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Photonic Iridescence of a Blue-banded Bee

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Although structural coloration in butterflies [1] has been extensively studied by entomologists, only recently it has caught the attention of physicists [2]. The more recent discovery of two-dimensional (2D) and three-dimensional (3D) photonic structures in a sea mouse and a weevil has attracted widespread attention. The 2D longitudinal arrangement of nano sea water filled tubules in a chitin matrix in the spines of the sea mouse gives rise to colorful iridescence [3]. The 3D opal-like closed-packed arrangement of nanospheres in the weevil results in green blue color seen from all angles [4]. We have studied the iridescent scales of a blue-banded bee using optical microscopy and spectroscopy, scanning and transmission electron microscopy.

Blue-banded bees (*Amegilla sp.*) are easily seen in Hong Kong. They are also common in South East Asia and Australia. The color of a blue-banded bee comes from scales on its back. The scales are typically 20×100 µm. Fig. 1 shows such scales in reflected light with the electric field vector nearly parallel (E_s) and perpendicular (E_p) to the scale axes . The scales are generally green with narrow blue patches (2 µm or less) perpendicular to the axis. The green hue is red-shifted to yellowish green when the scales are rotated by 90^0. In transmitted light, the scales are purplish with narrow yellow patches which are complementary to the reflected colors. The structure responsible for the iridescent color is thus perpendicular to the axis of the scale. This is confirmed by scanning and transmission electron microscopy. Hexagonal array of tubules in a matrix is clear seen in the SEM and TEM images of transverse sections of the scales (Fig. 2). The array is not regular, the spacing of the tubules is about 200 nm. The diameter of the tubules varies considerably with a typical value of about 80 nm. The number of tubule layers in a scale is about 10. The lattice formed by the tubules are rotated about their horizontal axis by about 30^0 within a region of 2 µm or less. The tubules are also tilted. The change of color is thus correlated with the rotation and tilting of the transverse tubules in the scales.

Spectra obtained from a local yellowish green area of a scale with the electric field vector parallel and perpendicular to the tubules are show in Fig. 3. There are two peaks in the E_s spectrum at about 510 and 560 nm. The 510 nm peak disappears in the E_p spectrum. Presumably, the 510 nm peak red- shifted by 50 nm to 560 nm. Theoretical modeling is undertaken to confirm this.

The tubules in the scales of the blue-banded bee is filled with air instead of sea water as in the case of the sea mouse, 10 layers instead of 88 layers of tubules is enough to effect high reflectance. .

References

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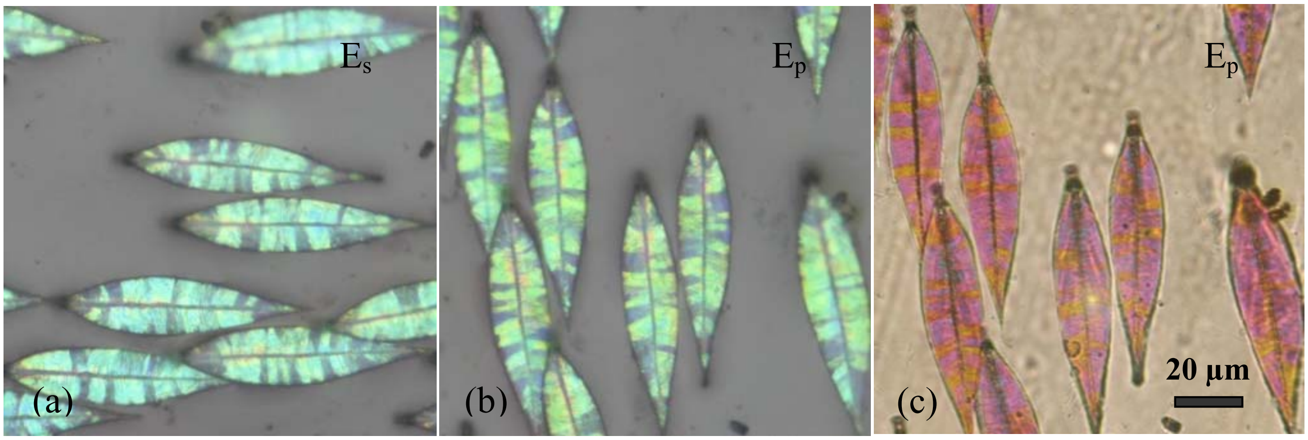
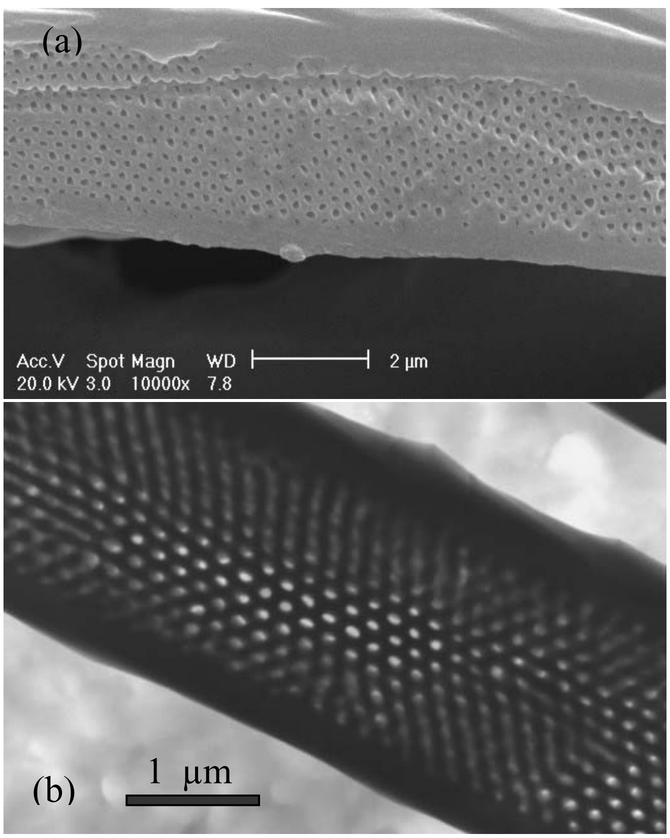


Fig. 1. Reflection images taken with the electric field vector perpendicular (a) and parallel (b) to the nano-tubules in the scales. (c) Transmission image corresponding to (b). Note the red-shift of hue in (b) and the complementary colours in (c).



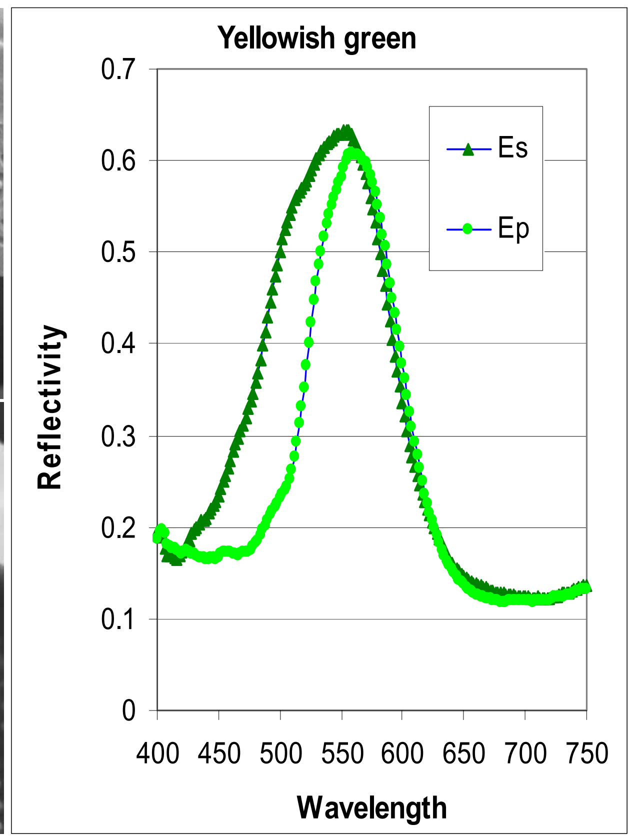


Fig. 2. SEM (a) and TEM (b) images of transverse sections showing the array of air tubules in a chitin matrix in the scales. The rotation of the "lattice" is clearly visible in both images. The tilting of the tubules is also evident in the TEM image.

Fig. 3. Spectra taken from a yellowish green area on a scale with the electric field vector perpendicular (Es) and parallel (Ep) to the air tubules in the scale.

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