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# Photonic crystal micro- and nanostructures in iridescent butterfly wings

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Photonic crystals are periodic dielectric composite structures that affect the propagation of light. The existence of complex photonic crystals structures in Nature has boosted research in the field of optical biomimetics to support the development of better designed structures in optical devices, colorants and in the clothing industries. This paper reviews the natural micro- and nanosized photonic crystal structures that exist in the iridescent scales of some butterfly wings.

## I. INTRODUCTION

Recently, research in structural colors of biological species has progressed rapidly especially in vision-related fields such as the paint, automobile, cosmetics, printing and textile industries [1]. Opposed to pigment colors, structural colors rely on physical structures that produce long-lasting colouration which is apparent even in low light levels [2],[3]. Structural colours in Nature are a result of either (and/or a combination of) thin-film interferences, multilayer interferences, diffraction grating effects, photonic crystals (PhC) and light scattering effects [1]. Among these effects, biological PhC structures are realised when a submicrometer periodic structure with periodicity comparable to the wavelength of visible light is formed hence creating either a full or partial photonic bandgap (PBG), where some/all electromagnetic waves are forbidden to propagate and exist within the crystal [4]. As a result of partial PBGs, iridescence materializes where a change in hue occurs when the angle of observation is shifted [5].

## II. VARIOUS BUTTERFLY WINGS: NATURAL PHOTONIC CRYSTALS

The PhC-based structural colour or iridescence in butterfly wings supports for mate-finding, camouflage and startling of predators [6]. Natural PhCs have been proposed to be formed from multilayers of simple cubic (SC), face-centred cubic (FCC) or body-centred cubic (BCC) lattices. Large varieties of geometries such as the inverse opal, woodpile, diamond network, Yablonovite and gyroids have also been proposed for these natural PhCs [7]. Fig.1(a) shows the iridescent blue colour found in the wings of *Morpho* butterflies. The scanning electron microscope (SEM) images in Fig.1(b) show "Christmas tree" PhC profiles with a multilayer combination of cuticle and air which give a wavelength peak at around 440 nm at a viewing-angle of about $30^0$. Fig 1(c) is a mimic of the PhCs in *Morpho* butterflies fabricated with the focused ion beam chemical vapor deposition (FIB-CVD) method but in micrometer scale [8]. Fig. 2 (a) shows the butterfly *Parides sesostris* where the green colour in the scales of its wings is formed by reflection from a tetrahedral PhC configuration which offers the highest reflectivity over the broadest angle for a given refractive index contrast between component media. Fig. 2 (b) and Fig. 2 (c) are the SEM and TEM images respectively [5].

### *References*

[1] S. Kinoshita, and S. Yoshioka, "Structural colors in nature: the role of regularity and irregularity in the structure," ChemPhysChem, vol. 6, pp. 1442-1559, 2005

[2] R. C. McPhedran, N. Nicorovici, D. R. McKenzie, G. Rouse et al., "Structural colours through photonic crystals" talk and presentation at University of Utah, 2005.

[3] T. R. Matin, P. S. Menon, S. Shaari, I. C. Gebeshuber, "Structural colours in biology and how these natural micro- and nanostructures inspire current technology," International Seminar on Science and Technology ISST, Padang, Indonesia, 2009

[4] K. Michielsen, and D. G. Stavenga, "Gyroid cuticular structures in butterfly wing scales: biological photonic crystals," Journal of the Royal Society Interface, vol. 5, pp. 85-94, 2008

[5] P. Vukusic, and J. R. Sambles, "Photonic structures in biology," Nature, vol. 424, pp. 852-855, 2003.

[6] Z. Han, L. Wu, Z. Qiu, H. Guan, L. Ren, " Structural colour in butterfly Aptura Ilia scales and the microstructure simulation of photonic crystal," Journal of Bionic Engineering Suppl, pp. 14-19, 2008.

[7] L. Poladian, S. Wickham, K. Lee, and M. C. J. Large, "Iridescence from photonic crystals and its suppression in butterfly scales," Journal of the Royal Society Interface, vol. 6, pp. S233-S242, 2009

[8] A. R. Parker, and H. E. Townley, "Biomimetics of photonic nanostructures," Nature Nanotechnology, vol. 2, pp. 347- 353, June 2007.

Figure 1. (a) Blue iridescent colour reflected from the wings of *Morpho* butterflies, (b) SEM images show "Christmas tree" PhC profiles with a multilayer combination of cuticle and air (c) A mimic fabricated with the FIB-CVD method. Scale bars: (b), (c) 100 nm [8]. Reprinted by permission from Macmillan Publishers Ltd: Nature Nanotechnology, vol. 2, pp. 347- 353, copyright (2007)

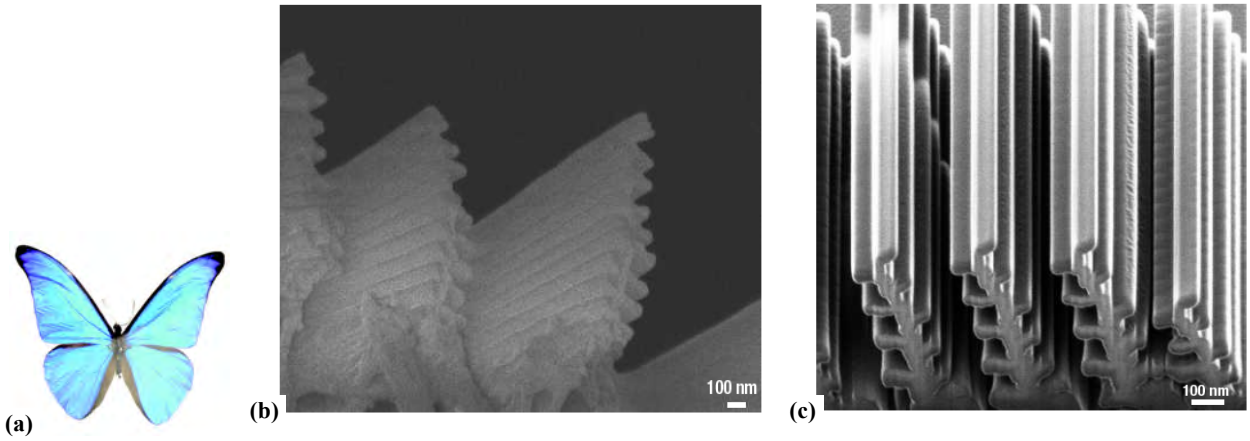


Figure 2. (a) The butterfly *Parides sesostris*. (b) SEM images of the PhC of the green scales of the wings after the superficial ridging has been removed (c) a TEM image the SEM image in (b) for a 50 nm section. Scale bars: (b) 1.2 μm and (c) 2.5 μm [5]. Reprinted by permission from Macmillan Publishers Ltd: Nature, vol. 424, pp. 852-855, copyright (2003)