Material Changes its Color, Depending on How You Look at It

Chrysochroa vittata (left) and Hoplia coerulea (right) possess natural photonic crystal structures which inspired the design of researchers’ iridescent materials. Image credit: Olivier Deparis, et al.

Looking at the metallic woodboring beetle head-on, the insect appears red. But viewing it from the side, the beetle starts to take on a greenish hue, and then turns completely green at an 80-degree angle. This color-changing feature is called iridescence, and scientists are taking notes from the beetle to design man-made iridescent materials.

The group of researchers, from the University of Namur in Belgium, has recently fabricated iridescent materials that closely mimic the structure and appearance of two species of Coleoptera beetles. By analyzing the underlying physical mechanisms that cause iridescence, the researchers can predict the colors displayed by specific material structures, and, conversely, determine what kind of structural properties are required to display certain colors. With this understanding, they have created a colorful variety of iridescent materials.

“In the context of iridescent materials, the greatest significance of our study is probably the fact that we are discovering new iridescent photonic structures in nature which give us inspiration to synthesize artificial materials whose (nano-) structures are presently out of reach of the human imagination,” lead author Olivier Deparis tells *PhysOrg.com*.

In a recent issue of the *New Journal of Physics*, the scientists explain what causes the vivid colors to change based on viewing angle. The beetles in the study (*Chrysochroa vittata* and *Hoplia coerulea*) have layers of materials with different thicknesses. When light waves reflect off the different layers at different depths, the light waves interfere. So when you look at a beetle, the color you see is due to the light’s reflection peak off not just one surface, but many surfaces combined. As your viewing angle increases from head-on to a side view, the reflectance peak shifts to shorter wavelengths. That’s why *H. coerulea*, for example, appears blue head-on, but violet (shorter wavelengths) from larger viewing angles.

Nature’s iridescence is surprisingly diverse. Both beetles – and nearly all animals that exhibit iridescence – use the same bio-material called “chitin“ for achieving a high refractive index, and a combination of air or water for the low refractive index component. Yet, no two species display the same colors. While this great diversity was originally a surprise to scientists, researchers now know that the different layer thicknesses of different species can “tune” the animals’ colors, even if the materials are the same. As Deparis explains, nature's diversity can offer many benefits for researchers looking to expand the abilities of man-made materials.

"Imagine a graph where the x axis is the degree of complexity of the nano-structure of an iridescent material and the y-axis is the diversity of basic materials which are used to build the nano-structure," he says. "Natural iridescent materials are mostly characterized by highly complex structures (involving order, disorder, hierachy, etc.) but employ only a few basic materials to realize these complex structures: that's the fascinating power of nature to evolve from basic structures to the most sophisticated and/or optimized ones during millions years of adaptation to the changing environment. In our graphical representation, natural iridescent materials therefore are confined to a region of high x (complexity) and low y (diversity) values."

On the other hand, Deparis continues, artificial materials are the opposite.

"Due to limitations in both industrial fabrication processes and human imagination, artificial photonic materials are often characterized by rather simple structures but often employ a large set of basic materials – think of the doped-semiconductor industry, for example. In our graphical representation, artificial iridescent materials therefore are confined to a region of low x and high y values. Our bio-inspired approach, in which natural structures are used as templates for the design of artificial ones, allows us to target unexplored regions of both high x and high y values, i.e. to come up with new artificial iridescent materials with more complex nano-structures made of basic materials available in a larger chemical composition range."

Using the beetles' nanometer-scale layers as a template, Deparis and his colleagues designed and fabricated iridescent surfaces out of titanium and silicon oxide layers. There were two variables that determined the iridescent properties: the period of the alternating layers, and the layer thickness ratio (one layer being thicker than the other). The period determined the dominant color (the dominant reflected wavelength) at head-on incidence. The layer thickness ratio largely determined what the scientists call "spectral richness," which is the extent to which the colors change (or the wavelength shifts) when the viewing angle increases.

Based on this understanding, the scientists created iridescent materials that precisely mimick the beetles' exocuticle coloring. Specifically, *C. vittata* (the red-to-green beetle) has a layer period of about 200 nanometers, corresponding to its red dominant color. It also has a small layer thickness ratio that causes a fairly large wavelength shift of about 110 nanometers as the viewing angle increases from 20 to 60 degrees. *H. coerulea* (the blue-to-violet beetle) has a layer period of about 100 nanometers, corresponding to its blue dominant color. Its layer thickness ratio is larger than *C. vittata*, causing a fairly small wavelength shift of about 20 nanometers over the same viewing angles.

"In the case of the present study, this [bio-inspired] approach is exemplified by the fact that we used two materials [titanium and silicon oxide] which were chosen among a large range of available oxides in order to generate very different iridescent aspects by taking advantage of the complexity," Deparis says. "Here the complexity was introduced by considering the thicknesses of both layers as free and independent parameters, which is not usually the case in the design of standard multilayer Bragg reflectors."

The group also developed a model that can predict the reflectance spectrum of an iridescent material at any viewing angle. By tuning the layer thicknesses, the researchers can now fabricate a wide variety of iridescent materials with vivid, changing colors. Iridescent materials could have uses in various industries on large-scale surfaces, which would be an engineering challenge. Another challenge, the researchers explain, may be the deposition of these multilayer films on different substrates, such as flexible polymer foils or curved objects.

"Possible applications of iridescent materials are mainly in art (why not iridescent sculptures!)," says

Deparis, “or architecture (glass or metal iridescent panels for decoration), painting (iridescent structural ‘pigments’ in the form of small particles in a solvent), ophtalmic glasses (here, coatings for which the color almost does not change with viewing angle may be interesting, similar to *Hoplia coerula*).”

More information: Deparis, Olivier, Rassart, Marie, Vandenbem, Cédric, Welch, Victoria, Vigneron, Jean Pol, and Lucas, Stéphane. “Structurally tuned iridescent surfaces inspired by nature.” *New Journal of Physics* 10 (2008) 013032.