Photonic Crystals: Mystery of Colours of Butterfly Wings

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***Abstract* - The delicate beauty of butterfly wings lies in their colour and it is due to its intricate structure and functionality. The butterfly wings are covered by scales built of chitin of refractive index 1.58. The typical dimensions of scales are in micrometer range. Each side of the wings of butterflies is covered by two distinct layers of scales. Thus, they form layered periodic microstructures with contrast refractive index and act as photonic crystals. These quasi-ordered multilayer structures may behave as photonic bandgap materials and produce different colours.**

***Index Terms* - Colour, Butterfly, Photonic crystal, Photonic bandgap.**

INTRODUCTION

Colour is the characteristic of human visual perception described through colour categories. This perception of colour derives from the stimulation of cone cells in the human eye by electromagnetic radiation in the spectrum of light. Colour categories are associated with objects through the wavelength of the light that is reflected from them. Combination of spectral colours gives White light. If some frequencies are absorbed from white light, the emitted light will be coloured. The colour of an object depends on incident illumination, reflectance properties of the surface, angle of incidence and angle of view.

Gold nanoparticles have fantasized scientist for decades largely due to the ability of optical tuning by synthetic controlling of the particle size, shape, composition and structure [1]. In the nanoregime, size of the material affects its colour. Depending on the size of the material, the optical bandgap changes and colour changes. Besides the size factor for optical tuning, shape and structure variation can results in similar phenomenon [2].

Butterflies are universally considered attractive because of their bright coloration patterns. The delicate beauty of butterfly wings lies in their colour and it is due to its intricate structure and functionality. Structural colours are created by an optical effect rather than by a pigment. They arise from the periodic arrangement of microstructures interacting with light to produce a particular colour [3]. Variations in the spacing of the pattern often gives rise to an iridescent effect, as seen in butterfly wings, peacock feathers, soap bubbles, films of oil, etc.

The butterfly wings have several structural levels. The butterfly wings are macrometer size whereas the scales are in micrometer range. The typical dimensions of scales are 50-100 micrometer. The scales are comprised of which consists of an array of longitudinal, parallel ridges and transversal crossribs of nano size. Each side of the wings of butterflies is covered by two distinct layers of scales. Ground scales associated with wing membrane and the Cover scales associated with wing surface. Spacing in the pattern of cover scales is of the order of wavelength of visible light [4].

The butterfly wings are covered by scales built of chitin of refractive index 1.58 [4]. The surrounding air is of refractive index 1. Thus they form contrast refractive index. These layered periodic microstructures with contrast refractive index and act as photonic crystals. These quasi ordered multilayer structures may behave as photonic bandgap materials and produce different colours. Structural Variations of cover scales gives different colours [5]. The brightest and most vivid colours in nature arise from the interaction of light with surfaces that exhibit periodic structure on the micro- and nanoscale. In the wings of butterflies, for example, a combination of multilayer interference, optical gratings, photonic crystals and other optical structures gives rise to complex colour mixing.

Variations in the spacing of the pattern of butterflies lead to different colours [6]. The colours observed locally on the wing are also due to the degree of scale stacking. The scale elements creating structural colours can be almost perfect thin films, as in the papilionid butterfly Graphium sarpedon perforated multilayers in the scale lumen of lycaenids, multilayers in the scale ridges, as in Morpho butterflies, or complex three-dimensional photonic crystals, as in some lycaenids [7-15]

Photonic Crystals are multi- dimensional periodic structures with a period of the order of optical wavelength. They are categorized by the dimension of periodicity [16-18]. Based on variations in refractive index, there are 3 categories of photonic crystals namely 1-D, 2-D and 3-D. Most important property of a photonic crystal is the existence of a photonic bandgap. Photonic bandgap is a forbidden gap of photons of characteristic frequency. In this gap, certain frequency of light cannot enter the crystal and certain frequencies are trapped inside the crystal depending on the structure. These phenomena will allow a perfect control of light propagation and radiation. Photonic bandgap acts as an insulator of particular frequency of light. The light velocity will be changed from vacuum velocity c to zero (stopping condition), so the light matter interaction can be controlled. From the white light, certain frequencies are trapped inside the crystal and we get colour.

APPLICATIONS

Biomimicry of butterfly wing structure can lead to powerful solar cells. Butterfly wing structure is artificially made from photonic crystals of titania. It traps large quantity of photons and can be used as more efficient solar cells. Bioinspired designs can be used in textile industry.

CONCLUSION

The delicate beauty of butterfly wings lies in their colour and it is due to its intricate structure and functionality. Scales of butterfly wings are layered periodic microstructures with contrast refractive index. These quasi ordered multilayer structures act as photonic crystals and produce different colours.

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