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Insect's photonic crystals and their applications

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Photonic crystals are periodic dielectric structures that have a band gap that forbids propagation of a certain frequency range of light. This property enables one to control light with amazing facility and produce effects that are impossible with conventional optics. In some butterflies, for example, layers of cuticle are intercalated with layers of air in order to generate efficient interference colors. Arranged of nanoscale photonic crystals in insects wings can be useful in insects taxonomies. Scientists have dreamed of computer chips that manipulate light rather than electricity. The chips require crystals that channel photons as nimbly as silicon channels electrons and though engineers have been able to imagine the ideal photonic crystal, they've been unable to build it. Researchers at the University of Utah describe how the inch-long Brazilian beetle's iridescent green scales, *Lamprocyphus augustus* are composed of chitin arranged by evolution in precisely the molecular configuration that has confounded the would-be fabricators of optical computers. So, scientists were used the insect photonic crystals in manufacture of computer microchip. Other scientists revealed that how the insect crystals form. This result is opening the door to better solar cells, fibre-optic cables and more.

Key words: Photonic crystals, nanoscale, computer microchip.

Insect wings are a multifunctional material system having various distributions in size and shape, spatial heterogeneity in its structural arrangements, and orientation of the photonic architectures. Natural photonics structures in the transparent insect wings have attracted much attention in recent years not only because of their potential for various biomimetics technological applications but also as ideal test bed to learn principles of coherent manipulation of light by nature (Wiederhecker et al. 2009; Mathias et al. 2010; Shevtsovaa et al. 2011).

Photonic crystals are a topic of great interest in optics. One dimensional photonic crystals are used in thin film optics (Joannopoulos et al. 1995). Their applications are low-and high-reflection coatings on lenses or mirrors, color changing paints and inks etc. The two-dimensional ones are already spreading into commercial applications. They are available in the form of photonic-crystal fibers. Micro scale structure is used to limit light with radically different characteristics compared to conventional optical fiber characteristics. Nowadays, three dimensional photonic crystals are still far from commercialization.

Role of photonic crystals in some insects

Insects colors in some cases due to photonic crystals not by pigment. These colors called physical colors not chemicals. These colors play an important role in the life of some butterflies as they are used in intersexual signaling, communication, warning signs, etc (Saranathan et al. 2010).

The wings of Morpho butterflies produce bright, vibrant, iridescent colors when light interacts with the micro- and Nano scale architecture of the wing scales (Fig. 1). Each scale is made of chitin, an abundant biopolymer and supports an array of parallel ridges. In cross-section, each individual ridge shows a periodic nan scale structure consisting of vertical and horizontal struts, resembling the shape of a tree. The iridescence of the Morpho wings is produced by light interference on the horizontal sections and by light diffraction on the vertical portions

(Potyrailo et al. 2007).

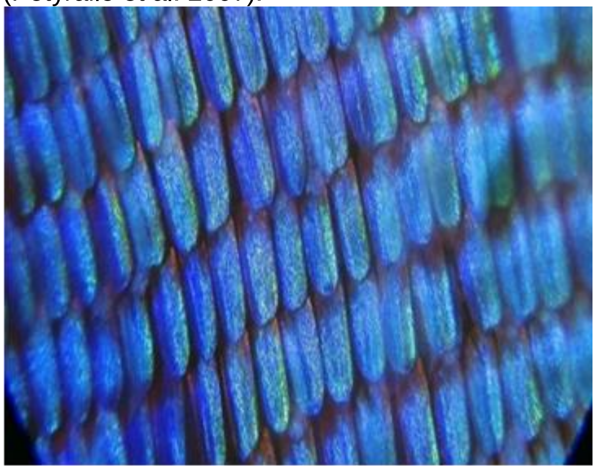

Figure 1. The scales on a wing of a Blue Morpho butterfly attain their hues through structural color.
Source & Copyrights: Grover Schrayer/Flickr.

New research on the color of Morpho wings at GE Global Research has determined that the scales also have an optical response to changes in thermal energy. Absorption of infrared (IR) radiation and the subsequent conversion to thermal energy by the chitin results in an expansion of the nanostructure; this morphological change produces an observable change in the wing's iridescence.

The wings of Morpho *butterfly* amplify the effects of iridescence because they have many more layers for the light to pass through and thus many more opportunities for the light waves to reflect and magnify one another (Fig. 2).

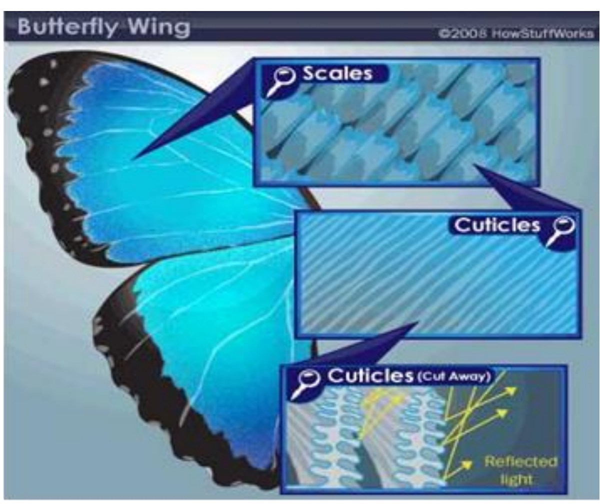

Figure 2. Morpho butterfly wings
Source& Copyrights: HowStuffworks 2008

As small as they are, butterfly wings are covered by thousands of microscopic scales, split into two to three layers -- thus their Greek order name, Lepidoptera, meaning scaled wings. In turn, each scale has multiple layers separated by air. Rather than having just the constructive interference from the top and bottom layer that you have in a bubble, the many, equally spaced layers of butterfly wings create multiple instances of constructive interference. When light hits the different layers of a butterfly wing, it is reflected numerous times. The combination of all these reflections causes the intense colors of many species.

Insect's photonic crystals and some applications

The speed and sensitivity with which the layered wing scales react to IR photons were previously unattainable in manufactured sensors. Scientists are now developing thermal sensors based on the nano scale structure of *Morpho* wings to improve not only response speed and thermal sensitivity but also to reduce the pixel size. Studies are also in progress to evaluate the vapor-response selectivity of the nano scale structure of Morpho wings. Continued research on Morpho wings may spur a new generation of sensor technologies (Pris et al. 2012) (Fig. 3).

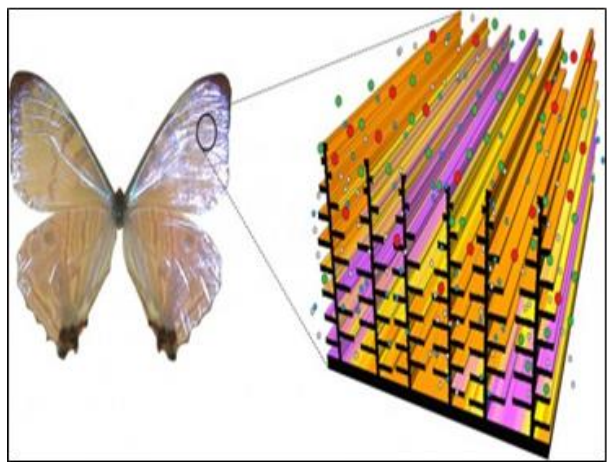

Figure 3. Representation of the chitin nanostructure seen in butterfly wings.
Source & Copyrights: Potyrailo et al. 2007

On the other hand, nocturnal moths are able to see at night because their eyes absorb a high proportion of light instead of reflecting it. Made of nanoscale structures in a, this architecture advantageously directs incident light to increase the insect's light sensitivity and to decrease external reflection visible to predators. The two components responsible for this light interaction are the tapetal mirror and the corneal nipple array (Takemura et al. 2007). The tapetal mirror situated behind the moth eye's photoreceptors allows light to reflect back through the eye structure, providing two opportunities to absorb incoming photons. The corneal nipple array-otherwise known as the “moth-eye” structure - covers the micron-sized facets of the eye and acts as an anti-reflective coating (Fig. 4).

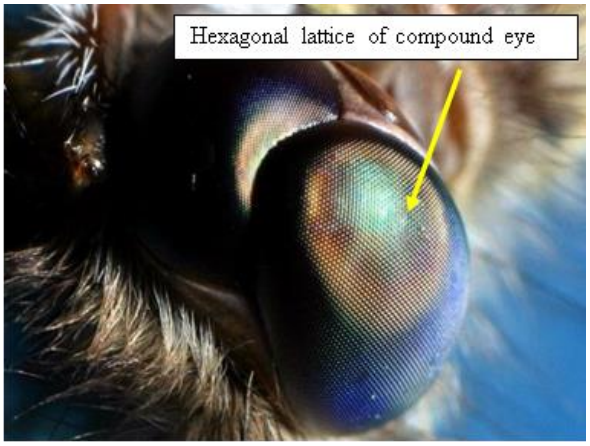

Figure 4. The photonic structure of moth eyes not only heightens their sense of sight but also decreases their detection by nocturnal predators.
Source: Copyright Rick Cowen

As a result, the moth is able to see in very low light conditions. Additionally, because the nanostructure of the eye absorbs such a high degree of light, the compound eye reflects little incident light, protecting it from detection by predators (Yamada et al. 2011).

Researchers at Nagaoka University of Technology in Japan have shown that applying anti-reflective “moth-eye” films onto existing solar panels increases the conversion of incident photons to usable “moth-eye” films onto existing solar panels increases the conversion of incident photons to usable electricity by 5%. Additionally, manufacturing techniques have been developed by researchers in the United States to incorporate moth-eye nanostructures in solar cells during their production, yielding increased solar cell efficiency (Sun et al 2008) (Fig. 5). A team of Shanghai Jiao Tong University researchers has used the shape of cicada wings as a template to create antireflective structures fabricated with one of the most intriguing semiconductor materials, titanium dioxide (TiO2) (Zada et al. 2016).

The antireflective structures they produced are capable of suppressing visible light—450 to 750 nanometers—at different angles of incidence.

Why cicada wings? The surfaces of the insect's wings are composed of highly ordered, tiny vertical "nano-nipple" arrays, according to the researchers (Fig. 6).

Cicadas (*Cryptotympana atrata* Fabricius) were obtained from Shanghai Natural Wild-Insect Kingdom Co., Ltd.

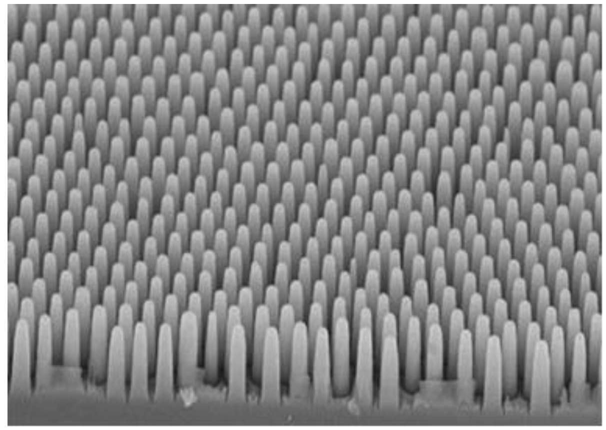

Figure 5. A manufactured anti-reflective “moth-eye” silicon film viewed through an electron microscope.
Source: Copyright Min et al. 2008

Figure 6. Cicada: spread wings

The cicada wings were washed with ethanol and deionized water thoroughly, and then air-dried for 30 min before being used as templates. Titanium sulfate (52 g) was dissolved in 70 ml of ethanol/water (4:3) containing a certain amount of Triton X-100 (30 drops). The mixture was then stirred for 60 min at 60 °C to obtain the Ti-precursor solution. The wings were pretreated with 8% NaOH, and then carefully dipped into the Ti-precursor solution and left immersed for 8 h at a constant temperature of 60 °C. The wings were then removed from the solution and cleaned thoroughly with absolute alcohol, after which they were then dried at 60 °C for 30 min. Finally, the wings were calcined in vacuum at 500 °C for 60 min to eradicate the organic template, leaving behind TiO2 with the surface structure of the cicada wing (biomorphic TiO2). Non-templated TiO2 was prepared by the same method as

Figure 7. The synthesis process of biomorphic TiO2 with the ordered nano-nipple arrays structures. Source & Copyrights: Zada et al. 2016

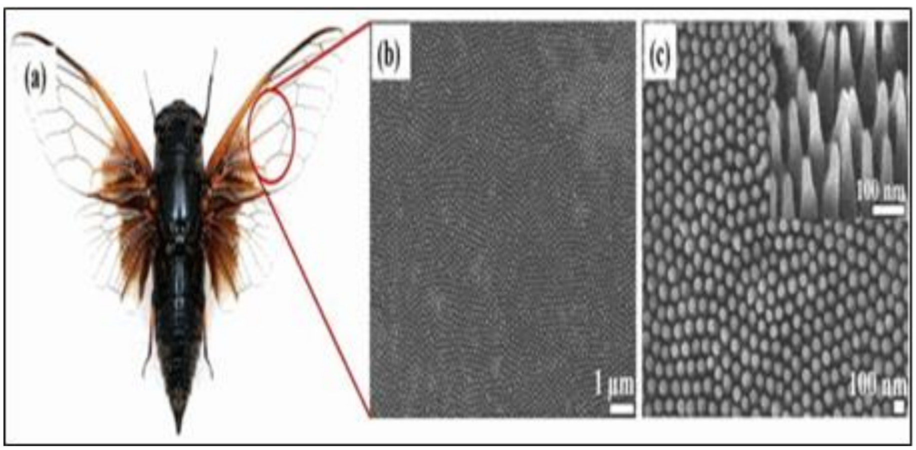

Figure 8. (a) Photograph of a black cicada (Cryptotympana atrata Fabricius) SEM images of the cicada wings; (b) low magnification top view; and (c) high magnification top view. The inset in (c) shows a side view. Source & Copyrights: Zada et al. 2016

described above, but without the bio-template. The synthesis process is schematically illustrated in figure 7.

Small spaces between the ordered nano-antireflective structures "can be thought of as a light-transfer path that let incident light rays into the interior surface of the biomorphic TiO2-allowing the incident light rays to completely enter the structure," Zhang continued. "The multiple reflective and scattering effects of the antireflective structures prevented the incident light from returning to the outside atmosphere.

The TiO2 was a purely anatase phase (a mineral form of TiO2), which has unique antireflective surfaces. This led to an optimally graded refractive index and, ultimately, to angle-dependent antireflective properties within the visible light range. Figure 8(a) shows a photograph of the original black cicada. It is evident that the wings of the cicada are completely transparent, excluding the parts with fibrous support network and some parts of the wing edges. Figures 8 (b) and (c) show low and high magnification top-view scanning electron microscopy (SEM; JSM-6700F, JEOL, Japan) images of the cicada wing surface, respectively.

Highly ordered assemblies of nano-nipples were apparent on the ventral and dorsal surfaces. The nano-nipples were arranged in a hexagonal array, with the average basal diameter of 140 nm, top diameter of 60 nm, top spacing (center to center) of 160 nm, and estimated nano-nipple height of 200 nm, as shown in Figure 8(c) and its inset. The nano-nipple arrays observed on the cicada wings have been reported to have a morphology very similar to that found in moths (Gonzalez et al. 2014; Ji et al. 2013). It has been suggested that such kinds of structures have antireflection properties because they introduce a refractive index gradient between those of air and the wing, and decrease the reflectance of the wing over a broad wavelength range (Zhang et al. 2013). Chitin, a crystalline polymer with a high Young's modulus of 7–9 GPa and high molecular weight (Vincent and Wegst, 2004) is the most important component of the cicada wing, and has a key role in preserving the original nanostructure of the wing surface during the replication process.

Butterfly wing material is somewhat like silk. In that they're both animal-produced substances which scientists are very interested in copying. In the case of butterfly wings, it's their ability to brilliantly reflect light in a variety of iridescent colors that could prove particularly useful to humans. Researchers from the Korea Advanced Institute of Science and Technology (KAIST) are reporting success in replicating the reflective properties of the insects' wings, using tiny glass beads. Prof. Shin Jung Hoon led the team, which set out to copy the wings of the morpho butterfly. According to the researchers, the secret to the morpho's striking wings is that their reflective microstructure is at once ordered and chaotic. Analyzed at the 100-nanometer level, the structure is in disarray. Zoom out to the 1-micrometer level, however, and it becomes uniform. The scientists replicated this arrangement by first randomly aligning glass beads of various sizes, although all of them measured approximately a few hundred nanometers across. That took care of the chaotic structure. Then, they used a semiconductor deposition process to deposit a thin film over top of the beads. This made the structure appear ordered when viewed as a whole. They sealed the resulting film in thin clear plastic, to protect it and give it more structure. The finished product was said to produce a better quality and brightness of reflected light than the butterfly wings themselves. Additionally, the color of the film changes less than that of the wings, when viewed from different angles. Ragaei and Sabry (2013) found that silicon (semiconductor) in the wings of dragon fly adults and sphingid moth.

CONCLUSIONS

Some Lepidopteran and Coleopteran insects have nonoscales structure in their wings and cuticle. These nanoscales are called photonic crystals. The color of these insects is produced by the reflection of light by these photonic crystals not due to melanin pigments. These nanostructures can be used in other some industries such as reflection glasses, night camera and microchips in computers and mobiles.

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