technique, called conformal-evaporated-film-by-rotation (CEFR), recently developed by R.J. Martín-Palma, C.G. Pantano, and A. Lakhtakia of The Pennsylvania State University, involves thermally evaporating an inorganic glass onto a rotating biological sample, to replicate at the micro- and nanoscale the morphology of a butterfly wing.

As reported recently in *Applied Physics Letters* (DOI: 10.1063/1.2973167), the researchers replicated a wing of the butterfly *Battus philenor* with chalcogenide glass ($Ge_{28}Sb_{12}Se_{60}$), chosen because of its large index of refraction at visible and infrared (IR) wavelengths, and its high transmittance in the IR. In addition, illumination of chalcogenide glasses can modify the optical bandgap and index of refraction, making them suitable for passive and active infrared devices. The researchers thermally evaporated the chalcogenide glass using a current of 95 A for 30 min, directing the vapor flux toward the substrate at an angle of 85° to normal, with the substrate rotating at a constant speed of 0.5 rotations/s, resulting in a coating about 0.5 μm thick. Scanning electron microscope images show that the replicated structure is composed of thousands of scales with typical dimensions of about 50 μm by 200 μm, arranged in rows. A grid of raised longitudinal, quasiparallel lamellae runs the length of a typical scale, spaced at about 2.5 μm. Filling the space between adjacent lamellae is a netlike reticulum, composed of fine tubes. The researchers said that both the lamellae and the reticulum are the optical elements that give the wing its particular color. The researchers used energy dispersive x-ray spectroscopy to show that they fabricated a high-fidelity, chalcogenide glass replica of the original biotemplate without disturbing the original structure. In addition, specular and scattered reflectance spectra in the visible and IR (200 nm–2 μm) are similar for the original specimen and the replica; the minor differences were explained by the researchers as due to the difference in the indices of refraction of the wing material and the glass. In addition, the researchers said, "Since the morphology of the butterfly wing makes it a very efficient diffuser of light, the replica could be used as an antireflection structure for increased photon trapping and optical diffusers," and "the CEFR technique might be useful for the development of high-efficiency biomimetic optical devices."

STEVEN TROHALAKI

Higher Order Stop Gaps Observed in Photosensitive Chalcogenide Glasses 3D Photonic Crystals

Photonic crystals (PCs) are key components for the next generation of miniaturized photonic devices because of their capability to control and manipulate the flow of light on a wavelength scale. E. Nicoletti and co-workers from the Swinburne University of Technology, Victoria, and D. Bulla and co-workers from the Australian National University, Canberra, have reported in a recent issue of *Optics Letters* (posted online on September 8) on the observation of first- and second-order stop gaps in the near-infrared wavelength region on three-dimensional (3D) PCs based on photosensitive chalcogenide glasses (ChGs) fabricated by direct-laser-writing.

The researchers used ~16–20-μm-thick As_2S_3 films deposited on glass slide substrates by thermal evaporation of As_2S_3 bulk glass in a vacuum chamber at 2×10^{-7} Torr and 310°C. Such films contain disconnected molecular cagelike structures (e.g., As_4S_4, As_4S_6) that can "open" when thermally or optically excited. The researchers produced this effect using a femtosecond Ti:sapphire laser beam (wavelength 800 nm, repetition rate 1 kHz), tightly focused into the films, leading to re-bonding and polymerization of the glass network in highly localized areas of the glass through a two-photon–induced nonlinear process. Subsequently, the researchers dissolved the unpolymerized glass in a solution of diisopentylamine and dimethylsulfoxide in multiple steps, starting with a highly concentrated

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solution (2–3 mol%) for about 5 min, followed by immersions in a diluted solution (0.5–1 mol%) for 10 min. In this way, the researchers achieved a 16-layer woodpile PC with an in-plane spacing of 1 μm and a layer spacing of 1.2 μm, built up by smooth rods, 150 nm in thickness, and excellent mechanical strength. The resolution limit of the direct-write fabrication process and multi-step etching process is beyond the diffraction limit and comparable to the fabrication limit achievable in photosensitive polymers. The researchers attributed this resolution limit to the threshold of the fabrication technique, combined with the multi-step etching process. Due to the ellipsoidal shape of each rod and the geometry of the woodpile structure, no complete bandgap could be achieved, and the researchers only observed partial bandgaps along the stacking direction.

According to calculations produced by the researchers, the fabrication process should produce two pronounced dips in the transmission spectrum, a first-order stop gap at a normalized frequency of 0.28–0.29 and 74% suppression ratio in transmission, and a higher order gap at a frequency of 0.40–0.41 and 25% suppression ratio. The measured optical response of the woodpile PC is in good agreement with the results of the calculations. Further calculations performed by the researchers revealed that these bandgaps could be engineered and tuned by either changing the filling ratio or the lattice constant of the PCs, which they confirmed experimentally.

The researchers consider that the use of such higher order bandgaps "provide an effective alternative to achieve photonic bandgaps in the telecommunication wavelength region, circumventing the need for structural miniaturization of the PCs."

JOAN J. CARVAJAL

Materials Design Principles from Ancient Armored Fish Give Clues for Improved Engineered Biomimetic Structural Materials

Dermal armor in fish first appeared ~500 million years ago in the Paleozoic period. As ancient fish became more predatory, armor design evolved incorporating smaller plates instead of larger plates and fewer, thinner layers replacing multiple, thick layers resulting in a lighter weight, balancing protection with mobility for maximum survival. B. Bruet, J. Song, M. Boyce, and C. Ortiz of the Massachusetts Institute of Technology have used nanoindentation and finite element analysis simulations to uncover structure–property–function relationships in individual scales of a model species of armored fish, *Polypterus senegalus*. The materials design principles of *P. senegalus* fish armor in the context of their primary environmental threat, penetrating bite attacks, and mechanically protective function, could lead to better bio-inspired engineered designs for human body armor, according to the researchers.

In the September 2008 issue of *Nature Materials* (DOI: 10.1038/nmat2231 p. 748), the researchers reported on a multiscale experimental and computational approach to examine multilayering and gradation within individual scales from *P. senegalus*. These freshwater fish, also known as the Gray bichir or Senegal bichir, appeared about 96 million years ago but still retain characteristics of their ancient predecessors. The researchers reported that *P. senegalus* scales consist of four organic–inorganic nanocomposite layers: ganoine (~10 μm thick), dentine (~50 μm thick), isopedine (~40 μm thick), and a bone basal plate (~300 μm thick), from the outer to inner surface, respectively. Penetration-resistance and elastic and plastic mechanical properties of the layers were examined spatially on individual scales by nanoindentation.

One overlying mechanical design theme revealed by these experiments was the juxtaposition of multiple distinct reinforcing layers each with its own unique deformation and energy dissipation mechanisms. Multiple cross-sectional indents revealed a decrease in Oliver–Pharr indentation modulus and hardness from outer to inner

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