

# Nature as an inspiration for printing angle-insensitive structural colors using two-photon polymerization

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In nature, colors that result from the interaction of light with structures on the micro- and nanoscale are referred to as structural colors. Typically, these colors are used by animals or plants to generate functions that ensure their survival, such as camouflage, mimicry, or communication [1]. For this purpose, organisms have developed sophisticated surface structures on their epidermis that often produce unique optical properties due to a combination of regular and irregular structural features, which delimits them from classical photonic crystals [2]. In this context, the most famous examples are the blue butterflies of the genus *Morpho*, whose color is produced by multilayers. However, the color surprisingly appears almost angle-insensitively due to specific disorder characteristics within the photonic structures [3].

Inspired by those butterflies, this work presents how a transparent photosensitive material can be processed by two-photon polymerization to mimic the angle-insensitive blue coloration. The morphology and optical properties of the biological and biomimetic surface structures were analyzed using scanning electron microscopy and angle-resolved spectroscopy. In addition, the great design freedom of the 3D printing technique enabled the processing of different structural geometries on the microscale and different feature sizes on the nanoscale in such a simple workflow not achievable by any other manufacturing technique. Therefore, it was possible to simultaneously tune the color hue and set the direction in which angle-insensitive colors appeared to an observer. As a result, numerous opportunities are conceivable to generate a broad diversity of highly complex patterns for counterfeit protection.

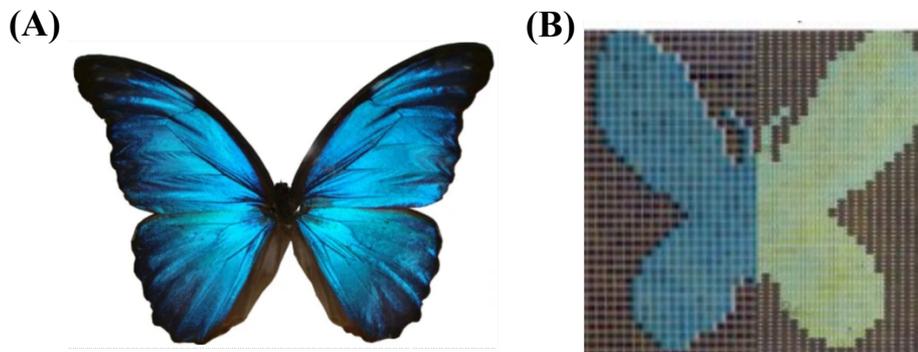


Figure 1: (A) The structural color of a *Morpho didius*. (B) Structural color generated by *Morpho*-inspired structures using two-photon polymerization.

## References

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- [3] S. Kinoshita, S. Yoshioka, J. Miyazaki. *Rep. Prog. Phys.* **71**, 076401 (2008).

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