Soft chiral superstructure enabled dynamic polychromatic holography

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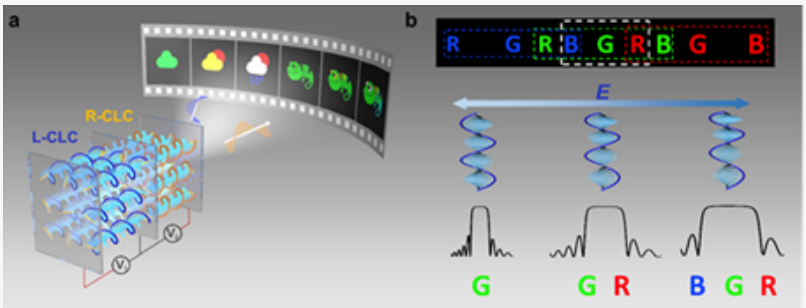

Figure 1 Schematic of wavelength- and spin-multiplexed dynamic polychromatic holography.

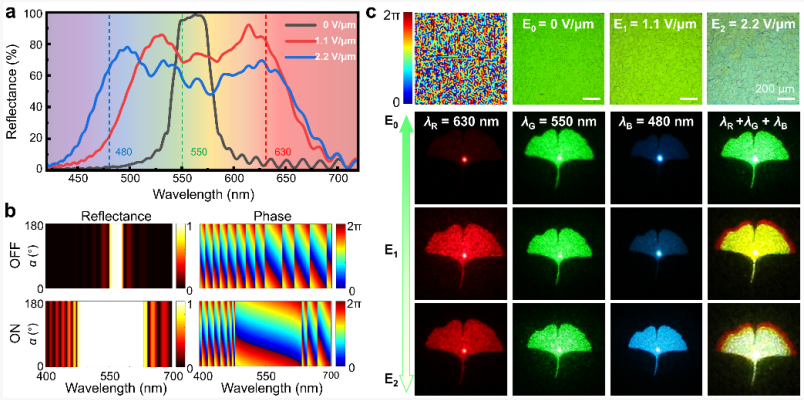

Figure 2 Electrochromic holography via polymer-stabilized CLCs.

Light, as a core carrier of information, possesses multiple dimensions such as wavelength, polarization, and phase. These dimensions act like a complex set of codes that collectively determine the world we see and the capacity for information transmission. In modern information technology, the efficient and dynamic manipulation of these light "codes" is key to achieving high-capacity data storage and high-security information encryption. Traditional optical elements, such as lenses and gratings, operate based on the gradual accumulation of phase changes along the propagation path, often resulting in bulky sizes and fixed functionalities. In recent years, planar optics based on metasurfaces has emerged. By precisely arranging nanostructures on a plane thinner than the wavelength, it can arbitrarily shape optical wavefronts, greatly promoting the miniaturization and integration of optical devices.

However, the functionalities of most metasurfaces become fixed once fabricated, making dynamic regulation difficult. This has become a major bottleneck for planar optics moving towards practical applications, especially in scenarios requiring real-time interaction (such as dynamic holographic displays and reconfigurable optical processors). Therefore, scientists have turned their attention to another type of "smart" material: liquid crystals. Liquid crystals, the core material of liquid crystal displays (LCDs) in our daily lives, possess unique soft matter characteristics in their molecular arrangement: under external stimuli (such as electric fields,

temperature, light), their molecular orientation can undergo reversible and rapid changes, thereby dynamically modulating the properties of light passing through them. This inherent "electrically controllable" characteristic makes them an ideal candidate for realizing dynamic planar optics.

Currently, achieving broadband, dynamic, and polychromatic regulation deeply integrated with complex wavefront modulation (such as holography) in a single device remains a significant challenge. Existing solutions mostly rely on spatially stacking multiple independent devices or complex structural designs, still suffering from precise alignment, constrained working bands, or complicated fabrication. Therefore, it is imperative to develop new planar optics with dynamic and multichannel functions.

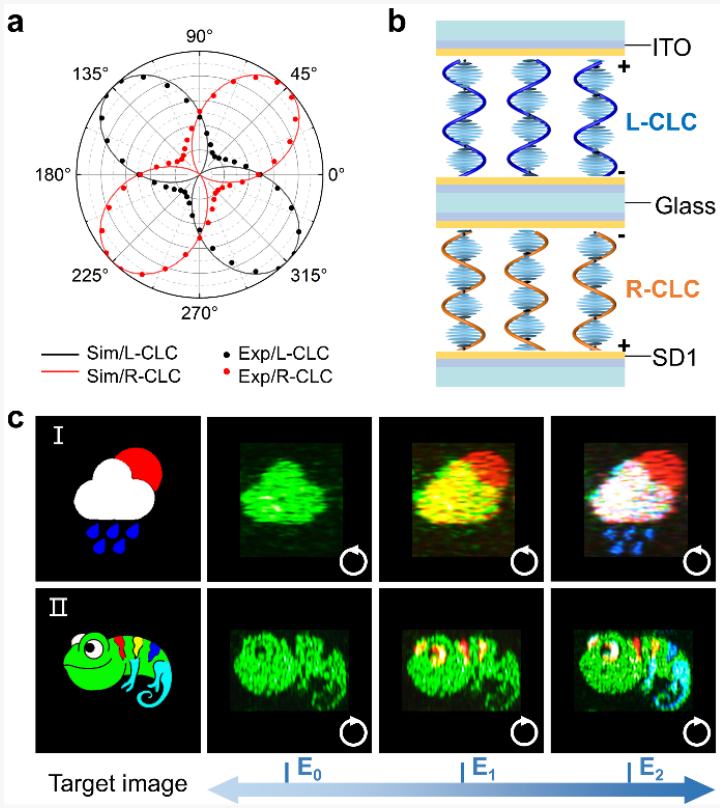

Figure 3 Spin-complexed dynamic polychromatic holography.

The authors of this article propose dynamic polychromatic holography based on the programming of a polymer-stabilized chiral superstructure. Polymer-stabilized cholesteric liquid crystals (CLC), a soft matter chiral superstructure, were used to successfully achieve dynamic polychromatic holographic display with dual multiplexing of wavelength and polarization.

The technical core of this research lies in the organic integration of "structural programming" and "dynamic broadband response." The research team first employed a modified Gerchberg-Saxton algorithm combined with k-space engineering, calculating and synthesizing off-axis phase-type holograms with specific deflection angles for the three primary colors: red (R), green (G), and blue (B). Subsequently, they used high-precision digital photopatterning technology to encode the phase information into the initial molecular orientation of the polymer-stabilized CLC layer, completing the "writing" of the holographic function. The dynamic performance of the device originates from its unique electric response mechanism: Under zero electric field, the liquid crystal maintains a uniform pitch with a narrow photonic bandgap (~40 nm), efficiently reflecting and modulating only incident light of a specific band (e.g., green light), presenting a monochromatic holographic image. As the DC electric field strength increases, the helical structure transforms into a gradient pitch, continuously broadening the reflection bandwidth to 180 nm, covering the entire visible light range. At this point, the pre-encoded red and blue light holographic channels are sequentially "activated," ultimately synthesizing with the green light channel in space to dynamically reconstruct a high-quality full-color holographic image. The

entire process is fully reversible, with switching times on the order of hundreds of milliseconds.

Furthermore, the inherent spin selectivity of CLC Bragg reflection and the resulting geometric phase (i.e., Bragg-Berry phase) modulation characteristics was leveraged. By cascading polymer-stabilized CLCs of opposite helicity, each encoded with different holographic information (such as "weather symbols" and "chameleon"), spin-complexed polychromatic holography with switchable hexa-channel functionalities is demonstrated. This device can selectively display the corresponding holographic image based on the left-handed or right-handed circular polarization state of the incident light. Moreover, the color channels can be reversibly dropped or added by controlling the applied voltages. This design achieves orthogonal multiplexing in the two dimensions of polarization and wavelength, constructing up to six independently addressable optical information channels on a single device platform, significantly enhancing the functional density and information-carrying capacity of the device.

This research marks a crucial step for dynamic planar optics moving from static pattern display towards intelligent multi-parameter regulation. This technology is well-suited for applications in high-security dynamic optical anti-counterfeiting, switchable multi-dimensional information display, and high-density optical information encryption/storage systems. For example, in high-end anti-counterfeiting, the colored holographic image presented by a label can change dynamically with the verification voltage and requires matching specific polarized light for reading, thereby constructing multiple anti-counterfeiting barriers. This work explores the capability of chiral soft matter in active spatial light modulation and may supply a compact, dynamic, and multi-channel platform that will trigger fantastic applications in dynamic holographic displays, beam shaping, information processing, and high-security encryption.

Keywords: polychromatic holography, cholesteric liquid crystals, polymer stabilization, geometric phase, photoalignment
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