**Printing Mechanochromic Chiral Structural Colors**

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**Abstract**
A high-throughput structural-color printing strategy creates mechanochromic chiral graphics through direct ink writing and evaporation-induced self-assembly of chiral liquid crystal inks. This breakthrough, recently reported in *Matter* by Wang, Feng, and co-workers, provides unprecedented levels of versatility and controllability to prepare structural-color graphics.

**Main Text**
Optical materials captivate both scientists and artists with their extraordinary light-manipulating abilities. Nature offers fascinating examples, such as the vivid structural colors of butterfly wings, the selective light reflection of beetle cuticles, and the dynamic stimuli-responsive color changes of chameleon skins. These phenomena inspire one question: Can we create smart adaptive optical materials that mimic these natural capabilities? A team led by Wang and Feng at Tianjin University has taken a significant step towards this goal. They have developed an advanced structural-color printing technique based on chiral liquid crystal (CLC) inks, creating mechanochromic graphics that reflect light selectively and change colors dynamically.[1]

Structural colors arise from the interaction of light with periodic micro- or nanostructures, leading to vibrant and long-lasting diffraction colors. Recently, structural color printing has been recognized as a compelling method to create images, often employing micro- and nanoscale building blocks as printable inks that can be precisely tailored to specific designs, color schemes, and substrate types.[2,3] For high-quality structural color printing, the inks should be carefully formulated to facilitate both microscopic self-assembly and macroscopic printing. While colloidal nanoparticles are commonly used due to their ability to form photonic structures through self-organization,[4,5] they often suffer from local structural cracks or lattice distortions that can impede the quality of the final photonic patterns. Moreover, structures printed using conventional methods tend to be static and lack dynamic adjustability. Therefore, high-throughput fabrication of structural-color graphics with superior optical properties, dynamic tunability, and responsive functionalities remains a significant challenge, but holds immense promise for future applications.[6-8]

The team developed a high-throughput structural-color printing technology, providing a streamlined and versatile method to produce vivid structural colors. The printed patterns not only show high brightness and color saturation but also exhibit circularly polarized reflections and mechanochromic responses across the entire visible spectrum. Their strategy combines direct ink writing and evaporation-induced self-assembly

(EISA) of CLC inks. These inks contain reactive mesogens as monomers, chiral mesogens to tune chirality and pitch, chain extenders to adjust the crosslinking density and elastic modulus, and toluene as the solvent. In the direct-writing process, CLC inks are precisely deposited onto substrates along preset paths to create customized graphics. After printing, the molecules in the CLC inks rapidly self-organize into helical nanostructures through the EISA process, followed by a Michael addition reaction that facilitates initial crosslinking at room temperature. Upon complete evaporation of toluene, the graphics undergo a second stage of photoinduced crosslinking under UV light to further solidify and stabilize the structural colored pattern.

This structural color printing technology allows for creating customizable patterns that can display different colors and circularly polarized reflections. For example, by varying the content of chiral mesogens in the CLC ink, the team successfully printed Eiffel Tower patterns that reflect three different colors (Figure 1a). Similarly, a multicolored Temple of Heaven pattern was achieved using multiple nozzles dispensing different CLC inks (Figure 1b). These structural-color graphics could be printed on various substrates, such as glasses, polymethyl methacrylate (PMMA) plates, polished metals, silicon wafers, and paper. Additionally, the chiral nanostructure of the CLC endowed the printed graphics with circularly polarized reflections, mimicking the structural colors found in jeweled beetles in nature (Figure 1c). Further, the researchers created a circular polarization cinefilm by printing complementary patterns with two CLC inks of opposite chirality. When this cinefilm was rotated, a depiction of a running puppy could be observed through left and right circular polarizers (Figure 1d). We envision that this technology can print more complex patterns that display varied optical information under different polarizers.

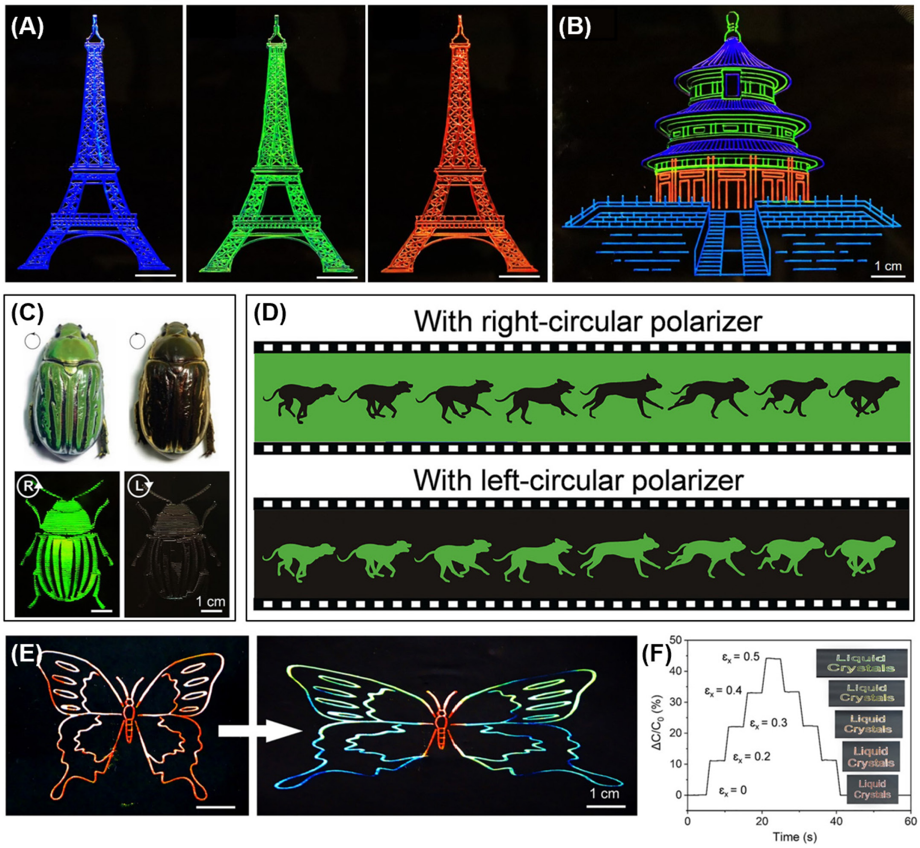


**Figure 1. Direct ink writing of mechanochromic graphics.**
(A) Eiffel Tower patterns printed using red, green, and blue inks. (B) Temple of Heaven pattern printed using four different inks. (C) Appearance of jeweled beetle C. gloriosa under polarizers (top) and printed beetle patterns (bottom). The bright green reflection color was observed under a left-circular polarizer (LCP) and disappeared under a right-circular polarizer (RCP). (D) Circular polarization cinefilm viewed under RCP and LCP. (E) Photos of a butterfly pattern under stretching. (F) Relative resistance ($\Delta C/C_0$) on the stretchable photonic film as a function of time at different strains ($\varepsilon_x$).

Notably, mechanochromic photonic patterns have been achieved by directly writing CLC inks onto stretchable elastomeric films pre-treated with functional silanes to enhance adhesion. These as-prepared photonic patterns demonstrated real-time and reversible color changes as the elastomeric substrates were stretched and relaxed. Moreover, the mechanochromic properties of these patterns could be easily adjusted by varying the chain extender content in the CLC inks, which altered the crosslinking density and elastic modulus of the printed patterns. For example, a butterfly pattern was engineered to initially display a single red color and then transform into a multicolor butterfly with distinct color separation upon stretching, achieved by using multiple CLC inks with varying chain extender content (Figure 1e). Intriguingly, these structural-color patterns have also been successfully printed onto stretchable electronics, enabling visual and electrical dual-signal outputs (Figure 1f). Such dual-signal systems hold significant potential for developing novel wearable devices that facilitate advanced human-machine interactions.

By integrating the EISA process of CLC inks and direct ink writing technology, followed by photopolymerization to stabilize the printed graphics, this versatile structural-color printing strategy allows customization of multicolor patterns on various substrates, ensuring high mechanical and thermal stability. Incorporating chirality into photonic crystals with dynamically tunable photonic bandgaps enables the real-time modulation of circularly polarized reflection properties. Moreover, when combined with emerging luminescent materials or quantum dots, these chiral structural-color graphics could facilitate the modulation of circularly polarized luminescence, paving the way for application in dynamic information encryption and flexible 3D displays.[9,10] Additionally, printing smart adaptive optical materials on flexible substrates such as textiles or elastomers can lead to novel wearable devices that provide real-time visual monitoring of physiological parameters or environmental conditions. This exciting advancement opens the door to developing high-throughput structural-color printing technologies with unprecedented applications in bioinspired artificial skin, wearable displays, human-machine interaction, interactive soft electronics, and beyond.

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**Declaration of interests**
The authors declare no competing interests.

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