nanOntario

Centre for Nanomaterials in Manufacturing Innovation

Learning Nanotechnology from Ontario's Great Outdoors

Year 3 | Structural Colour

Materials Science & Engineering
UNIVERSITY OF TORONTO

Message from the Publisher

Professor Uwe Erb

Welcome back to nanOntario. Our third year research theme is "**Bio-inspired Structural Colour**". Structural colour, in contrast to pigment-based colour, is the display of colour by objects or living things which is solely the result of the interaction of incident light with sub-micrometre surface structures. Through a diverse set of light-surface interaction mechanisms, certain wavelengths of light are selectively absorbed, reflected, or scattered, and depending on the exact structure and mechanism, different colours and types of colours are produced. The presence of structural colour on animals is usually believed to be for the purpose of the attraction of mates, or for the intimidation of rivals or predators.

To examine **structural colour**, a variety of birds and butterflies were investigated. Birds such as the **Blue Jay** and the **Peacock**, as well as the **Morpho butterfly** were found to exhibit such colour, while birds such as the **Northern Flicker** and the **Red Cardinal** did not. This difference is solely due to the presence or absence of surface (or near-surface) structures on the animals. The presence of these structures results in **light-surface interaction mechanisms** such as diffraction, thin-film/multilayer interference, or photonic crystal mechanisms. There is a special sub-type of structural colour in which the colour, hue, or colour intensity vary with a change in light incidence angle or angle of viewing. This is called, 'iridescence' and is present on a variety of animals.

Using these animals as inspiration, several companies and institutions have successfully mimicked different types of structural colour effects. Current applications are mostly decorative, such as the two-colour iridescent decorative paints by JDSU being used on automobiles and electronic devices. Applications currently in development include anti-counterfeiting security on banknotes and other objects by using unique iridescent marks, and photonic crystal fibres as an improvement of optical fibres. A possible future application based on the principles of structural colour is optical computing, as opposed to electronic computing.

1. The Nature

The Morpho Butterfly

Morpho butterflies are popular for their brilliant blue colour on their wings. There are over 80 species of Morpho, which are found mostly in Central and South America. The Morpho's iridescent blue colours are the result of a nanostructure effect, while its brown, black, and red colours are produced by pigments.

Blue Jays are commonly found in central North America and Canada and are recognized for their bright blue colour. Blues Jays are intelligent birds, capable of imitating calls of other birds. Many feathers of Blue Jays exhibit a blue structural colour due to light scattering caused by nano-scale air pockets within the barbs of their feathers.

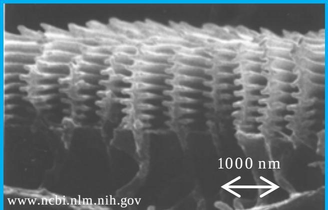
The Blue Jay

Ontario's Autumn colours

Unlike the aforementioned structural colours, leaf colours are dominated by distinct pigments depending on which season they are in. **Chlorophyll (green)**, **carotenoids (orange)** and **xanthophylls (yellow)** are the main pigments plants use during photosynthesis to create carbohydrate energy from sunlight. The red colour is slightly more complicated and is the result of pigments called **anthocryanins**.

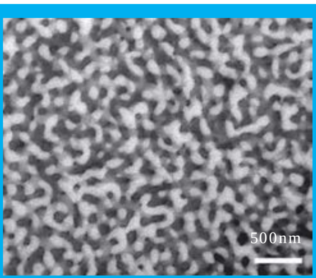
A red blood cell is about 6000-8000 nanometres in diameter.

2. The Structures



Cross-sectional view of the surface structure of a single Morpho butterfly scale

The source of the Morpho butterfly's iridescent colour is structural. The colour is produced by the interaction of light with the naturally occurring photonic crystal on the surface of the wing scales. Through a multilayer interference mechanism, light reflection caused by the alternating layers of chitin and air resulting in constructive interference of incident light and the strong reflection within a selective wavelength range (i.e. blue).



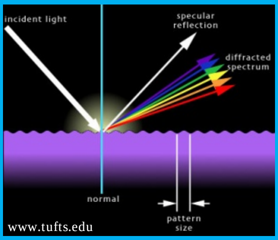
The keratin and air nano-structured barb of the Blue Jay feather

The Blue Jay feather contains nano-scopic air pockets in a keratin particle matrix which are responsible for the preferential scattering of the blue light waves. When light hits the Blue Jay feather, this structure reflects and scatter the light with shorter wavelength (in this case the blue light wave). Thus, we see a vivid blue colour on the Blue Jay's feather.

3. The Theory

Structural Colour

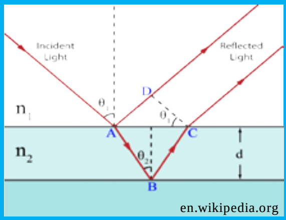
i) Diffraction Gratings



www.tufts.edu

A diffraction grating is a material surface which is composed of equally spaced parallel grooves. The diffraction grating produces structural colour through the diffraction of light waves by each of the grooves and the resulting constructive interference between individual colours and differential bending of separate colours. The resulting appearance of the material is that of the colour components of visible light.

ii) Thin-film/Multilayer Interference

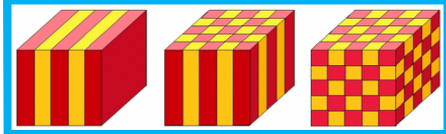


en.wikipedia.org

Thin-film interference occurs when a light source interacts with a nanometre to micrometre thick film that is composed of a top and bottom surface with two different refractive indices. Incident light is both transmitted and reflected at both interfaces and constructive and destructive interference occurs depending on the resulting phase relationships. Multilayer interference can be seen as a special case of thin-film interference in which two thin films alternate to form a multilayered structure.

iii) Photonic Crystal Structures

Photonic crystals are regular arrays of materials with differing refractive indices. They can be compared to semiconductor crystals in that they affect the motion of photons in a manner similar to the way the periodicity of a semiconductor affects the motion of electrons. They contain photonic bands and band gaps, which allow only certain wavelengths to move through the structure.


ab-initio.mit.edu

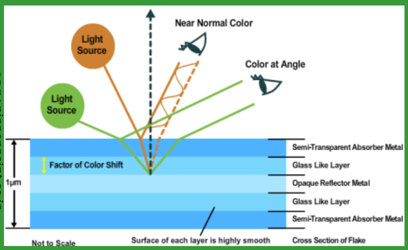
4. The Applications

i) JDS Uniphase ChromaFlair® Light Interference "Pigments"

JDSU's ChromaFlair® Light Interference "pigments" are comprised of tiny multilayered flakes that are added to paints, coatings, plastics, textiles, and packaging to give them the ability to exhibit a wide range of hues when viewed from different angles.


www.asknature.org

The product made by JDSU actually contains no conventional pigments. The range of colour changes observed (i.e. iridescence) is the result of a thin-film interference effect . The flakes are composed of multi-layer platelets in between a substrate and a clear plastic protective coating. The flakes are approximately 1 µm thick, and each flake is composed of five layers.



www.nipponpaint.co.jp

ii) Morphotex® Fibre

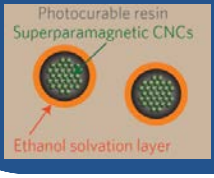
Morphotex® fibre by Teijin Fibers Ltd. is the world's first structurally coloured fibre and, as its name suggests, it is inspired by the Morpho butterfly. The effect is achieved by using numerous alternating polyester and nylon fibre layers and controlling the thicknesses of these layers from about 70 to 100 nm, resulting in a multilayer interference effect.


http://www.ecouterre.com

iii) Seoul National University: BiNEL's 'M-Ink'

Developed by engineers at the Biophotonics and Nano Engineering Lab, SNU, M-Ink is a photonic crystal material which exhibits structural colour that is magnetically tuneable, and fixable by UV light exposure.

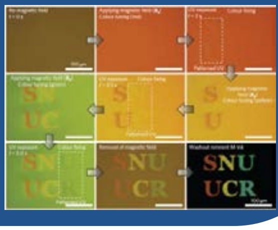
The material system is composed of three phases: superparamagnetic colloidal nanocrystal structures (CNCs), a photocurable resin in which the structures are dispersed, and an ethanol solvation layer.



binel.snu.ac.kr

The CNCs form chain-like structures with different spacings depending on the external magnetic field applied, resulting in the production of different structural colours, which can be fixed through UV light exposure.

Potential applications include cheap and fast structural colour printing, anti-counterfeit protection, and structurally coloured design materials.



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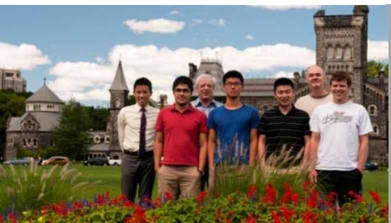

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