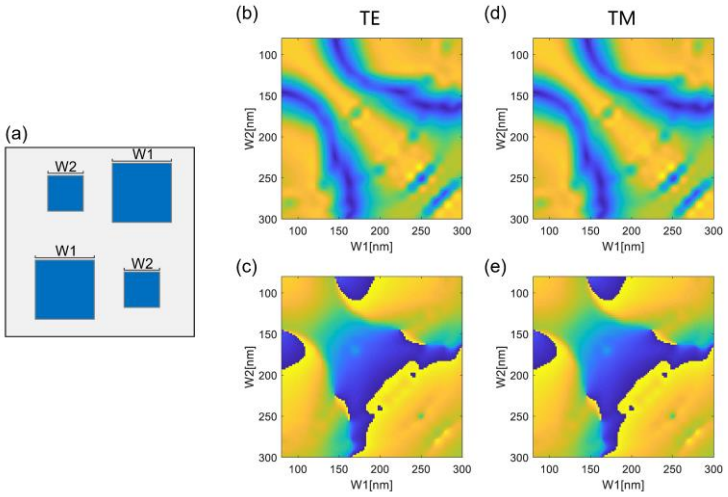

Fig. S2 Construction of a strictly polarization-independent metasurface. (a) Schematic diagram of the unit cell structure. (b,c) Amplitude and phase responses for the TE mode. (d, e) Amplitude and phase responses for the TM mode.

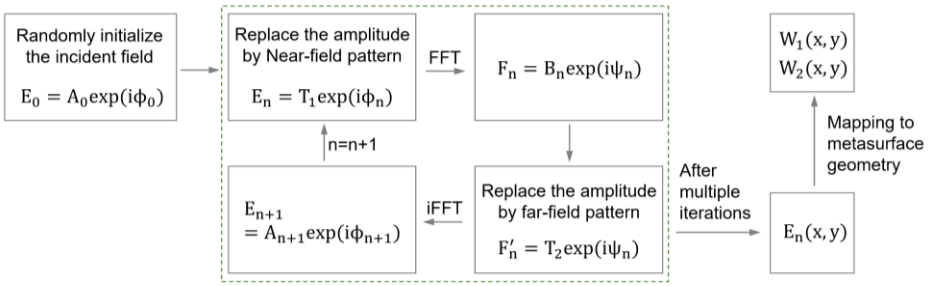

Fig. S3 Design process for the nanoprinting and Fourier holography hybrid metasurface display.

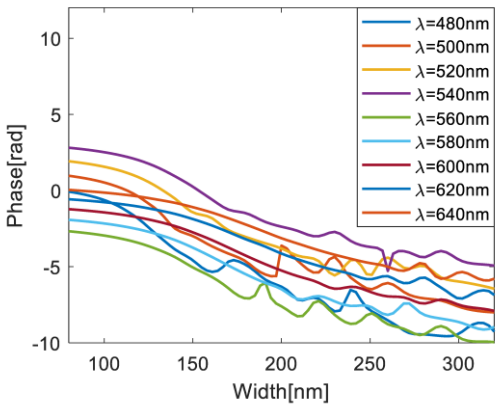

Fig. S4 Phase response of a single meta-atom at different wavelengths. The curves exhibit similar and continuous

property, ensuring the stability and broadband characteristics of the interference process.

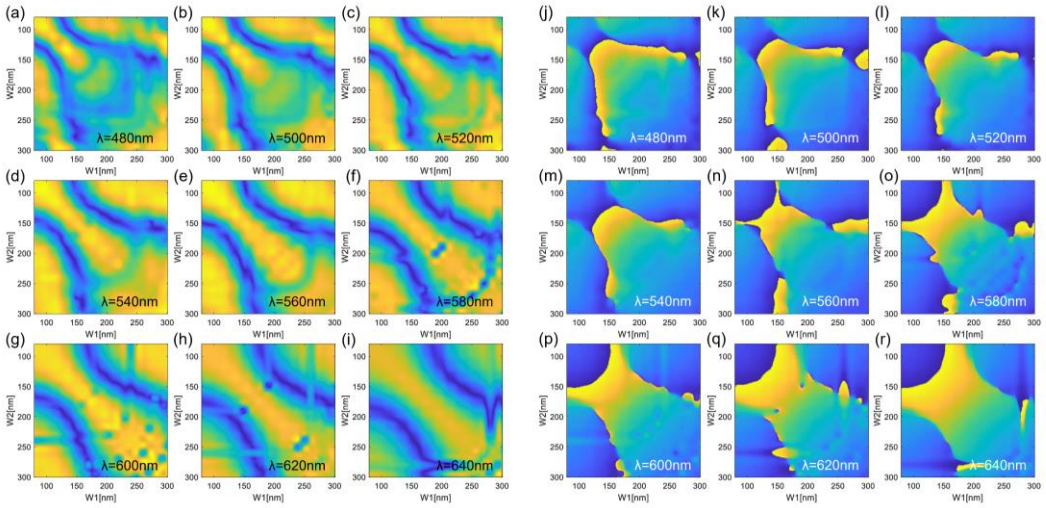

Fig. S5 (a-i)Amplitude and (j-r)phase responses of the superlattice at different wavelengths. For ease of comparison, an absolute phase is added for each wavelength. The simulations were performed using rigorous coupled-wave analysis.