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Microscopy and Chemical Inversing Techniques to Determine the Photonic Crystal Structure of Iridescent Beetle Scales in the Cerambycidae Family

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Photonic crystals (PCs) are periodic structures that manipulate light by defining allowed and forbidden frequency bands known as photonic band gaps (PBGs). PBGs have strong similarities with semiconductor band gaps. Despite satisfactory production of PC structures operating at infrared wavelengths, visible counterparts are difficult to fabricate because smaller periodicities must satisfy the diffraction criteria for optical wavelengths (400-700 nm) [1]. Such optical PCs would be applicable in photonic integrated circuits, quantum optics, miniature lasers and light-emitting diodes [2]. While some researchers use self-assembly techniques to arrange colloidal spheres into opal-based PCs, we turn to the 3D structures of iridescent beetles in the insect family of Cerambycidae as templates to create PC devices in the optical range [2].

Using an FEI XL30 ESEM FEG, we viewed the internal scale structure of *Glenea celestis* and *Anoplophora elegans* (Fig. 1) by opening the scales lying on top of the exoskeleton with a glass knife (Fig. 2). In both cases the internal structure is composed of nanoscopic spherical building blocks similar to opal gemstones (Fig. 3 and 4). However, while these spheres are highly ordered in the iridescent jewel-like blue colored *G. celestis*, the pastel green coloration of *A. Elegans* is produced by seemingly disordered sphere arrays. To understand such structural colors by calculating photonic band structures (and determining possible band gaps), it is therefore imperative to know the exact lattice structures.

Scales of *A. elegans* were embedded in Spurr's resin and sections were viewed on a glass slide using the ESEM as can be seen in Fig. 4 [3]. The microtome was used in an attempt to obtain a cleaner cross section and clearer picture of the internal ordering of the spheres [4]. The interior structure of sliced scales can be seen in Fig. 4. Transmission Electron Microscopy (TEM) imaging was difficult for these samples as the resin did not adhere to the scales nor penetrate internally. Despite these cleaner cuts, the small spheres continued to fall out of the scales.

To overcome this problem, a chemical replication process was used by filling spaces between the spheres with a hybrid silica sol-gel compound and burning out the original spheres [5]. Such inverted scales were viewed with the ESEM in low vacuum mode varying from 0.5-0.8 Torr at 20 kV as seen in Fig 5. From a combination of the biological and replicated images, a layering of hexagonally ordered sheets of spheres seems probable for G. celestis, whereas the photonic structure of *A. elegans* appears to contain hexagonal short-range order, lapsing into different planes (Fig. 5).

A stack of images using a slice-and-view technique [4] with the Helios was obtained. One image is shown in Fig. 6. This will allow for a 3D reconstruction of the scales permitting internal viewing of the structure so as to decipher the ordering of the spheres and calculate the photonic band structure (dispersion relations) [6].

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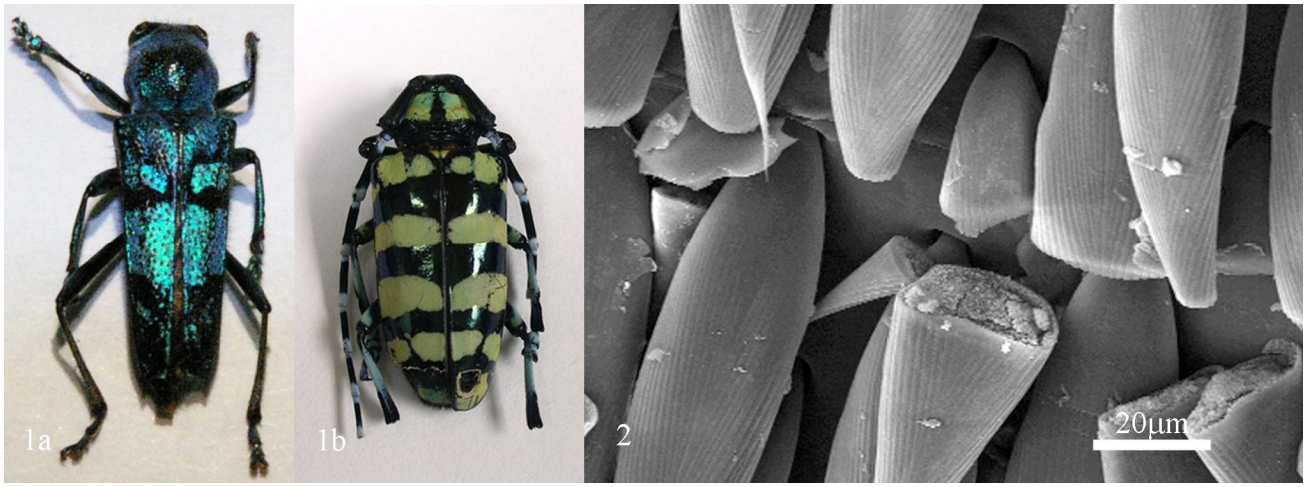

FIG. 1. Insects *G. celestis* (a) and *A. elegans* (b) with blue and pastel green scales respectively.
FIG. 2. Low Vacuum ESEM image of sliced scales attached to the insect exoskeleton.

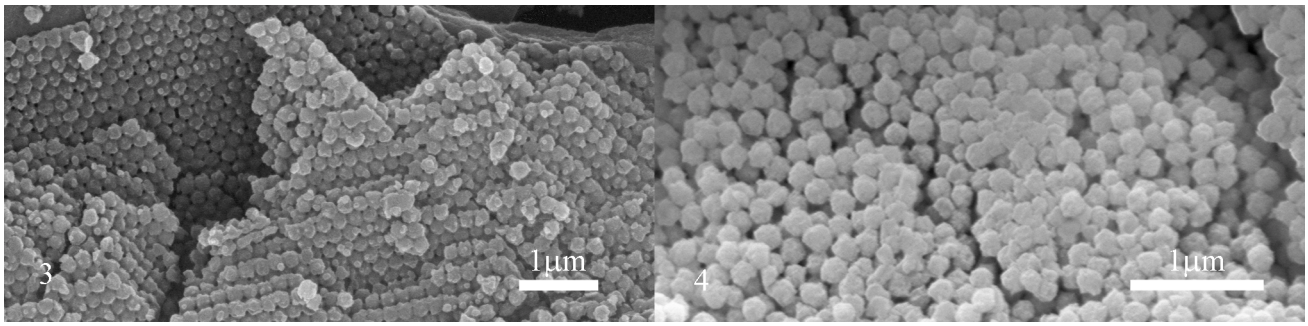

FIG. 3. ESEM internal "opal" structure of *G. celestis* with glass knife slicing method.
FIG. 4. Resin embedded ESEM images of an *A. elegans* scale.

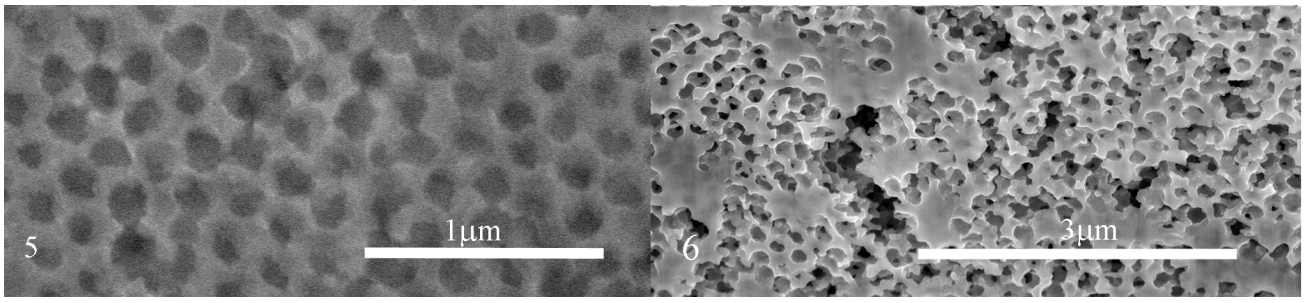

FIG. 5. Low-Vacuum ESEM image of chemically replicated structure of *A. elegans*.
FIG. 6. Single FIB image of *A. elegans*. Multiple images will be combined to produce a 3D model.

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