Ultrathin metasurface enables high-efficiency vectorial holography

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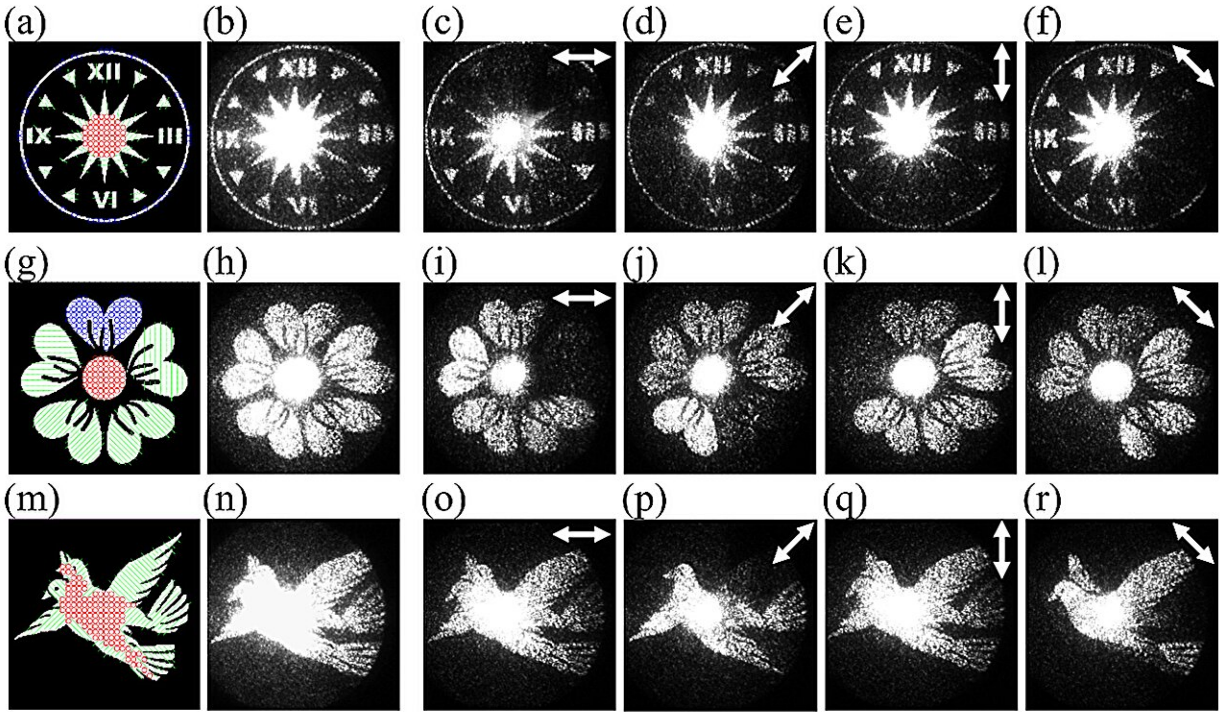


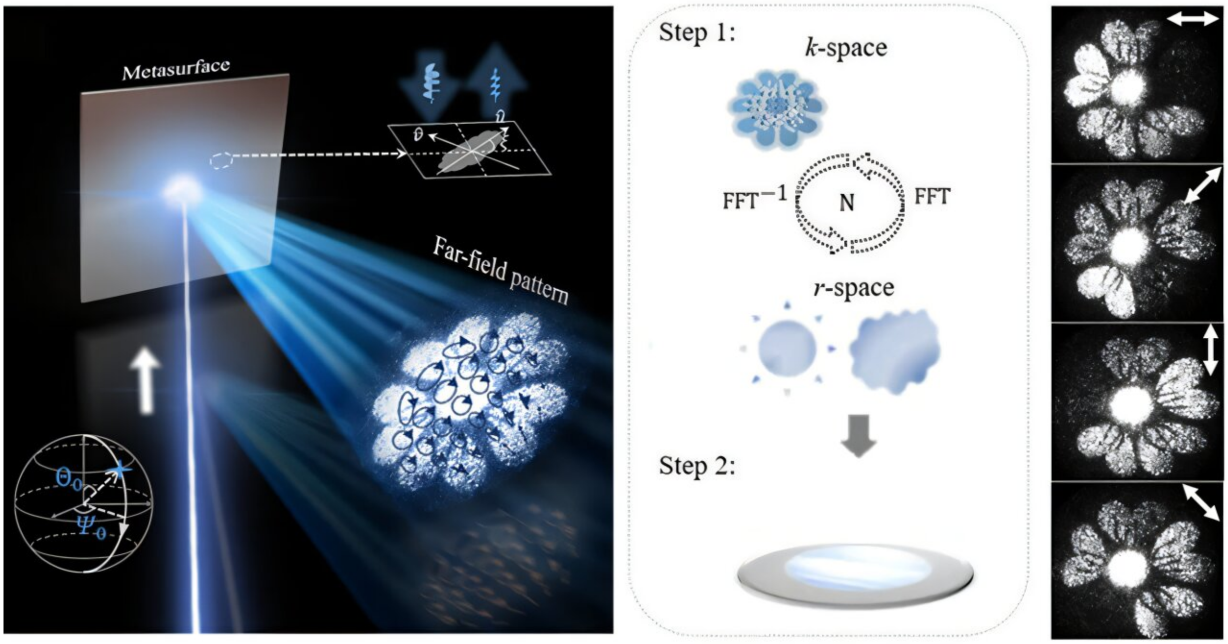
Experimental demonstrations of different vectorial holograms. Target holographic images to be reconstructed: (a) a vectorial clock; (g) a vectorial flower; (m) a vectorial flying bird. Segments and circles denote local polarization states of the images. Panels (b), (h) and (n) depict the experimentally observed patterns as three fabricated metahologram samples are illuminated by left-circular-polarized (LCP) light at 1064 nm, respectively. Panels (c)-(f), (i-l) and (o)-(r) depict the polarization filtered patterns with a rotatable polarizer placed at different angles in front of the charge-coupled device, as three metahologram samples are illuminated by LCP light at 1064 nm, respectively. Credit: T. Liu, C. Dai, D. Wang, et al., doi 10.1117/1.AP.7.5.056004.

Holography—the science of recording and reconstructing light fields—has long been central to imaging, data storage, and encryption. Traditional holographic systems, however, rely on bulky optical setups and interference experiments, making them impractical for compact or integrated devices. Computational methods such as the Gerchberg–Saxton (GS) algorithm have simplified hologram design by eliminating the need for physical interference patterns, but these approaches typically produce scalar holograms with uniform polarization, limiting the amount of information that can be encoded.

To overcome these limitations, researchers from The Hong Kong University of Science and Technology, Fudan University, and the University of Hong Kong have developed a generic strategy for vectorial holography—holograms that encode both intensity and polarization—using ultrathin metasurfaces. As reported in *Advanced Photonics*, this method works under arbitrary incident polarizations and can generate complex images with spatially varying polarization states, significantly expanding the information capacity of holograms.

The research team achieved this by combining the GS algorithm with a wave-decomposition technique to calculate the scattering properties required for each meta-atom, the building block of the metasurface. These meta-atoms, based on a metal–insulator–metal structure, were engineered to control both phase and polarization conversion.

By adjusting geometric parameters and rotation angles, the researchers achieved precise control over reflection phases and polarization states, leveraging both structural resonances and the Pancharatnam–Berry phase. This approach allows the design of metasurfaces that are ultrathin—about one-quarter of the operating wavelength—and compact, with sample sizes under $200 \times 200\ \mu m^2$, making them ideal for on-chip integration.



On-chip imaging based on high-efficiency vectorial metaholograms. Credit: C. Dai, Fudan University; D. Wang, Hong Kong University of Science and Technology.

To demonstrate the concept, the team fabricated metasurfaces using electron-beam lithography and tested them under near-infrared light at 1064 nm. They created two series of vectorial holograms: one with rotational symmetry as a benchmark and another with complex, asymmetric patterns, including a clock, a flower, and a flying bird.

Each image displayed distinct polarization states across different regions, and when viewed through a rotating polarizer, the patterns appear to change dynamically, effectively "telling stories" as different parts appear or disappear. This feature suggests potential applications in optical encryption and anticounterfeiting. Importantly, the metasurfaces achieved high efficiency, with one device reaching nearly 68%, outperforming previous vectorial holography systems.

This work introduces a versatile platform for high-efficiency, polarization-independent vectorial holography. Its ultrathin design and compatibility with on-chip photonics make it promising for applications such as secure data storage, next-generation anticounterfeiting, and integrated optical systems. The method is also adaptable to other wavelength ranges and transmissive modes, and future improvements—such as using dielectric materials—could further boost performance.

More information: Tong Liu et al, High-efficiency vectorial holography based on ultra-thin metasurfaces, *Advanced Photonics* (2025). DOI: 10.1117/1.AP.7.5.056004

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