
BIOPHOT MEETING
ABSTRACT BOOK
1μm
2007 Budapest

BioPhot Workshop 2007

Complexity and evolution of photonic nanostructures in bioorganisms: templates for materials science (BioPhot)

Workshop VI, Budapest, Hungary, 24-25 September, 2007

The Second BioPhot Meeting in Budapest, Hungary

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On the front cover: Butterflies: *Morpho rhetenor*; *Cyanophrys remus* dorsal and ventral wings (left); Transmission Electron Micrograph of *Cyanophrys remus* dorsal wing (center); *Albulina metallica* dorsal and ventral wings (right).

Further informations:

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PROGRAM

9:00 - 9:05	**Prof. István Bársony** Director of the MTA-MFA	Opening Words
9:05 - 9:25	**J P Vigneron**, M Ouedraogo, M Rassart	Hemispheric multilayer causes colour mixing on the African shield-backed bug Calidea panaethiopica
9:25 - 9:45	P Váraljai, K Buczkó, **A Kertész**, Z Bálint	Studying filament nanostructures in Transylvanian populations of Edelweiss (*Leontopodium alpinum*) along an altitudinal gradient
9:45 - 10:00	**Z Vértesy**, K. Kertész, G. Molnár, M. Erős, Zs. Bálint, L P Biró	SEM and TEM investigations in the scales of the European nymphalid butterfly Apatura ilia dark and light phenotypes
10:00 - 10:30	Coffe break	
10:30 - 10:50	**S Berthier**, J Boulenguez, C Andraud	Order and disorder in Natural Photonic structures: Characterization
10:50 - 11:10	**L. P. Biró**, G. Molnár, K. Kertész, Z. Vértesy, A. A. Koós, Z. E. Horváth, G. I. Márk, L. Tapasztó, Zs. Bálint, O. Deparis and J. P. Vigneron	Tailored multilayer nanoarchitectures inspired by the scales of Albulina metallica
11:10 - 11:30	**M Rassart**, J P Vigneron	Hygrochromic behaviour of the hercules beetle (Dynastes hercules : Coleoptera)
11:30 - 11:50	Z Bálint, **G Makranczy**	An example for discolouration in carabid beetles (Coleoptera: Carabidae)
11:50 - 13:40	Lunch break	
13:40 - 14:00	**S Berthier**, J Boulenguez	Moiré patterns: application to the determination of the wings deformations

14:00 - 14:20	**I Tamáska**, Z Vértesy, K Kertész, G. I. Márk, Z Bálint, L P Biró	New type of photonic crystal in the green scales of Chrysirida Ripheus
14:20 - 14:40	**O Deparis**, M Rassart, C Vandenbem, V Welch, JP Vigneron	Fabrication of SiO2/TiO2 multilayer films mimicking Chrysochroa vittata and Hoplia coerula
14:40 - 15:00	Coffee break	
15:00 - 15:20	**K Kertész**, Z. Vértesy, Z. Bálint, L P. Biró	Optical gas sensing of photonic crystal-type butterfly scales
15:20 - 15:40	**G. I. Márk**, Z. Vértesy, K. Kertész, L. P. Biró	Reciprocal- and direct space study of butterfly wing scale structures of long range order, medium range order, and short range order
15:40 - 16:00	General discussions & Closing remarks	

Welcome!

It is our special privilege to welcome our physicist, biologist colleagues, or specialist of any other background, interested in the beauty and the science of living colors of structural origin!

The BioPhot project is in its third, terminal year and the fruitful collaboration on the topic of photonic nanoarchitectures of biologic origin between the Phyiscs Department of Facultes Universitaires Notre-Dame de La Paix, Namur, Belgium (FUNDP); the Lepidoptera Collection of the Hungarian Natural History Museum, Budapest Hungary (HNHM); and the Nanotechnology Department of the Research Institute for Technical Physics and Materials Science, Budapest, Hungary (MTA-MFA), started in 2002. This is the second BioPhot Workshop in Budapest, the first one took place in 2005 in the Hungarian Natural History Museum.

The many exciting results presented in the previous BioPhot Workshops in Budapest, Paris, Namur (2) and London (2), very convincingly demonstrated the enormous potential and inventivity of biologic evolution to "design" and "bring to perfection" very complex nano-optical devices, which are of crucial importance in sexual communication and cryptic behavior, therefore have a major influence on the chances of the individual to survive and reproduce.

The joint work of the five participating groups in the BioPhot project pinpointed new aspects of bioispired photonic nanoarchitectures like the "switchable" structural color of the tortoise beetle, blazed gratings, the questions of order and disorder, methods to characterize quasiordered nanoarchitectures and possible ways of not necessarily copying the structures engineered by evolution, but gaining inspiration from these structures in the full sense of **bioinspired materials**. At this stage of the project, the titles of the proposed talks very clearly point into this direction of bioispired artificial structures.

On the behalf of the BioPhot Teams of the MTA-MFA and HNHM we wish you an exciting workshop which we hope, may open new paths and new collaborations!

Dr. Zsolt BÁLINT
HNHM

Dr. László P. BIRÓ
MTA-MFA

The BioPhot Project

FP6 NEST/PATHFINDER/BIO-PHOT-012915

NEST/PATHFINDER initiatives:TACKLING COMPLEXITY IN SCIENCE

Start date of project: 1st of May 2005

Duration: 36 months

Project coordinator: Jean Pol Vigneron

Project coordinator organisation name: Facultés Universitaires Notre-Dame de la Paix, Namur.

The BioPhot concept

The physical explanation of the extraordinary appearances of many living entities faces complexity. Another side of this complexity is the way in which living organisms use their appearance and interaction with the most important segment of the electromagnetic spectrum – visible light – and its neighboring ranges like UV and IR to enhance their survival and reproduction chances. This "evolutionary pressure" during many millennia of evolution yielded highly optimized "optical devices and materials" which accomplish complex tasks ranging from sexual signaling to thermal management.

On the other hand, such structures cannot be efficiently investigated just from one point of view, a complex, multidisciplinary approach involving: high resolution structural and physical characterization, evolutionary data both in time and geographic spread, modeling and the study of the behavior of the presently living organisms is needed to obtain a sufficiently detailed and deep insight on one hand the evolutionary processes which optimized a certain structure for a well defined task and on the other hand in the way in which different but related structures exhibit altered properties.

Using a combination of microscopy techniques, we wish to develop knowledge of the micro- and nano-morphology of specific bio-organisms, selected for their particular ability to use light scattering as part of their living mechanisms. This knowledge will be complemented by the precise characterization of the light filtering functions of the structured organs, making use of micrometer-resolved spectrophotometric and thermal exchange measurements. The relation between these and the optical density will be consolidated by large-scale numerical simulations.

On the other hand, the targeted organisms will be studied from the point of view of ecological and phenological history. In particular, closely related, or competing species will be designated for further physical examinations. Interdisciplinary exchanges, including, when available, paleontological data, will attempt to determine whether the optical scattering mechanisms constitute a possible evolutive advantage which could explain the permanence of the bioorganism in its ecosystem. With regard to the problem of complexity, different methods will need to be developed at each stage of the investigation.

The study of the bio-organism in its environment, eventually at different evolutionary epochs, will require an analysis of a large number of interactions and dependencies among living populations; the experimental and theoretical study of the light-filtering functions will also cope with complexity, as it requires to account for a multidimensional hierarchical data set, including the knowledge of reflection, absorption and, polarization changes as a function of frequency, incidence and emergence angles, at various points of the bio-organism surface. Understanding such hierarchical assemblies of elements with several length-scales is expected to provide guidance for the design of synthetic structures and to the improvement of available simulation and modelling tools which can significantly reduce the development costs of the new photonic materials structured on the nanoscale.

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Hemispheric multilayer causes colour mixing on the African shield-backed bug Calidea panaethiopica

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The African shield-backed bug */Calidea panaethiopica/* is a very colourful insect which displays a range of yellow, green and blue iridescent reflections. The cuticula of the dorsal side of the insect, on the shield, the prothorax and the head, is pricked of uniformly distributed hemispherical cavities (about 100 micrometers wide). Under normal backscattering, such an hemispherical well produces two distinct colours: a yellow spot arising from the bottom of the well, and a blue annular source that seems to float above and around the yellow spot. The yellow colour is produced after one reflection on the cavity wall multilayer, while the blue backscattering needs two reflections. To our knowledge, such an effect was reported only on butterfly scales with much smaller cavities (such as *Papilio palinurus*). This work shows that other insects have naturally evolved hemispheric yellow multilayers to reach a greenish appearance.

Studying filament nanostructures in Transylvanian populations of Edelweiss (*Leontopodium alpinum*) along an altitudinal gradient

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1. With the aid of Scanning Electron Microscope we studied Edelweiss (*Leontopodium alpinum*) (Figure 1) samples from Romania (Transylvania). Collecting sites of different altitudes: 500 m ("Felsőgáld, Alsó-Fehér megye"), 1100 m ("Máriakő, Csík megye") and 2200 m ("Terica, Fogaras megye") provided plants tested for micron- and nanosized ribs situated in the filaments covering various vegetative parts. In our work we pose the question whether there is a correlation between rib development and altitude. The samples are from the herbaria of the Hungarian Natural History Museum.
2. It was revealed that the filaments of the bracts are structured by nanosized ribs in the whole range of elevations. Ribs cover not only the bracts but further vegetative parts in the 2200 m sample as the stems and leaves. These cannot be discovered in the sample from the lowest elevation (500 m), where only the bracts are micron- and nanostructured. The 1100 m sample takes an intermediate position from this point of view (Figure 2).
3. The bract filaments of the Edelweiss with their nanosized ribs are working as photonic crystals, but their role is most probably not only a kind of protection against harmful UV radiation as it was previously hypothesised.[1] Because of the bract filaments in the sample from the lowest altitude (500 m) where the UV radiation is not significant also possess nanosized ribs we suppose that they function in generating a signal for pollinators.
4. The nanostructures absorb in the ultra violet (UV) spectrum of the solar radiation, and this results in a black pattern in an environment rich in UV. Hence the black pattern is becoming more intensive with higher altitudes. This from one side gives more protection against the harmful UV radiation, as it was

experimentally tested but from the other side generates a more conspicuous pattern for the pollinators, who have less time available for their activities in high altitudes with more extreme climate, therefore have to be more efficient.

[1] Vigneron, J.-P., Rassart, M., Vértesy, Z., Kertész, K., Sarrazin, M., Biró, L. P., Ertz, D. and Lousse, V., 2005. Physical Review E 71: 011906-1-8.

Figure 1. *Leontopidium alpium*, 3000 m, Sion, Switzerland, VIII. 2006. (photo: A. Kertész)

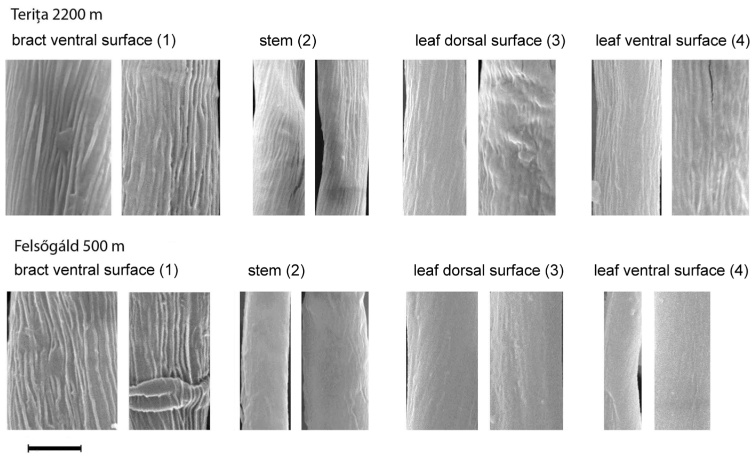

Figure 2. Rib surface structures in *Leontopodium alpinum* samples from the elevations 2200 m and 500 m. Scale bar: 5 μ.

SEM and TEM investigations in the scales of the European nymphalid butterfly *Apatura ilia* dark and light phenotypes

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The species *Apatura ilia* (Denis et Schiffermüller, 1775) is distributed from Western Europe to the Amur region in Pacific Asia along brooks and rivers in riparian forests. In the whole range it is represented by two phenotypes: the dark *forma ilia* and the light *forma clytie*. The dark phenotype mainly occurs in cooler regions where the larval development is long, while the light phenotype inhabits warmer habitats, where the caterpillars grow faster. As all the members of the genus, the male dorsal wing surfaces of both *Apatura ilia* phenotypes show intensive violet iridescence (Fig. 1.)

Fig. 1. *Apaturia ilia f. ilia* (left row) and *Apatura ilia f. clytie* (right row) in the drawer of the 28/34, Lepidoptera collection, HNHM.

SEM and TEM techniques were applied to investigate the scale structures of the two phenotypes. The investigations show that both forms of *Apatura ilia* posses classical *Morpho*-type scales. The nanostructures of the scales in the two forms of *Apatura ilia* are similar as shown in SEM images (Fig. 2*a* and 2*b*). However, the high-magnification TEM micrographs of the corresponding cross-sections reveal differences in size, shape and number of the lamellas (see Fig. 3*a* and 3*b*).
With the application of our observations taken via SEM and TEM techniques we were able to conduct some preliminary experiments for artificially reconstructing *Morpho*-type nanostructures.

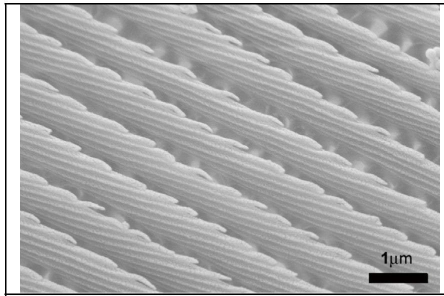


Fig. 2*a*. Typical view of ridges and lamellas in *Apaturia ilia* f. *ilia*

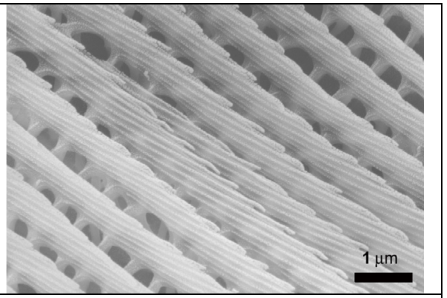


Fig. 2*b*. Typical view of ridges and lamellas in *Apaturia ilia* f. *clytie*

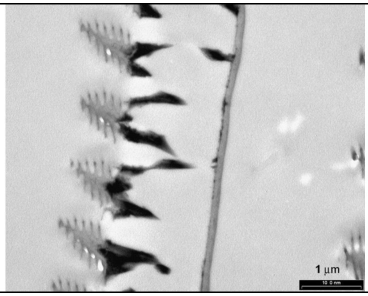


Fig. 3*a*. Cross section of *Apatura ilia* f. *ilia*

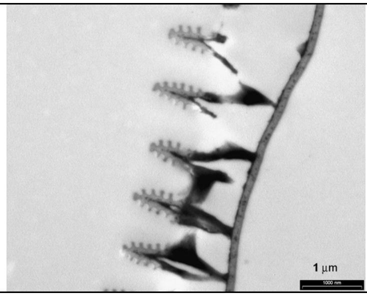


Fig. 3*b*. Cross section of *Apatura ilia* f. *clytie*

Order and disorder in Natural Photonic structures: Characterization.

Serge Berthier, J. Boulenguez, C. Andraud.
INSP, Université Pierre et Marie Curie, Université Denis Diderot.

The natural photonic structures founded in insects wings or elytrons, known to be at the origin of their coloration and other specific optical properties, are characterized by a more or less strong disorder. Even more, this disorder appears at each scale of the structure, and so acts both on the coherent and incoherent optical phenomenon. This disorder give the structures a large invariance, according to the external conditions: the sturdiness.

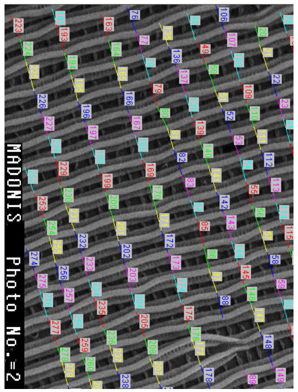
It is the important to characterize this disorder by the way of a concept, first developed by Brillouin: The configuration entropy.

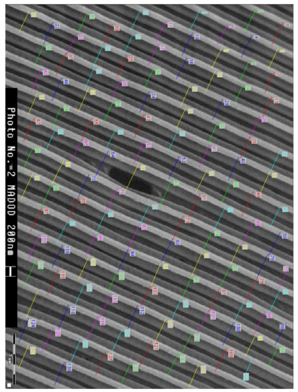
Given a system with N possible configurations k and p_k the probability of occurrence of the configuration k, the configuration entropy can be defined as:

$$S = \frac{\sum p_k \ln p_k}{\ln N}$$

This function varies from 0 for a perfect ordered system to 1 for a completely disordered system (equiprobability of the configurations).

Few examples will be presented for various scales of the structures of *Morphidae* and a first relationship with the corresponding optical properties will be established.





Configuration entropy of two different scales of Morpho marcus. S = 0.61 (left) and 0.5 (right)

Tailored multilayer nanoarchitectures inspired by the scales of the butterfly *Albulina metallica*

L. P. Biró[1], G. Molnár[1], K. Kertész[1], Z. Vértesy[1], A. A. Koós[1], Z. E. Horváth[1], G. I. Márk[1], L. Tapasztó[1], Zs. Bálint[2], O. Deparis[3] and J. P. Vigneron[3]

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The butterfly *Albulina metallica* (Felder & Felder, 1865) (Lepidoptera: Lycaenidae) is a blue (dorsal) – green (ventral) butterfly with "pepper-pot" type scales in the cover scales of both wing sides, similar to those found earlier in the *Polyommatus daphnis* (Denis et Schifferemüller, 1775) (Lepidoptera: Lycaenidae) [1]. The coloration of both wing surfaces is given by photonic band gap (PBG) materials, a composit able to manipulate the propagation of light. As the characteristic dimensions of a PBG material have to be in the range of the wavelength for which the photonic PBG will appear, the relevant length scale over which the composits in the scales of *A. metallica* are structured is in the 100 nm range. In other words, these composites are in fact nanoarchitectures composed of chitin and air.

The color generating nanoarchitectures in the cover scales of the blue - green wing surfaces of *A. metallica* were investigated by scanning electron microscopy and cross sectional transmission electron microscopy. A layered, quasiordered structure was revealed in the scales of both wing surfaces, with different length parameters, associated with their different colors. A successful attempt was made to reproduce the structure of biologic origin by using standard thin film deposition techniques to produce a quasiordered multilayer structure of SiO/(In&SiO). The position of the reflectance maxima of the artificial structure could be tailored by controlling the size of the In inclusion in the

(In&SiO) layers. Our results show that photonic band gap materials of biologic origin may constitute valuable blueprints for artificial structures.

It is worth to point out that often, the biologic PBG materials lack that very rigorous order which is demanded in artificial structures, still they can generate conspicuous colors, sometimes even with metallic glance. Although these quasiordered systems are unlikely to find application is photonic computing, they may reveal useful ideas for colorants, coatings and perhaps for textile and paper industry, too. The more so, that the practical realization of such structures, may be a lot less demanding than that of structurally perfect photonic crystals with band gap in the visible range.

[1] L. P. Biró, Zs. Bálint, K. Kertész, Z. Vértesy, G. I. Márk, Z. E. Horváth, J. Balázs, D. Méhn, I. Kiricsi, V. Lousse, and J.-P. Vigneron, Phys. Rev. E 67 (2003) 021907-1 - 021907-7.

Hygrochromic behaviour of the hercules beetle (*Dynastes hercules*: Coleoptera)

Marie Rassart and Jean Pol Vigneron

University of Namur

The elytron of the Hercules beetle Dynastes hercules, from Western South America, is known to passively and reversibly change colour from khaki-green to black as a function of the ambient level of air humidity (Hinton, 1972). Using a spectrophotometer in reflection mode, we have recorded the optical reflectance spectrum under various stabilized hygrometric conditions, in order to determine the progressive loss of green colouration near 80% humidity.

In parallel, we have lead nano-morphology investigations of the external part of the cuticle, with scanning electron microscopy, and determined the precise structure of the hygro-adjustable colouring layer. The precise structure of the green reflector has so been determined and it is shown that impregnation of the partly void structure with water (through cracks in the thick chitin layer covering the structure) is responsible for the reflector reversible destruction. The interpretation of the switching mechanism drawn from these observations is confirmed by 3D transfer-matrices calculations. The talk will also mention some possibilities of transfer of these mechanisms for the production of artificial hygrochrome materials.

An example for discolouration in carabid beetles (Coleoptera: Carabidae)

Zsolt Bálint and **György Makranczy**
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1. The concept of discolouration was worked out by Bálint for lycaenid butterflies (Lepidoptera: Lycaenidae),[1] pointing to the phenomenon observable in closely related taxa (sister species or monophyletic groups), where a coloured taxon possesses and a related, discoloured taxon does not possess structural colour in their wings.
2. It was hypothesized that discolouration is a kind of speciation mechanism in high altitude regions, where the discoloured taxon has a better thermal regulation. This was proved experimentally.[2]
3. We have studied two forms of the well-known and bright coloured carabid species *Carabus auronitens* Fabricius, 1792 (Figure 1), one of them known from high altitude regions of the Carpathians (Figure 4), and another one, almost totally lacking the lustrous metallic colouration of the regular form. As a comparison, we also studied *Carabus rutilans*, a member of the same subgenus *Chrysocarabus* C.G. Thomson, 1875, also a very brightly metallic species (specimen from Spain). We have examined the elytra and the thoracic plates of all three taxa by Hitachi S-2600 N Scanning Electron Microscope.
4. The taxonomic status of the two forms is unclear, therefore we call them '*auronitens'* and '*opacus'* without taxonomic rank. The Carpathian subspecies of *Carabus auronitens* is *Carabus auronitens escheri* Palliardi, 1825, but the name '*opacus*' is also available as a species-group name.
5. The elytra and the thoracic plates of *C. auronitens* '*auronitens'* and *C. rutilans* show the same qualitative character: below the surface the chitinous area is granulated. Supposedly the gleaming green colour can be attributed to this granulated structure (Figure 2). It was shown recently, that quasiordered structures may also generate structural color. [3]
6. The elytra and thoracic plates of *C. auronitens* '*opacus'* has no granulated structure, it is homogeneous, and along the breaks it shows finely lamellate structures in contrast to the coloured form, where the breaks are also granulated. There is no such structure in the elytra or thoracic plate which can raise colour (Figure 5).
7. *C. auronitens* '*auronitens'* and *C. auronitens* '*opacus'* live in the same region but exact habitats of the two "forms" of *Carabus auronitens* were previously unknown. It was hypothesized that the discoloured form lives in alpine regions, exchanging the regular, coloured form. During a field study, it was revealed that the discoloured form lives near melting snowfields (1900-2500 m altitude) and can be frequently found under stones (Figure 6). At this altitude, no wooded plant occurs. The regular, metallic form reaches as high as 1800m, where the last patches of wooded plants (*Pinus mugo*) can be found, providing a natural hiding

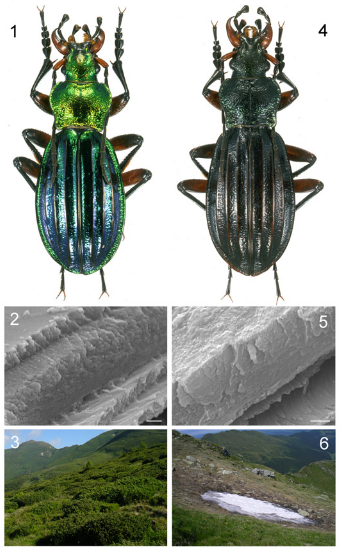
place for the beetles (Figure 3). The two distinct forms can live as close as a few hundred meters.

8. We can only speculate how *C. auronitens* '*auronitens'* uses its structural colour and why *C. auronitens* '*opacus'* does not need it. One of the most plausible explanations is thermal regulation: *C. auronitens* '*opacus'* is adapted to a cooler climate, when a more efficient thermal regulation was necessary, plus vivid colour in an open habitat was a hinder.

[1] Bálint, Zs. & Johnson, K., 1997. Neue entomologische Nachrichten, Marktleuthen 40: 1-68.

[2] Biró, L. P., Bálint, Zs., Kertész, K., Vértesy, Z., Márk, G. I., Horváth, Z.E., Balázs, J., Méhn, D., Kiricsi, I., Lousse, V. and Vigneron, J.-P-., 2003. *Physical Review* E: 67: 021907-1-7.

[3] Biró, L. P., Kertész, K., Vértesy, Z., Márk, G. I., Bálint, Zs., Lousse, V. and Vigneron, J.-P. 2007. *Materials Science & Engineering* C 27: 941-946.



Figures: 1 = fully coloured form of *Carabus auronitens escheri* Palliardi, 1825 (Romania, Munții Rodnei, Vf. Rosu, 1840m, 47°29' 43"N, 24°54' 46"E, 27.V.2007) dorsal view, 2 = same, thoracic plate, electron micrograph (scale bar = 2 μm); 3 = same, habitat; 4 = discoloured form of *Carabus auronitens escheri* Palliardi, 1825 (Romania, Munții Rodnei, Vf. Rosu, 2050m, 47°30' 25"N, 24°54' 37"E, 27.V.2007); 5 = same, thoracic plate, electron micrograph (scale bar = 2 μm); 6 = same, habitat.

Moiré patterns: application to the determination of the wings deformations.

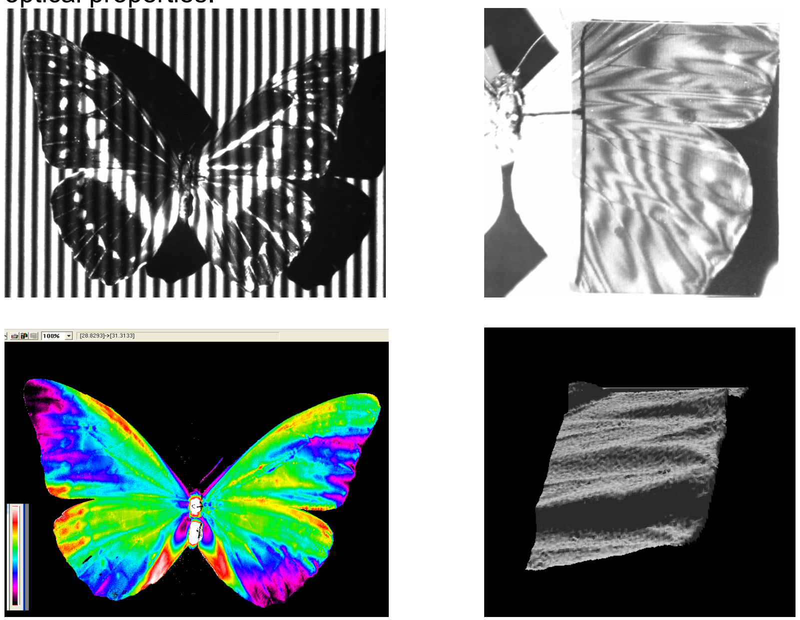
Serge Berthier, Julie Boulenguez.

INSP, Université Pierre et Marie Curie, Université Denis Diderot.

A Moiré pattern is an interference pattern created by two grids overlapping at an angle or having slightly different mesh sizes. This effect can be used to determine the deformation or the surface topography of an object. Two different techniques have been used to characterize the surface of the wings of two Morphidae (*Morpho cypris cypris and Morpho rhetenor augustinae*): the projection Moiré and the shade Moiré.

With the projection Moiré, the most simplest technique, the image of the grid is directly projected on the wing and the deformation of the image is interpreted in term of deformation. With the second technique, the shade Moiré, a Moiré pattern is obtained between the grid and its shade on the object. This approach is much more complicated but but its resolution higher.

The information collected is of great interest for the modelization of the optical appearance and message given by the butterfly, and constitutes the last scale caracterzation for a multi-scale model of the optical properties.



New type of photonic crystal in the green scales of Chrysirida Ripheus

I. Tamáska[1,2], Z. Vértesy[], K. Kertész[1], Zs. Bálint[3], L. P. Biró[1]

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[2] Budapest University of Technology and Economics (BME)
[3] Hungarian Natural History Museum, Lepidoptera

We investigated the scales of the day flying sunset moth (*Chrysiridia rhipheus*, also known as *Urania ripheus)*. This moth is most remarkable because it's rather unusual coloration on both its dorsal and ventral sides. Previous work on the transmission, reflection and absorption of individual scales has shown that these colors cannot be attributed to pigments. Indeed, a 1D Photonic Band Gap (PBG) material was revealed in the "purplish area" of the ventral scales and attempts were made to model the optical behavior of such a scale.

We investigated scales from two different green regions with reflectance spectroscopy, scanning- (SEM) and transmission (TEM) electron microscopy. A simple multilayer model was used to compute the reflectance on the basis of the structural data extracted from the TEM images.

The comparison of the measured reflectance with the computed ones revealed, that for one type of scales a satisfactory agreement is obtained between the experimental data and the reflectance, calculated on the basis of the structural data extracted from TEM images. For another type of scales a clear disagreement was found between the measured and calculated reflectance.

Comparing in more detail the TEM images corresponding to the two types of scales, it became clear that indeed, for that type of scale for which the disagreement was found a fairly high number of trabeculae were seen to connect the continuous layers. Efforts were done to break scales of the type giving the disagreement of measured and computed spectra in a plane parallel with the plane of the scale. In the SEM image can be seen, that the trabeculae linking the two adjacent layers are arranged according to a regular pattern that can be best described as a triangular lattice. So this structure can be interpreted as a combination of a 1D (known as Bragg reflector) and a 2D photonic crystal (trabuculaes in triangular lattice).

Fabrication of SiO_2/TiO_2 multilayer films mimicking *Chrysochroa vittata* and *Hoplia coerula*

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Chrysochroa vittata and *Hoplia coerulea* are two beautiful examples of iridescent Coleoptera which provide us with ideas for fabrication of multilayer films for various applications [1-2]. While the former gives us a nice template for reflecting surfaces which change their colour in a spectacular way as the angle of incidence is varied, the latter inspires us with a different design idea for reflecting surfaces which exhibit relatively stable colours. The theoretical analysis of the reflectance of multilayer films has revealed that both extreme behaviours (greatly changing colour - *Chrysochroa vittata* and stable colour - *Hoplia coerula*) can be achieved with the same combination of materials (air/chitin or SiO_2/TiO_2) by playing only with the layer thickness ratio. We report here on the fabrication of SiO_2/TiO_2 multilayer films by magnetron sputtering for the purpose of mimicking *Chrysochroa vittata* and *Hoplia coerulea* properties. From spectral reflectance measurements (specular arrangement) on the fabricated films, we show how radically different are the evolutions of the sample colour in the chromaticity diagram as the angle of incidence is varied.

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Optical gas sensing of photonic crystal-type butterfly scales

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In the past few years we revealed the scale structure on the wings of several butterfly species, and we described their structure and optical properties [1, 2]. In the present work we focus on reflectance spectra changes induced by modifying the atmosphere surrounding the wing by adding different vapours to the ambient atmosphere. The detected spectral change depends on the scale nanostructure as well as the kind, and concentration of the surrounding gas.
The wing scale nanostructure was revealed by SEM and TEM, the optical behaviour was investigated with an UV-VIS-NIR spectrophotometer.
We showed that the CIE Lab parameters are also suitable to demonstrate the difference between detected vapours. The response time of these sensors is in the order of seconds. When using different butterfly species, different vapours produce different signals, allowing the identification of the vapour present in the air. With a proper number of detectors and a suitable signal processing algorithm, a selective gas / vapour recognition is possible, as we showed before, in the case of a system based on functionalized carbon nanotubes. Due to the optical reading out of the wing-based sensors, there is no electric contact inside the gas chamber, this eliminates the risk of explosions for combustible species.
Looking forward the direct applications, the measurements on living photonic crystals give new ideas on developing intelligent sensors for complex tasks.

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Reciprocal- and direct space study of butterfly wing scale structures of long range order, medium range order, and short range order

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In order to study local order in TEM and SEM images of butterfly scales, we have recently developed [1] a simple direct space algorithm, based on averaging the local environment of the scattering sites. The method provides the statistical distribution of the local environments, including the histogram of the nearest neighbour distance and the number of nearest neighbours. In this contribution we apply this method to three characteristic situations: 1) scale structures possessing long range periodicity (dorsal, metallic blue side of *Cyanophrys remus*), 2) granular scale structures with medium range order (ventral, matte green side of *Cyanophrys remus*), 3) and short range periodicity (dorsal and ventral sides of *Albulina metallica*). It was found that in all the three cases the direct space averaging method was capable to extract that information from the micrographs which is responsible for the characteristic optical properties.

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