Photonics nanoarchitectures in butterfly scales allowing species identification

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INTRODUCTION

Vision and color constitute a very important communication channel in the living world. Chemical colors are based on the selective absorption of certain wavelengths by intramolecular processes while structural colors are arising from the interaction of light with photonic crystal (PhC) type nanoarchitectures with periodicity comparable with the wavelength of light. If the characteristic size of the nanostructures building up the PhC is in the range of tens to hundreds of nanometers, the color of the PhC will be in the visible range.

In the present work we investigated the photorefractive structural colors of nine Lycaenid butterfly species living in similar habitats with overlaps of their flying period (Figure 8). The dorsal side of the wings of these male butterflies has blue coloration of different hues. Entomologists distinguish these and other blue butterflies has blue coloration of different hues. The brachial pattern varies from species to species and even within species the color patterns are substantially different. The wings of butterflies are highly iridescent in the visible range. Entomologists use optical microspectroscopy to distinguish the species. Entomologists also use physical destructive techniques, such as laser scanning or SEM imaging to study the nanostructures within the scales.

EXPERIMENTAL

All the examined specimens were collected in the proximity of Budapest (Hungary) hills and originated from the Leopoldina collection of the Hungarian Natural History Museum. This material was available to us under the condition that during the experiment no specimens were harmed. The examined specimens were prepared by a special procedure, which allowed the reproducible spectral characterization of the butterflies without harming the museum specimens. First, we measured the visible reflectance of the wing, a properly trained neural network can identify an unknown butterfly species measured with the “spectroboard”. Using optical microscopy we observed the scale nanoarchitectures of the specimens and determined their characteristic size. The characteristic size of the nanoarchitectures is the main reason for the reproducibility a good concordance of spectral shapes is obtained from conspecific exemplars, a characteristic spectrum might be derived by averaging the curves of the same species but not from different species. By measuring the visible reflectance of the wing, a properly trained neural network can identify an unknown butterfly species measured with the “spectroboard”.

RESULTS AND DISCUSSION

The nanoarchitectures in the wing scale act as a photonic band gap composite, the color is determined by the physical dimensions arrangement and refractive index contrast of the components. The wing is mainly constituted of chitin, the structural differences should be responsible for different hues. To regularize well comparable spectra, with the “spectroboard” all specimens were measured in the same region of the right forewing. As a proof of reproducibility a good concordance of spectral shapes is obtained from conspecific exemplars, a characteristic spectrum might be derived by averaging the curves of the same species but not from different species. By measuring the visible reflectance of the wing, a properly trained neural network can identify an unknown butterfly species measured with the “spectroboard”.

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REFERENCES


Figure 1. Scanning and cross-section transmission electron microscope image of Polyommatus bellargus dorsal scale. Between longitudinal ridges and cross-rods linking these is the pepper-pot type nanoarchitecture. From 5 parallel perforated chitin layers only the upper 2 are seen in TEM images. The ridges and the area under the ridges also contain nanostructures.

Figure 2. Dorsal (top) and ventral (bottom) image of a Polyommatus icarus butterfly. Mean wing span x = 3.5 cm. The position of the shadow indicates the light incidence angle.

Figure 3. Dorsal side perpendicular view photographs of the nine investigated Polyommatus species: (a) P. amandus, (b) P. bellargus, (c) P. cordon, (d) P. damon, (e) P. daphnis, (f) P. dorylas, (g) P. icarus, (h) P. semiargus, and (i) P. thersites.

Optical microscopy was carried out using an Avantes 2048-2 modular fiber optic spectrometer. Due to the large number (110 pc.) of individuals used in the study it was necessary to elaborate a measurement method that allowed the reproducible spectral characterization of the butterflies without harming the museum specimens. We developed an instrument called “spectroboard” consisted from a basic magnification of the setting board used by the entomologists with additional mechanical parts that allows the illuminator and pick-up fiber to move over butterfly wings at a fixed distance [2]. The light incidence and detection are perpendicular to the wing. This setup allows the reproducible and characteristic spectra while it does not necessitate physical destruction of the specimens.