Wafer-scale structural coloration using interference lithography and grayscale-patterned secondary exposure

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Colors play crucial roles in daily lives for the ability to carry information. Most commonly, colors are generated from pigments by absorbing light of certain wavelengths. Recently structural colors using nanoscale building blocks to physically manipulate visible electromagnetic waves, have been increasingly investigated due to the higher resolution, saturation, and durability than pigment-based colors. However most published structural color works using two-dimensional (2D) nanostructures can only be fabricated on small areas of millimeter scale or less because they need to use electron beam lithography (EBL), which is an expensive and time-consuming tool for high-resolution patterning of spatially varying structures. Recently we have proposed a high-throughput and wafer-scale nanopatterning method of interference lithography and grayscale-patterned secondary exposure (IL-GPSE) that could spatially modulate nanostructure feature sizes on large scale while maintaining sufficiently high resolution[1]. Here, we employ the IL-GPSE method in the fabrication of wafer-scale structural color paintings that improves the patterning efficiency by orders of magnitude when compared with EBL, implying great potential applications of structural color metasurfaces such as biomedical sensing[2], anti-counterfeiting, and information encryption[3].

Figure 1a schematically demonstrates the fabrication of dimension-varying 2D nanostructures achieved by IL-GPSE, composed of a high-contrast IL for fabricating large-area periodic nanostructures and a secondary exposure for locally tailoring structural dimensions. **Figure 1b** shows the centimeter-scale photoresist pattern fabricated by IL-GPSE, displaying various colors while **Figure 1c** shows the corresponding SEM images of different feature sizes. **Figure 2** demonstrates that IL-GPSE allows large-area structural color paintings using a specially designed secondary exposure intensity distribution, such as bio-inspired butterfly patterns and renowned artwork replications.

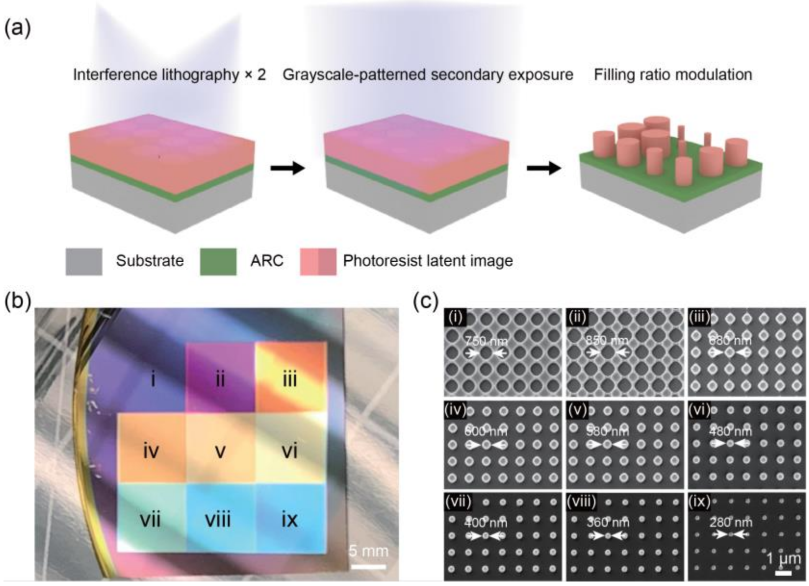

Figure 1 (a) Schematic of spatial modulation of filling ratio for 2D nanostructures using IL-GPSE. (b) The fabricated centimeter-scale structural coloration using different secondary exposure doses, displaying various colors. (c) SEM images of different regions in (b), showing nanostructures with different feature sizes modulated by IL-GPSE.

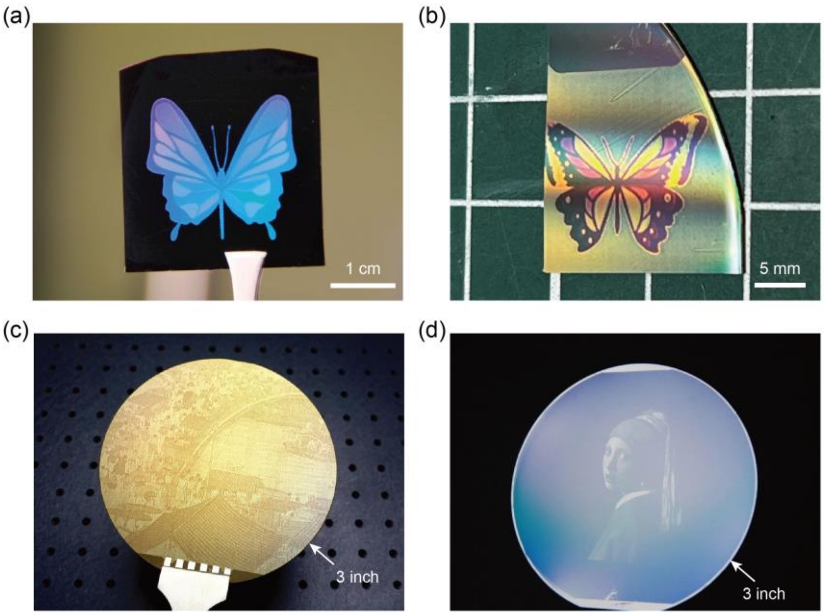

Figure 2 Structural color paintings based on IL-GPSE nanopatterning method. (a, b) Centimeter-scale bio-inspired structural color matasurface showing butterfly patterns. (c, d) Wasfer-scale structural color paintings of *Along the River During the Qingming Festival* and *Girl with a Pearl Earring*.

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2. Min, S. Y. et al. Ultrasensitive molecular detection by imaging of centimeter-scale metasurfaces with a deterministic gradient geometry. Adv. Mater. 33, 2100270 (2021).

3. Cai, J. X. et al. Dual-color flexible metasurfaces with polarization-tunable plasmons in gold nanorod arrays. Adv. Optical Mater. 9, 2001401 (2021).