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Full Gamut of Structural Colors in All-Dielectric Mesoporous Network Metamaterials

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Abstract: We engineer numerically and demonstrate experimentally a full gamut of structural colors in alumina network metamaterials fabricated by the electrodeposition method. The macroscopic-size mesoporous structures are attractive candidates for sensing, security, and color rendering applications.

OCIS codes: (330.0330) Vision, color, and visual optics; (330.1715) Color, rendering and metamerism; (350.4238) Nanophotonics and photonic crystals; (160.4670) Optical materials; (160.3918) Metamaterials.

Structural colors stem from the frequency-selective light scattering by micro- and nano-scale features within the material rather than from the tailored optical absorption spectra of pigments or dyes. They are abundant in nature, robust, and can be reversibly changed by temperature variations, material deformations, and saturation with gases or liquids. Materials with engineered colorimetric signatures detectable by the naked eye can find use in optical sensing and security applications [1–3]. However, many approaches to realizing artificial structural colors rely on low-throughput fabrication techniques, and some are limited to microscopic footprints. Here, we report on the optical design and high-throughput fabrication of the all-dielectric mesoporous materials with engineered colorimetric signatures and macroscopic footprints.

The mesoporous network metamaterials were fabricated via the electro-deposition method [4] by selectively etching through anodic aluminum oxide to create ordered (i.e., periodic or quasi-periodic) internal structure of layers with different porosity. Figure 1a illustrates variation of the structural colors of periodic photonic structures composed of low- and high-porosity layers (shown in Fig. 1b) predicted by optical modeling. The colors were calculated from the optical spectra of periodic porous network structures according to the CIE colorimetric standard [5], and are shown on top of the CIE 1931 color space chromaticity diagram. Different points on the diagram correspond to the colors predicted to be exhibited by the periodic structures with varying thickness of the low-porosity layers (shown as labels). The star-shaped labels correspond to the structural color coordinates extracted from the measured optical spectra of fabricated structures shown in Fig. 1c,d.

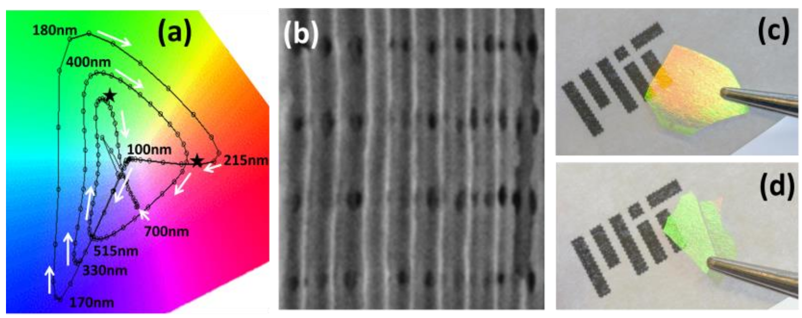

Fig. 1. (a) Colorimetric signature design space for periodic mesoporous photonic crystal structures with a varying thickness of the lower-porosity layer. (b) SEM image of the fabricated periodic mesoporous material. (c) Photographs of the fabricated structures with distinct structural colors stemming from different periodicity of the pore size distribution. The star-shaped labels in panel (a) correspond to the design parameters used in fabricating structures in panels (c) and (d).

The developed porous alumina network metamaterials can serve as colorimetric sensing platforms. We observed dramatic color changes in the material on top of various material substrates that themselves do not exhibit distinct colors. High porosity of the structures offers promise for strong color variations upon permeation with gas molecules or liquids. The alumina structures can be further used as templates in cheap and high-throughput fabrication of inverse-structure metamaterials made of plastics, metals and semiconductors. This can expand their application range and help achieve sensing selectivity.

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