R&D Highlights

RECOMMENDED READING

Denmark researchers pursue omnidirectional structural color

By **Tom Mackay**

Experiments by Denmark researchers are presenting a promising and innovative new approach to color engineering of manufactured goods without pigments and dyes: angle-independent structural colors.

Traditionally, manufacturers have added pigments and dyes derived from animal, plant, or mineral sources to color their products. Synthetic pigments and dyes are more commonplace in factories today. However, coloration provided by pigments and dyes can fade over time and some pigment and dye production may involve toxic chemicals.

One alternative from the field of nanophotonics, which could potentially yield long-term coloration without toxicity, is offered by structural colors, colors of a purely physical provenance.

Structural colors arise from optical phenomena such as interference, diffraction, or scattering, due to structures at microscopic- or nanoscopic-length scales. Many beautiful examples of structural coloration can be found in nature, from butterfly wings and fish scales to opals and pearls.

Recent advances in nanofabrication techniques present attractive opportunities for realizing synthetic materials that exhibit structural color.

Typically, materials that exhibit structural color are iridescent; the color perceived depends upon the angles of illumination and observation. However, many commercial applications require color that is angle-independent.

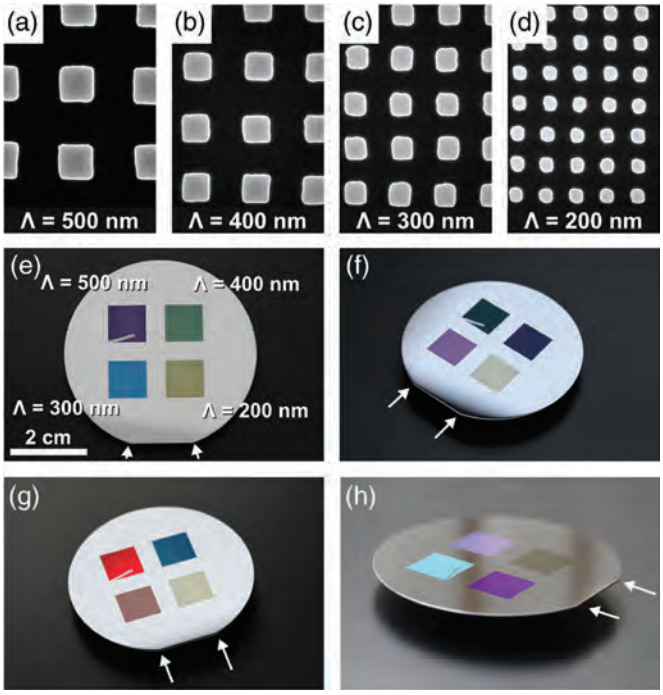
The quest for angle-independent structural color was pursued in "Angle-independent structural colors of silicon," a paper appearing in a special section on nanostructured thin films in the *Journal of Nanophotonics*.

The remarkably simple approach described by Emil Højlund-Nielsen of the Technical University of Denmark (DTU) and his co-authors involves a monolayer comprising a square lattice fabricated on a single wafer of silicon using electron-beam lithography and dry etching.

Højlund-Nielsen et al. reported approximately uniform structural color over a 60-degree angle-of-incidence range for a lattice of 200 nm period.

Furthermore, their experimental observations agreed well with predictions from their complementary rigorous coupled-wave analysis. This angle independence was attributed to suppression of diffraction and strong coupling to localized surface modes.

These findings, for a nanophotonic structure whose simplicity seems particularly appealing from a manufacturing perspective, bode well for future technological developments pertaining to angle-independent structural color.



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Examples of silicon structural colors. Figures a-d are scanning electron microscope images 1.00 μm wide of the four periodic samples. Figures e–h are photographs of the four samples from different angles. In figure e, the camera is slightly tilted around 10 to 15° compared with normal incidence to avoid lens reflections.

Co-authors include N. Asger Mortensen and SPIE Senior Member Anders Kristensen of DTU; Johannes Weirich and Joergen Garnaes of the Danish National Metrology Institute (DFM A/S); and Jesper Nørregaard of NIL Technology.

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