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Structural Colour in Butterfly *Apatura Ilia* Scales and the Microstructure Simulation of Photonic Crystal

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Abstract

The butterfly *Apatura ilia* is a species in the Northeast of China. There are billions of tiny scales on its wings, which overlap like roof tiles and completely cover the membrane, appearing as dust to people naked eye. The scales produce brilliant structural colour through their multilayer microstructure. In this paper, the microstructure and geometrical dimension of the scales were observed using a Scanning Electron Microscope (SEM). The cross section micro-configuration of the purple scales was achieved using a Transmission Electron Microscope (TEM). The reflectivity of the wing was measured by a spectrometer. The 3D multilayer microstructure of the ridges was optimized to 1D photonic crystal structure. The spectrometer experimental graph is in accord with the 1D photonic crystal simulation curves basically. In the end, the phenomenon of the purple structural colour was explained through the Snell equation.

Keywords: butterfly, scale, structural colour, photonic crystal

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1 Introduction

Butterflies are universally attractive because of their bright iridescences. These colorations serve many purposes in insects groups, including camouflage, which is used to elude their main predators; warning role, which is used as a mimic of bad-tasting butterflies; mate choice, which is used to attract and find their mates. The two categories, pigment and structural colour mark distinct classification of the colours found in all butterflies. Pigmentary colours in butterflies tend to be less remarkable than structural colours, which is generated through microstructure.

Investigations have been fulfilled for many years about how the structural colours are generated. A lot of descriptions have been put forward. In some butterflies, the structural colours come from the interference effects[1–5]. These kinds of butterfly wings have multilayer thin film structures in their scales. The multilayer structures have evolved to take advantage of the optical interference and produce a colorful iridescence from reflected sunlight. The diffraction grating structure makes the incidence diffract[6,7]. The third fashion is the photonic crystal effects[8–14]. The Tri-grating (antireflector) on the corneal surface of a butterfly (Vanessa kershawi) eye can form some structures colour found by Parker[15]. *Pierid* butterfly scales was explained to reflectance and scattering[16]. Here, we investigate the seemingly simple case of the wing colours of *Apatura ilia*.

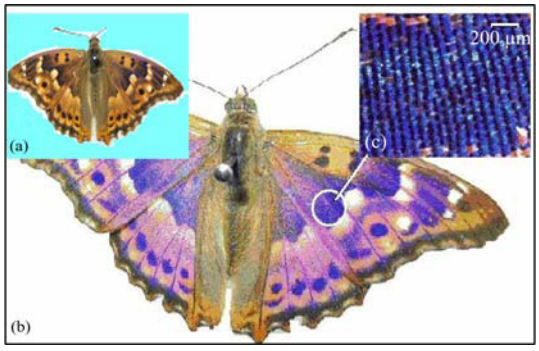

Fig. 1 *Apatura ilia* wings and its structural colour. a) dull brown colour; b) the colour change to shining purple with the angle change; c) specimen area for spectrophotometer experiment.

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As the butterfly *Apatura ilia* moves its wings up and down, the upper surface colour of the wings continually changes from bright purple to dull brown because of the transformation of the observing angle (Fig. 1).

The surface of *Apatura ilia* wing is covered with scales (with dimensions of the order of 60 μm by 150 μm) from which the flashing purple-structural colour originate.

2 Material and method

2.1 SEM experimental specimen

Specimen in this experiment was the wings of *Apatura ilia*. The specimen was rinsed by aether to get rid of the grume, grease and proteins on the wings surface. The following steps were a series of dehydration operations. Finally, the dry specimen was fixed on a metalline test-bed following by cold sputtered with gold.

2.2 TEM experimental specimen

Specimen was the shining purple part of the *Apatura ilia* wings.

The specimen was kept in 4% glutaraldehyde for 2 hours in order to avoid structure change due to the water evaporation after the cells death. Then, the specimen was dissolved in sodium cacodylate buffer solution for 1.5 hours. The specimen was kept in 1% osmic acid for 1.5 hours in the subsequent fixing step. Then it was followed by series acetone dehydration[17].

The next process was polymerization. The specimen was dissolved in the solution of epoxy dimethylmethane and embedding medium with 1:1 for 4 hours. Then, the specimen was put in the oven to be hardened. Finally, specimen was sliced into lamellas with 70 nm thickness for the TEM experiments.

2.3 Spectrometer measurement

Wing-reflectance spectra of the *Apatura ilia* were obtained by using a TU-1901 spectrometer with integral-ball. The light sources were halogen and deuterium lamps. The wing surface was 8° to the optical axis of the measuring instrument. The specimen size at the level of the wing was 4 mm × 4 mm that came from the most shining area of the dorsal wing (Fig. 1c). The reflectance spectra were calibrated against a white reflectance standard.

3 Results and discussion

SEM pictures showed that the scales arrange in a regular pattern of roof tiles. Each scale is covered with thin parallel ridges (Fig. 2a). Two distinct scale types were found on the specimen from the SEM pictures (Figs. 2b and c). Both types of scales bear longitudinal ridges. On upper surface of type-II (Fig. 2c), there are

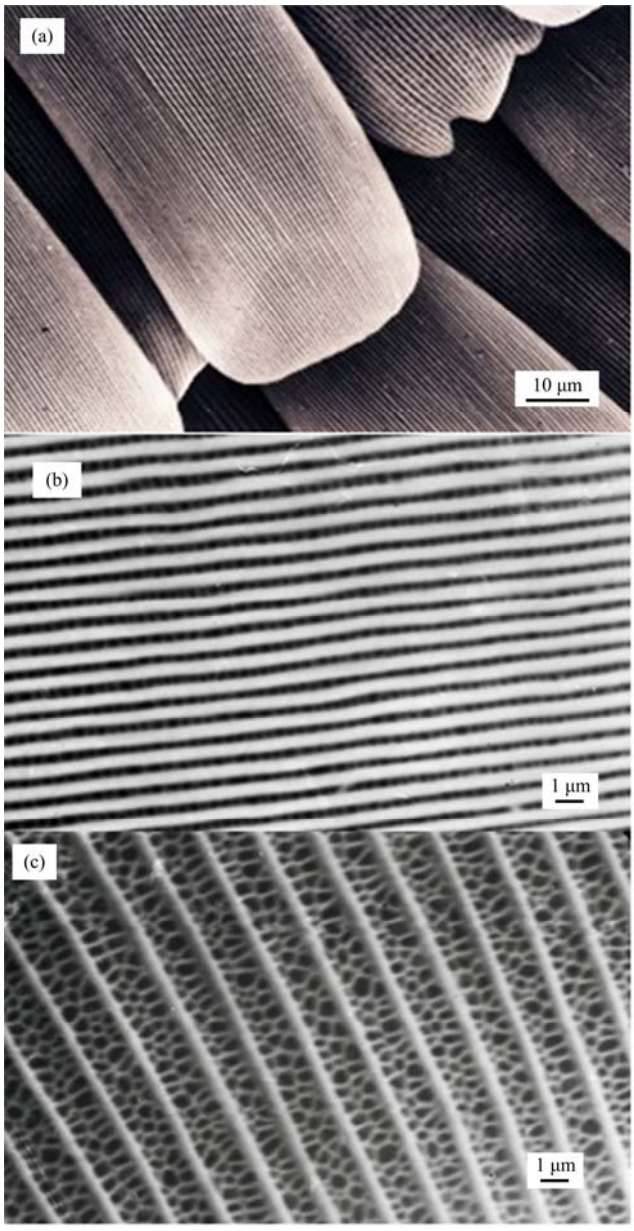

Fig. 2 SEM experiments results. (a) two kinds of overlapping scales; (b) type-I scale; (c) type-II scale.

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