http://spectrum.ieee.org/feb06/2811

Butterfly Effect

By: Justin Mullins

Sophisticated method of manipulating light is discovered in Princeps nireus

In 2001, Alexei Erchak at the Massachusetts Institute of Technology, in Cambridge, unveiled a groundbreaking light-emitting diode that suffered none of the light losses that can plague ordinary LEDs. Erchak's device was modified with a special reflective layer and an optical structure, known as a photonic crystal, that together captured light that would otherwise have been lost and channeled it into a useful beam. The design funneled six times as much light into its beam as an unmodified one, an improvement that astounded LED researchers at the time.

Now a UK team says the structure that makes Erchak's LEDs so special is not unique after all. Look hard enough and you can find it in the fluorescent wings of male African swallowtail butterflies of the Princeps nireus species. What is more, the structure of these wings is subtly different from the MIT design in a way that may offer clues for improving LEDs further.

INTELLIGENT DESIGN:

Peter Vukusic finds a Bragg reflector in butterfly wings. PETER VUKUSIC of UNIVERSITY OF EXETER

P. nireus is found in eastern and central Africa and has dark wings with patches of bright blue-green markings. The markings are not highly unusual in the butterfly world, but the way in which they produce their light is. "The Princeps is unique, as far as we know, in the way it produces color," says Peter Vukusic, an optical physicist at the University of Exeter, in southwest England, who has been studying the scales that make up the brightly colored regions of the creature's wings. These scales contain a pigment that absorbs light at wavelengths of around 420 nanometers - roughly sky blue - and radiates it at 505 nm in the blue-green region where butterfly eyes are particularly sensitive.

The trouble with this mechanism is that while half the fluorescent light radiates away from the butterfly, the other half radiates into the wing structure. That half of the light would be lost were it not for the extraordinary structure of the scales.

Vukusic discovered that the base of each scale is a highly efficient three-layered mirror - a structure known as a distributed Bragg reflector. Light from the pigment bounces between these layers, interferes constructively, and then escapes in the direction it came from.

Distributed Bragg reflectors are not perfect, however; some light always becomes trapped on the surface of the reflector and is lost. But the butterfly has another neat trick to get around this. Vukusic and his colleague Ian Hooper discovered that in each scale, sitting just above the mirror, is a slab of material filled with hollow cylinders of air that run perpendicular to the mirror. These cylindrical holes channel the light away from the reflector, preventing it from getting trapped. The slab, says Vukusic, is what optical physicists call a photonic crystal.

The end result is a highly specialized structure that converts skylight into blue-green light, captures this light, and finally channels it out to act like plumage to attract female butterflies.

Designing LEDs, Erchak solved essentially the same problem by placing a distributed Bragg reflector beneath his LED and a photonic crystal above it - just as nature has done for P. nireus. "Who knows how much time could have been saved if we'd seen this butterfly structure 10 years ago," says Vukusic.

P. nireus may have more to teach. In Erchak's LED, with its perfectly periodic crystal, light is better transmitted at some angles than others. But there may be a work-around in the quasiperiodic structure of P. nireus's photonic crystals.