

# Bioinspired photonics for tomorrow's technological applications

Sébastien R. Mouchet

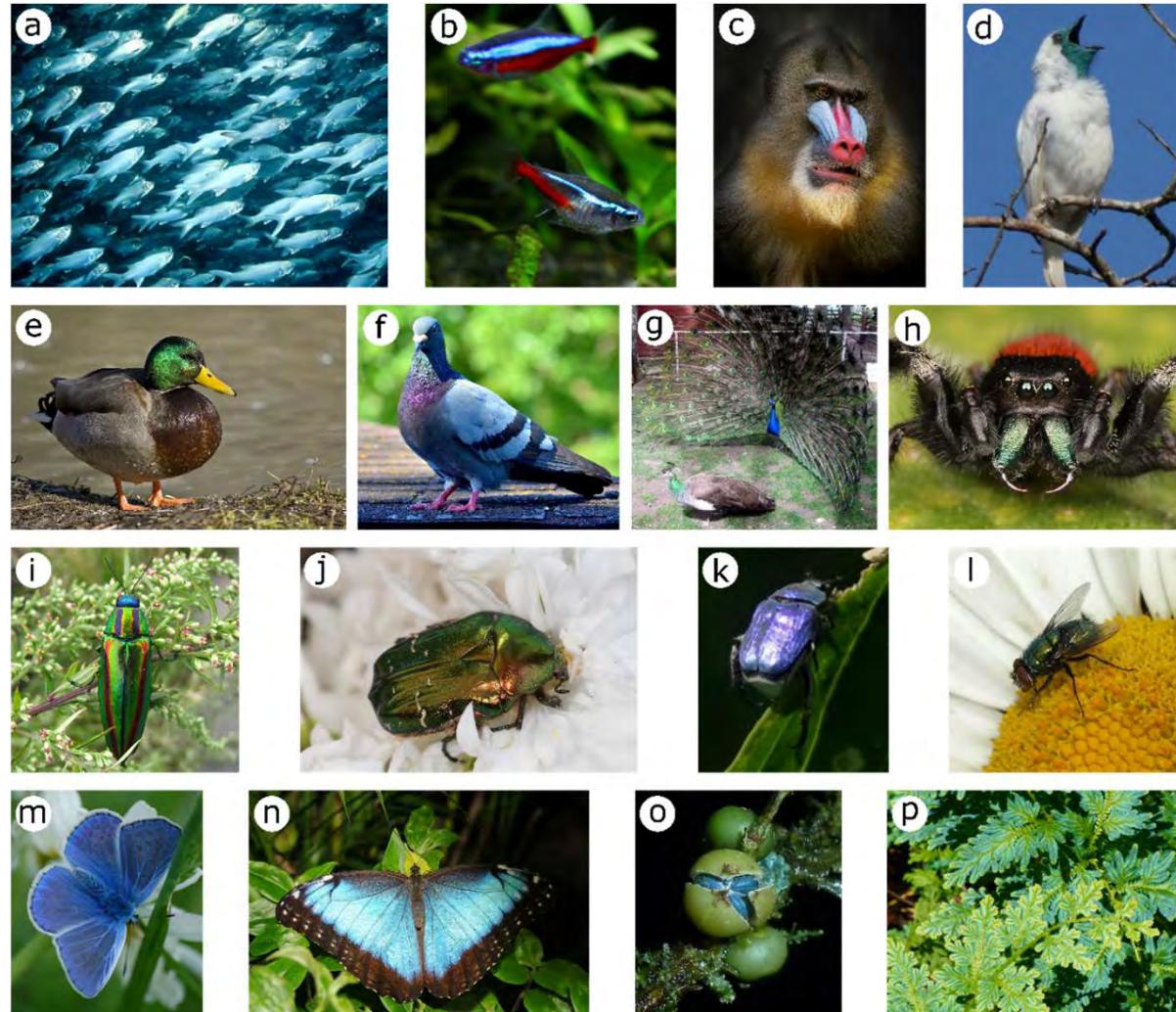
Journées Nationales de la Lithographie par  
Nanolmpression  
Lyon, 11-12/05/2023



University  
of Exeter



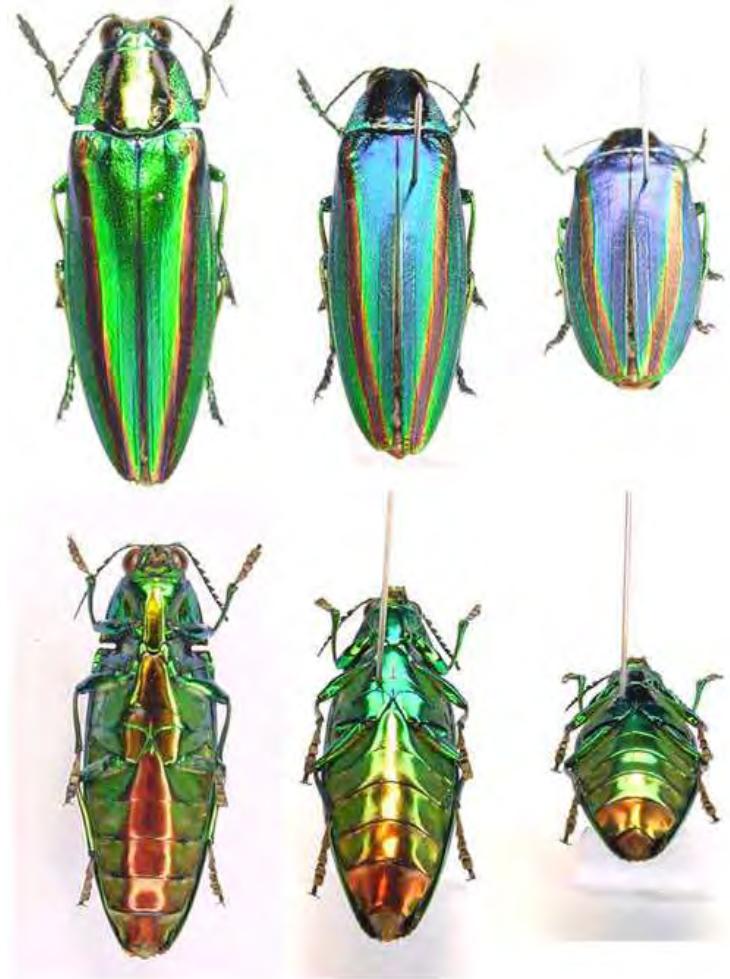
# Structural colours in natural organisms



In the biological world, many structural colours produced by the interaction between light and photonic structures

# Properties of natural photonic structures

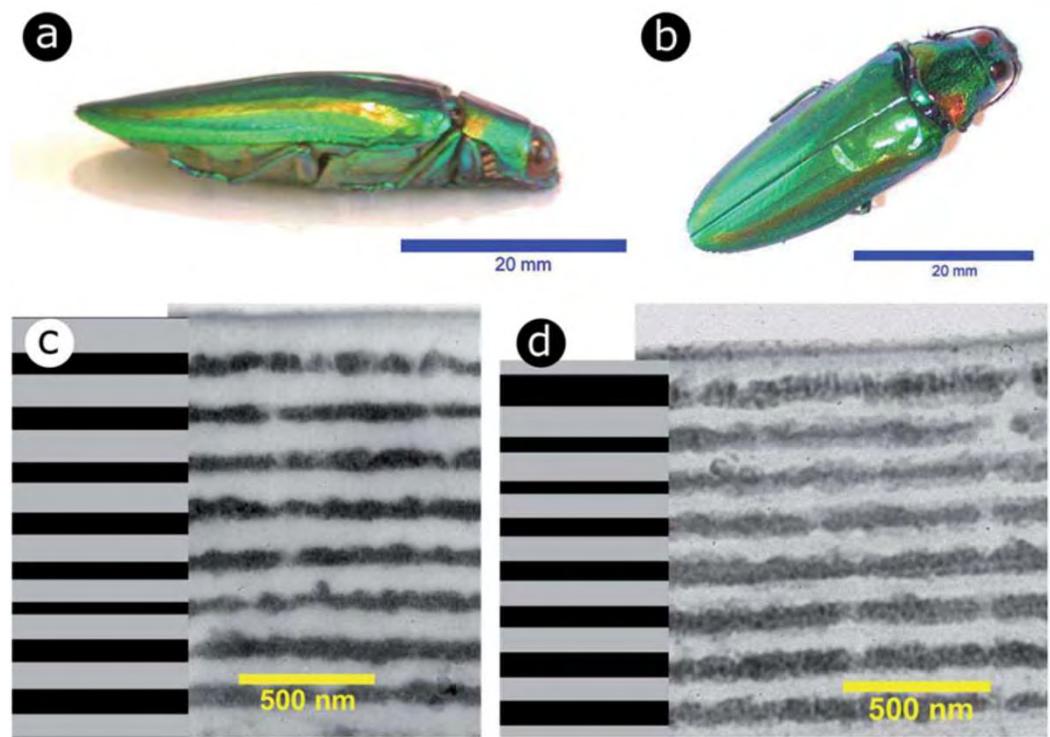
## Iridescence



Kinoshita, *Structural Colors in the Realm of Nature*, 2008

# Properties of natural photonic structures

## Iridescence

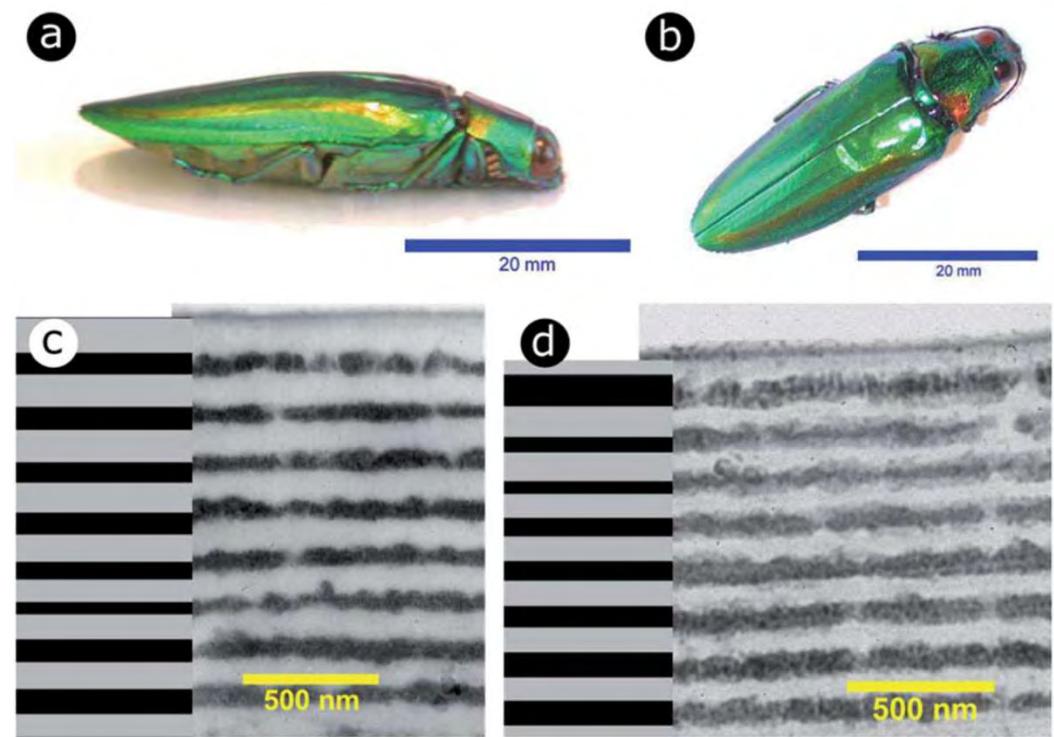
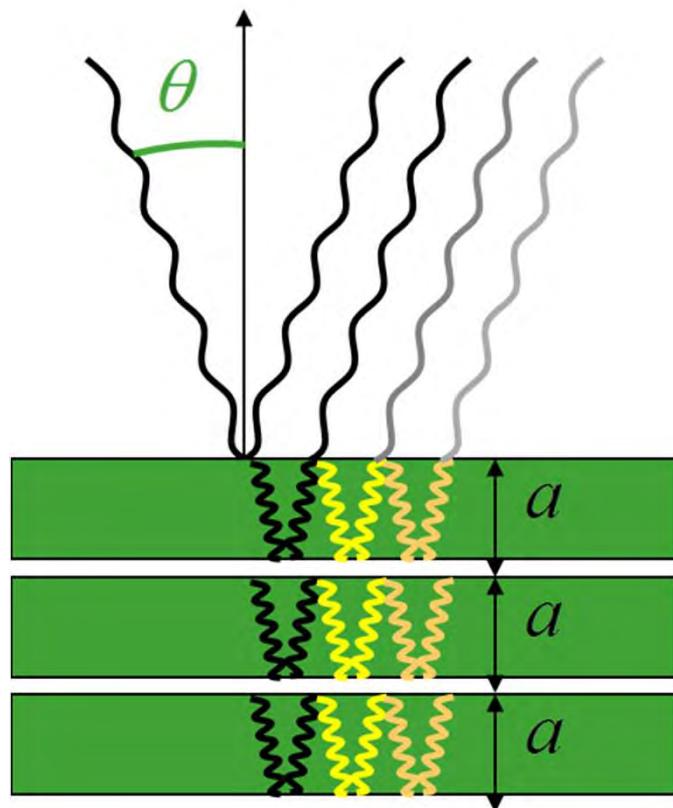


Natural photonic structure!

Kinoshita, *Structural Colors in the Realm of Nature*, 2008

# Properties of natural photonic structures

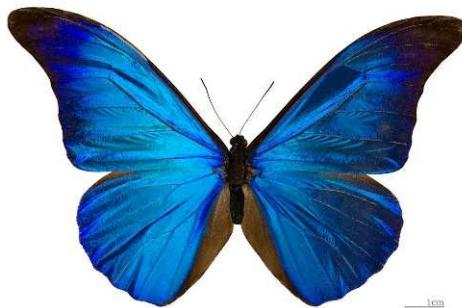
## Iridescence



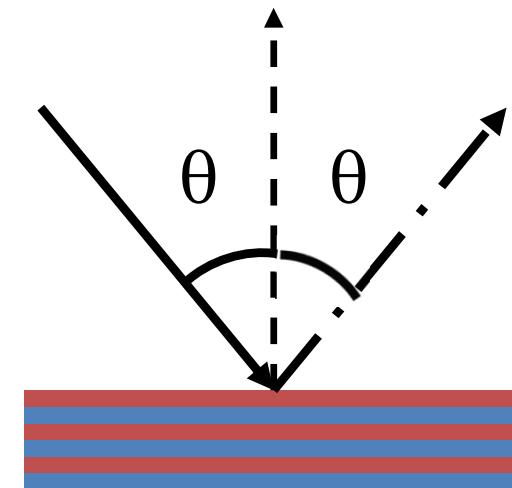
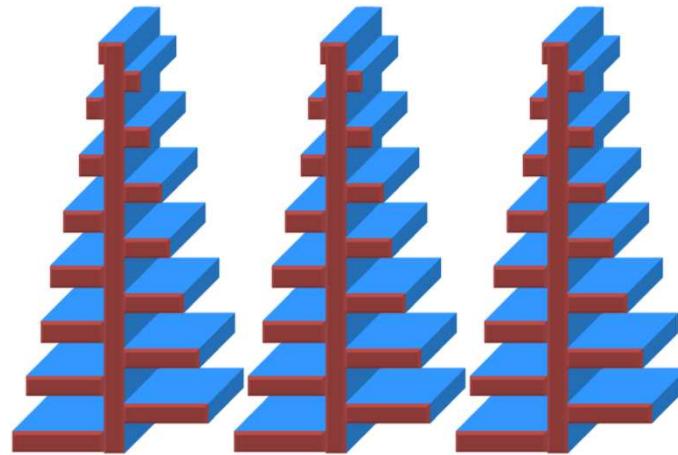
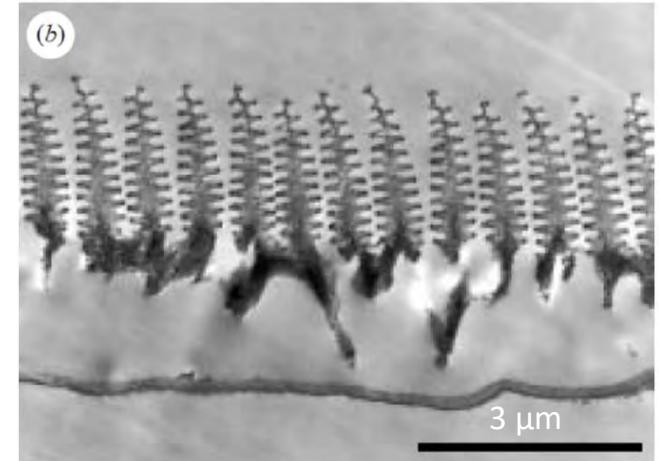
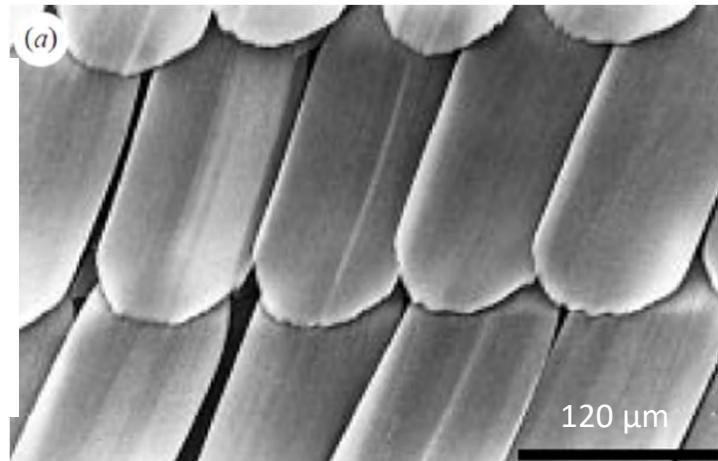
Natural photonic structure!

# Properties of natural photonic structures

Iridescence

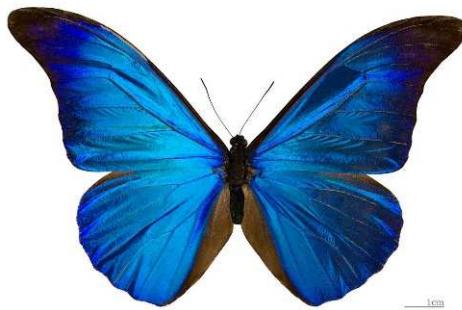


*M. rhetenor*

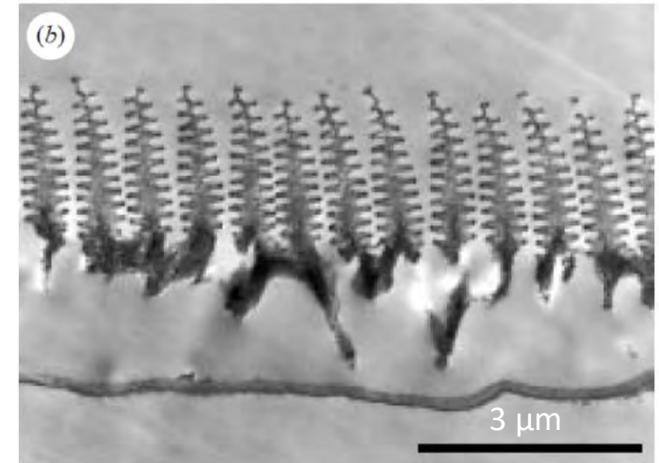
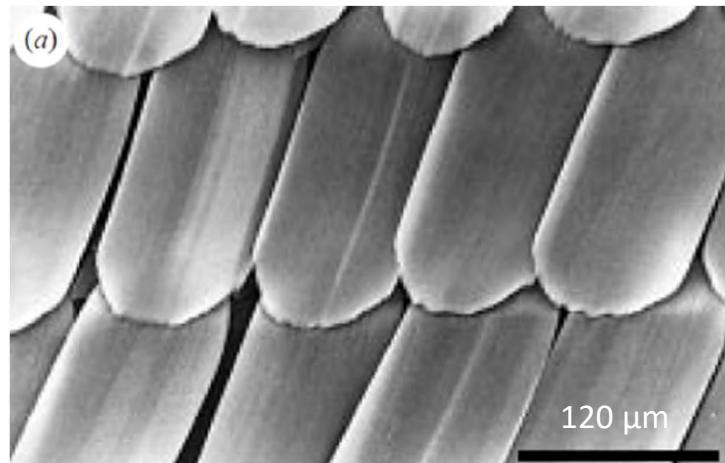


# Properties of natural photonic structures

Iridescence



*M. rhetenor*



Vukusic *et al.*, Proc. R. Soc. B 266, 1999

# Liquid-induced colour change

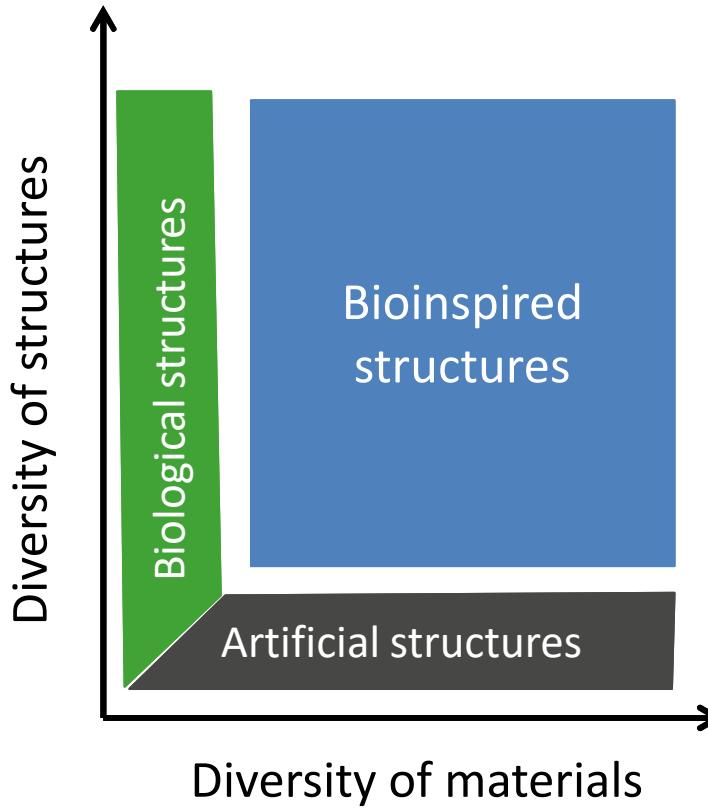
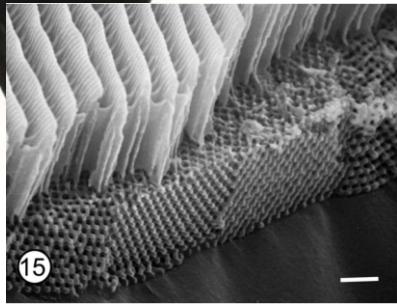


All these lepidopteran photonic structures are generally open to air, the surrounding environment.

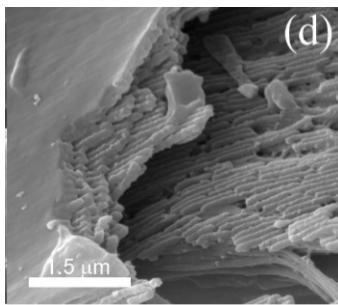
# Bioinspiration



*Parides sesostris*



*Pavo cristatus*



Morphotex fabric  
Teijin Limited



Morphotone painting

Kinoshita, *Structural Colors in the Realm of Nature*, 2008

Mouchet & Deparis, *Natural Photonics and Bioinspiration*, Artech House, 2021

# Liquid-induced colour change

*Charidotella egregia*



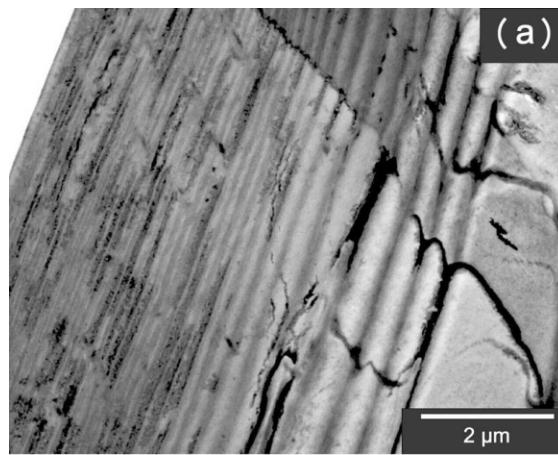
Vigneron et al., PRE 76, 2007

# Liquid-induced colour change

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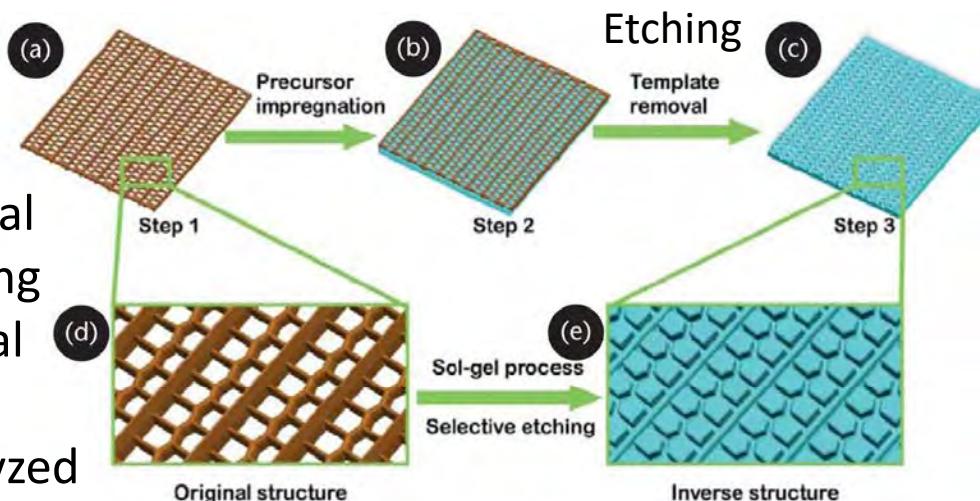
Chirped Bragg mirror



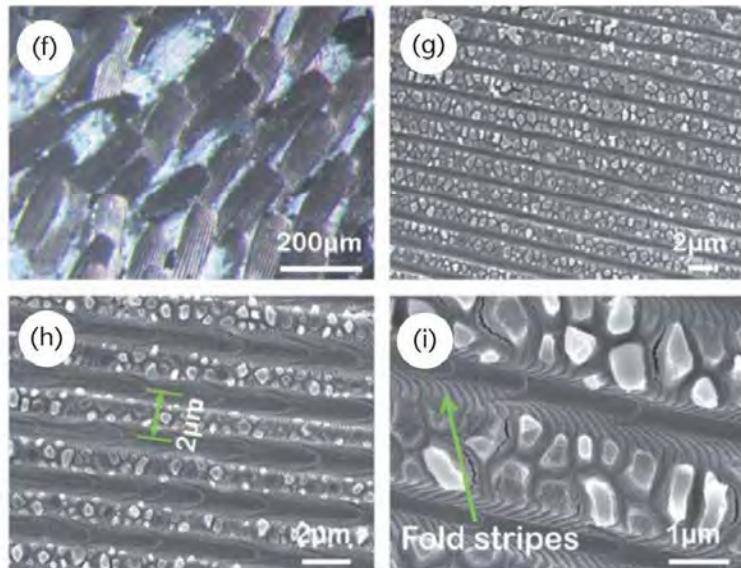
Vigneron et al., PRE 76, 2007

# Sol-Gel Methods

Hydrolysis of a colloidal solution (sol) containing precursors (e.g., metal alkoxides) and poly-condensation of hydrolyzed products, leading to the formation of a gel, i.e. a solid, inorganic network containing a liquid phase



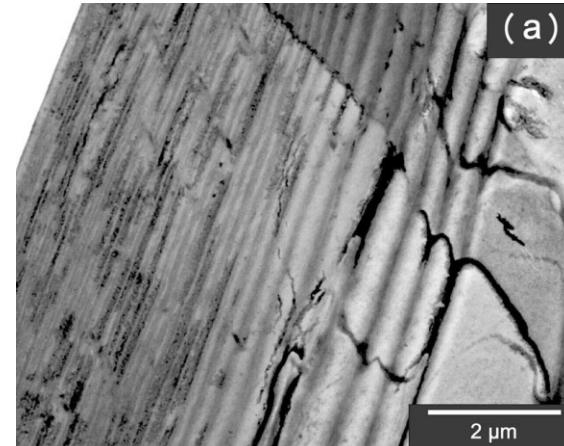
Deposition of  $\text{SiO}_2$ ,  $\text{TiO}_2$  or  $\text{Al}_2\text{O}_3$



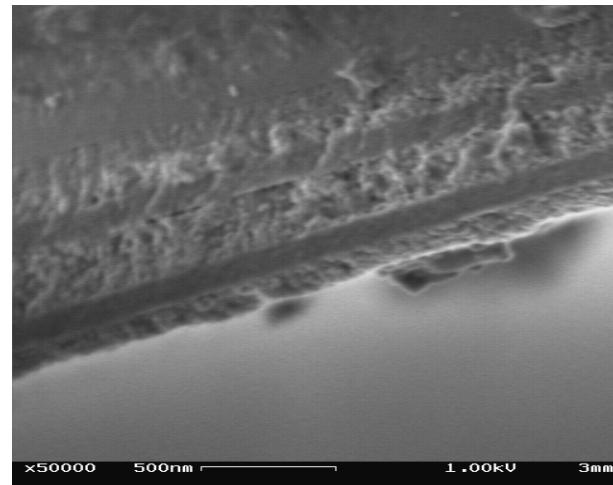
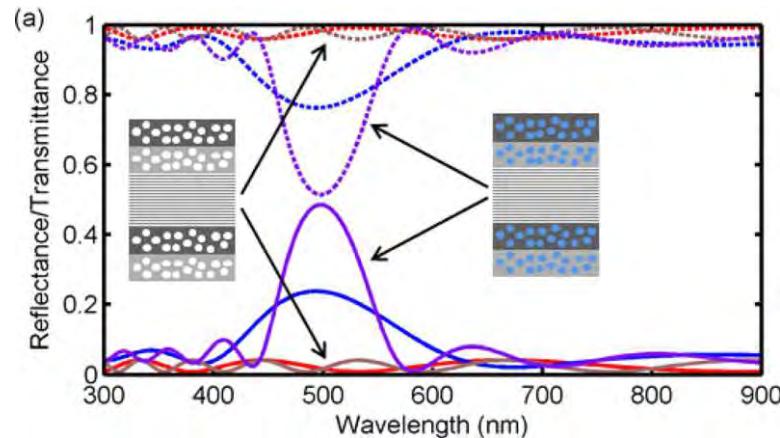
Inverse replica of butterfly wing

# Bioinspired smart glass coatings

*Charidotella egregia*



Vigneron *et al.*, PRE 76, 2007

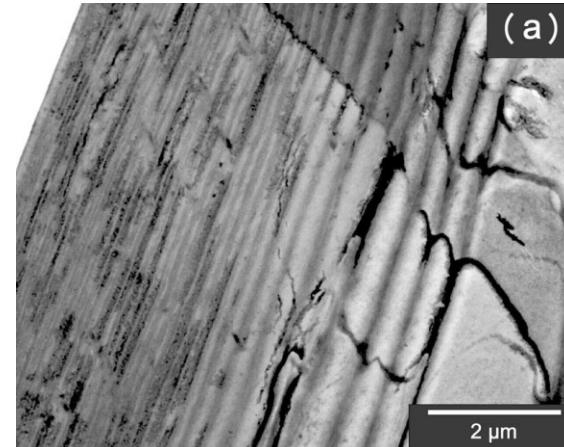


- Glass slide coated with mesoporous oxide Bragg layer stack
- Mesoporous oxides ( $L_1$  layers:  $x\text{TiO}_2(1-x)\text{Al}_2\text{O}_3$ ,  $L_2$  layers:  $\text{SiO}_2$ ) were synthesised by sol-gel method
- Molar ratio  $x$  of mixed oxide layers was adjusted in order to get a transparent Bragg mirror in dry condition

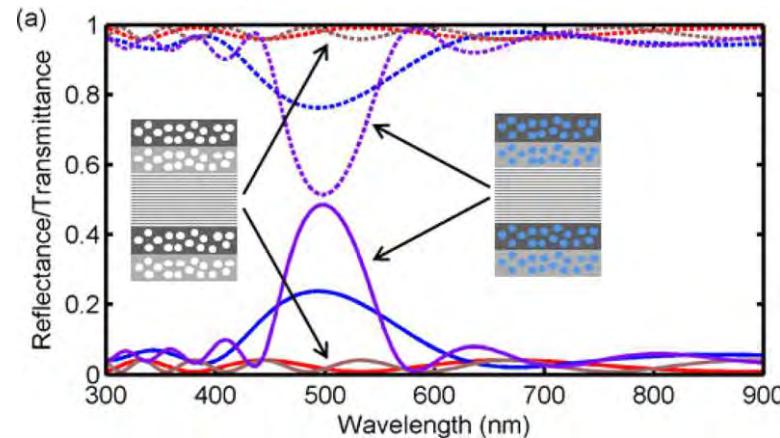
Deparis, Ghazzal, Simonis, Mouchet *et al.*, APL 104, 2014

# Bioinspired smart glass coatings

*Charidotella egregia*



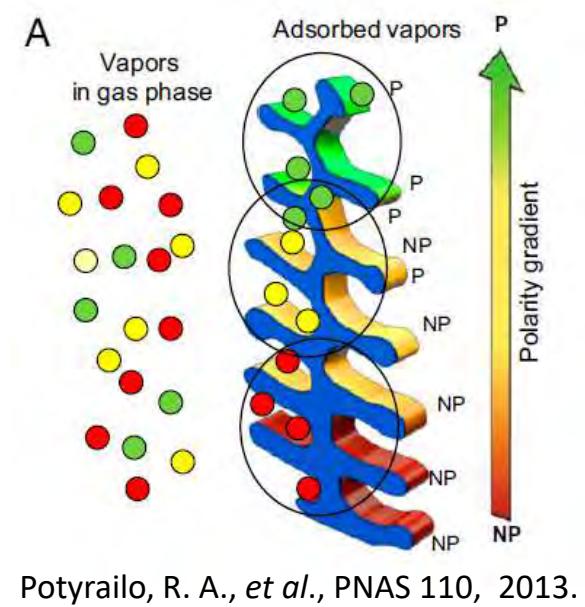
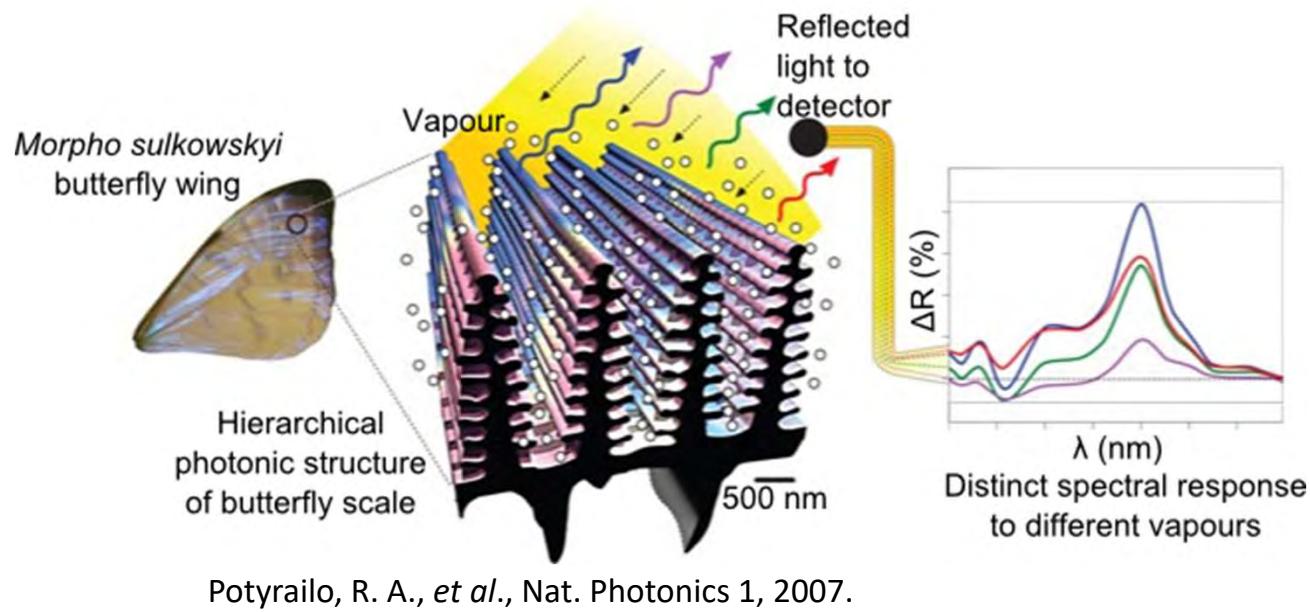
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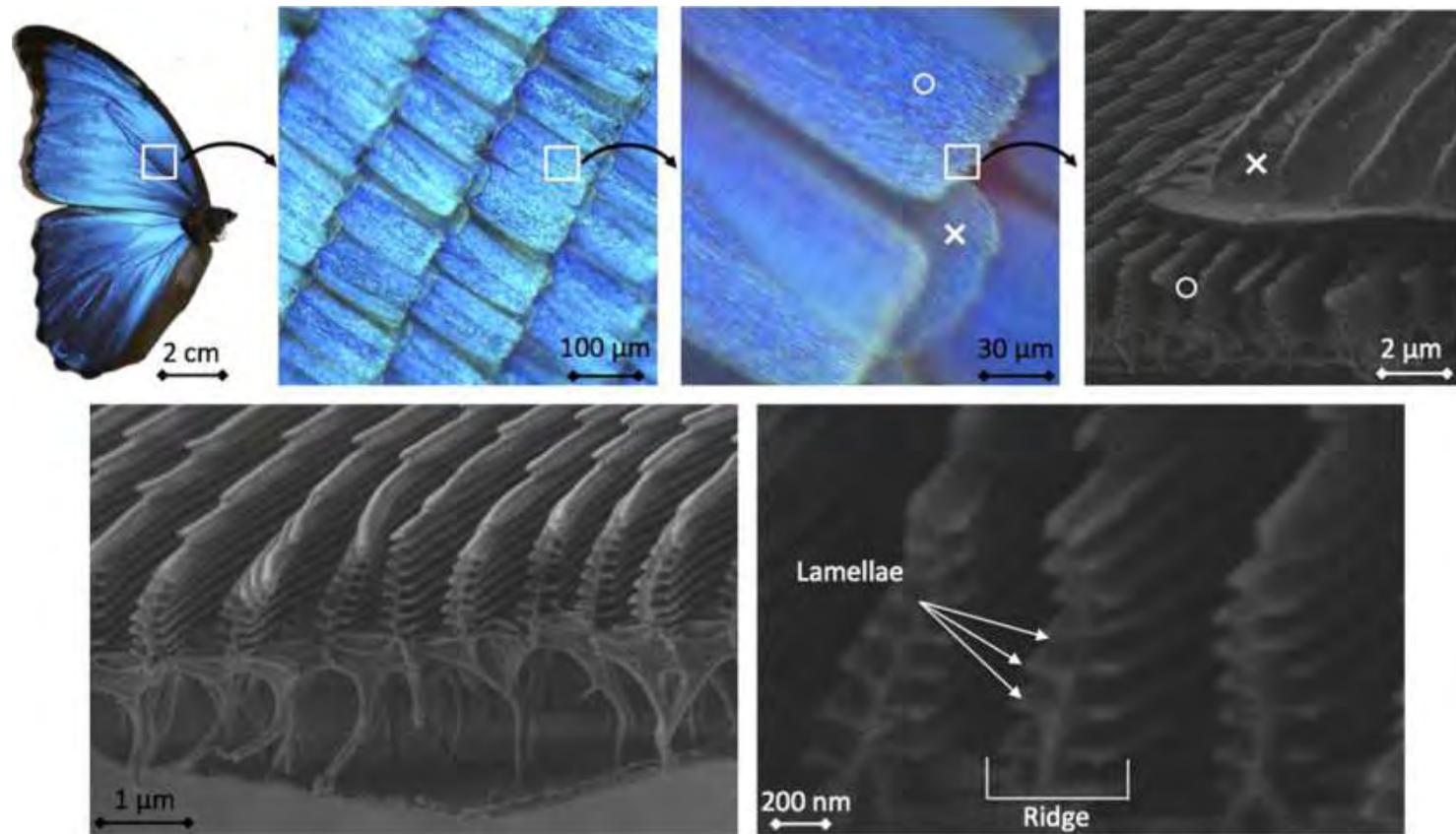
Deparis, Ghazzal, Simonis, Mouchet et al., APL 104, 2014

# Gas/vapour-induced colour change

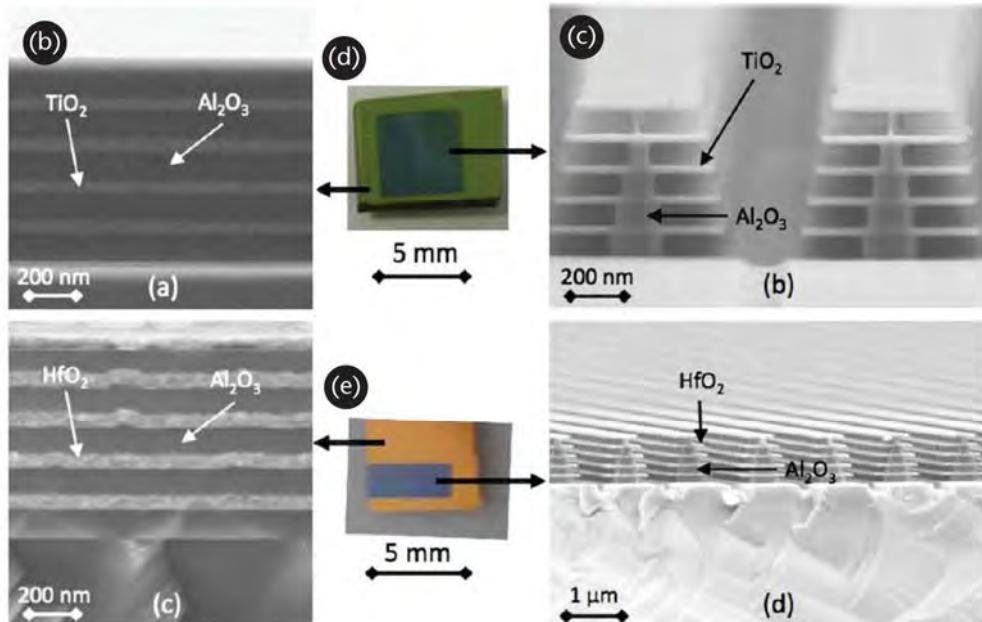


# Bioinspired photonic gas/vapour-sensors

*Morpho godarti*

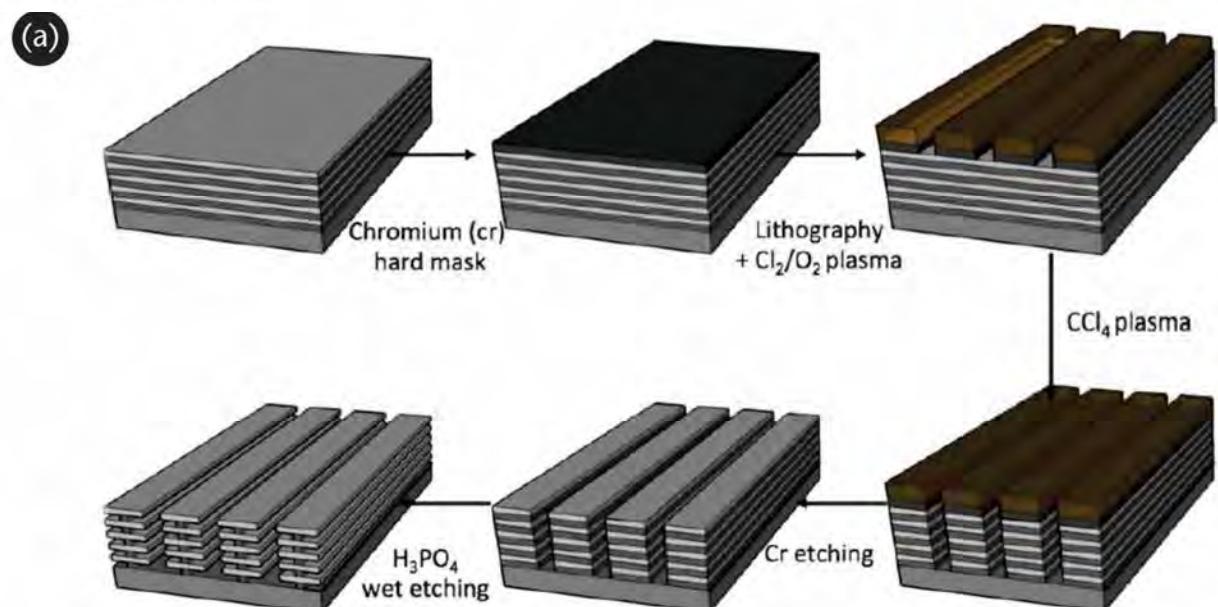


# Bioinspired photonic gas/vapour-sensors



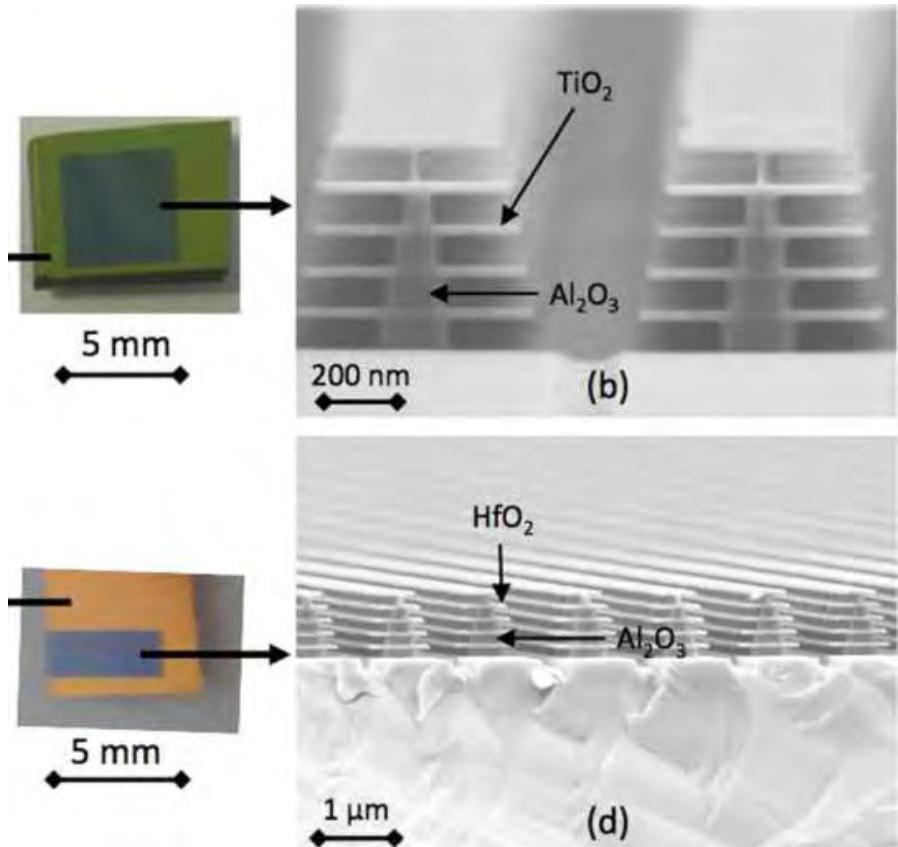
## Atomic Layer Deposition

Surface is repeatedly exposed to gas precursors, the adsorption of which forms monolayers

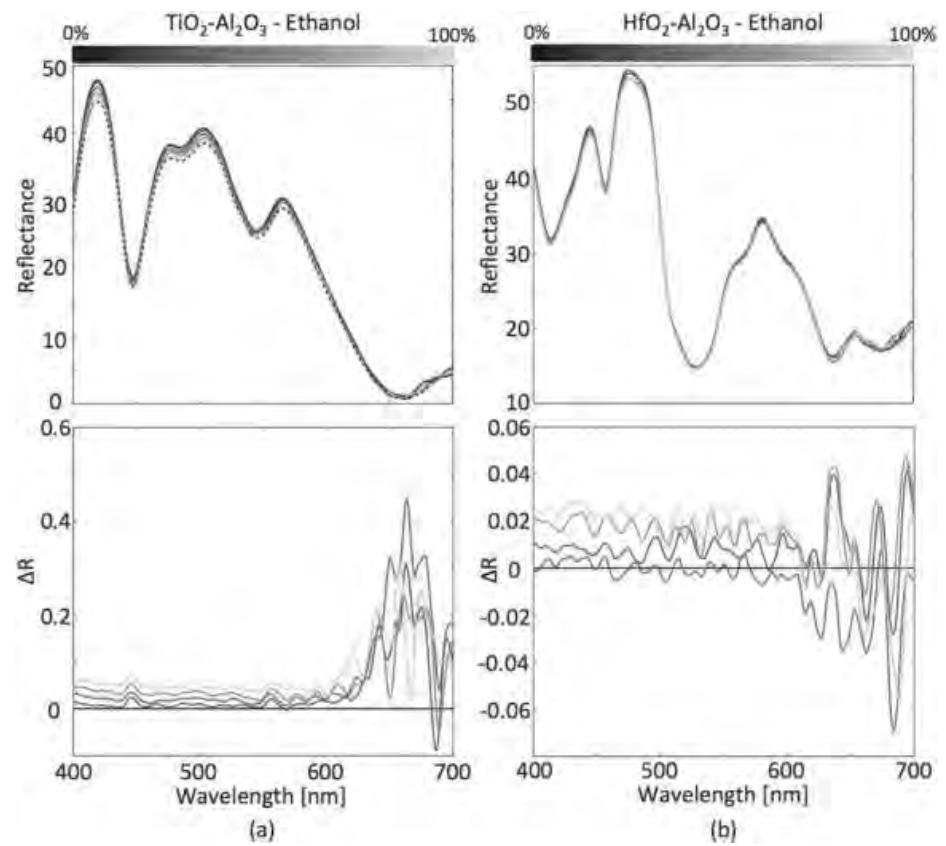


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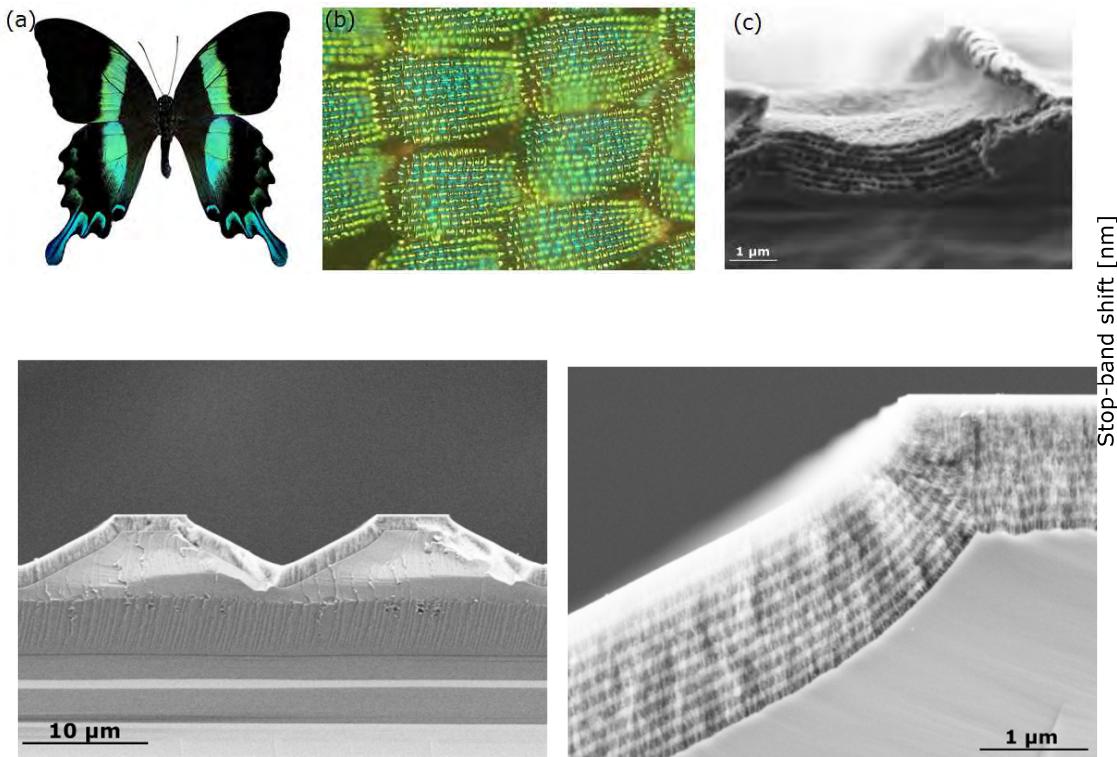


ALD Bragg mirrors of  $\text{Al}_2\text{O}_3/\text{TiO}_2$  or  $\text{Al}_2\text{O}_3/\text{HfO}_2$  nanostructured by etching

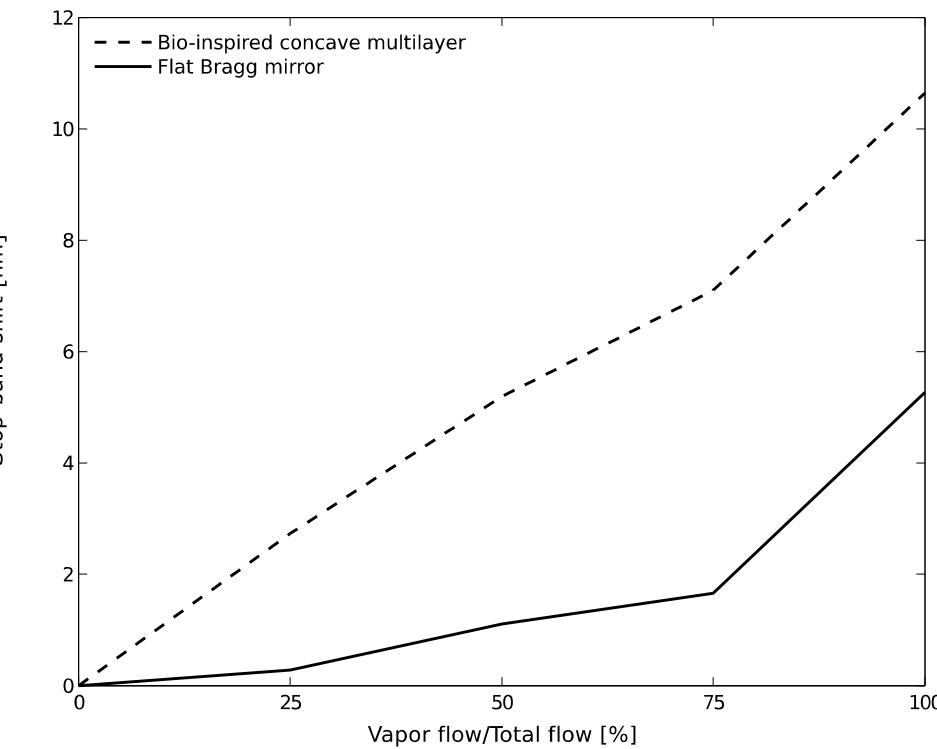


# Bioinspired photonic gas/vapour-sensors

*Papilio blumei*



Concave porous silicon multilayer synthesised  
by photolithography and etching

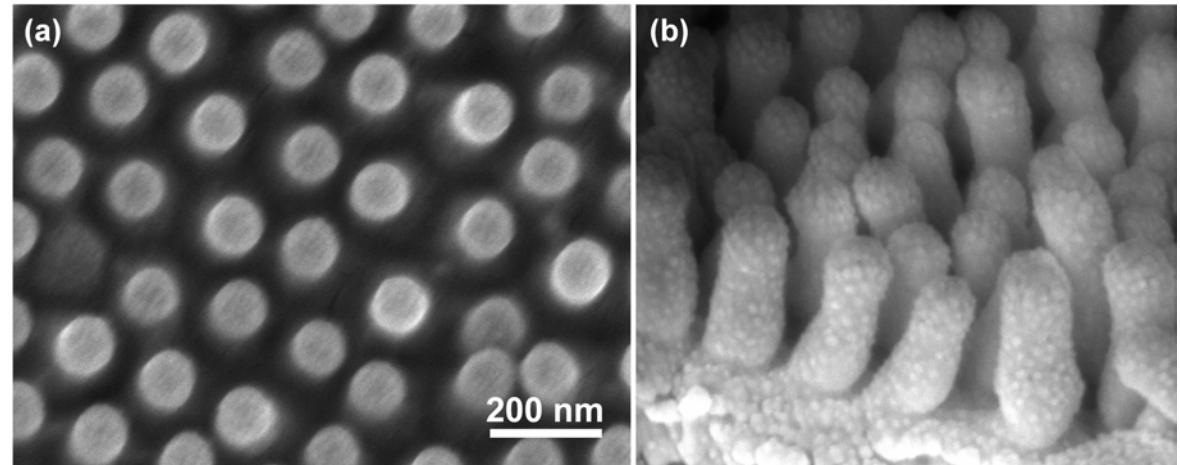
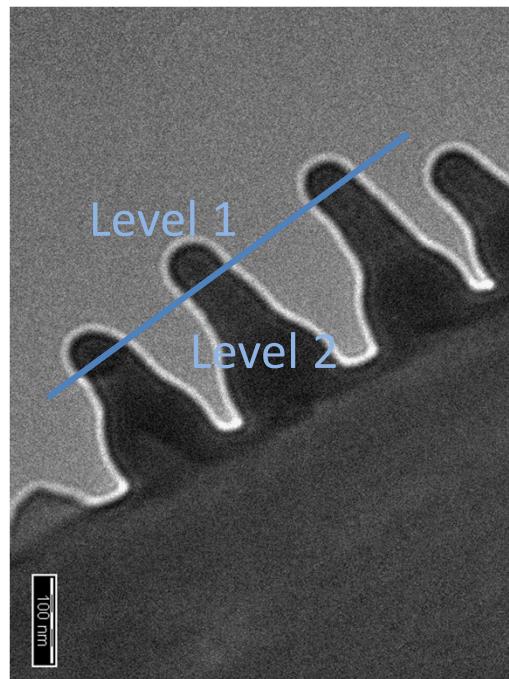


# Multifunctional nanostructures on the wings of *Cicada orni*

Transparent wings with

- antireflection effect and
- hydrophobic properties

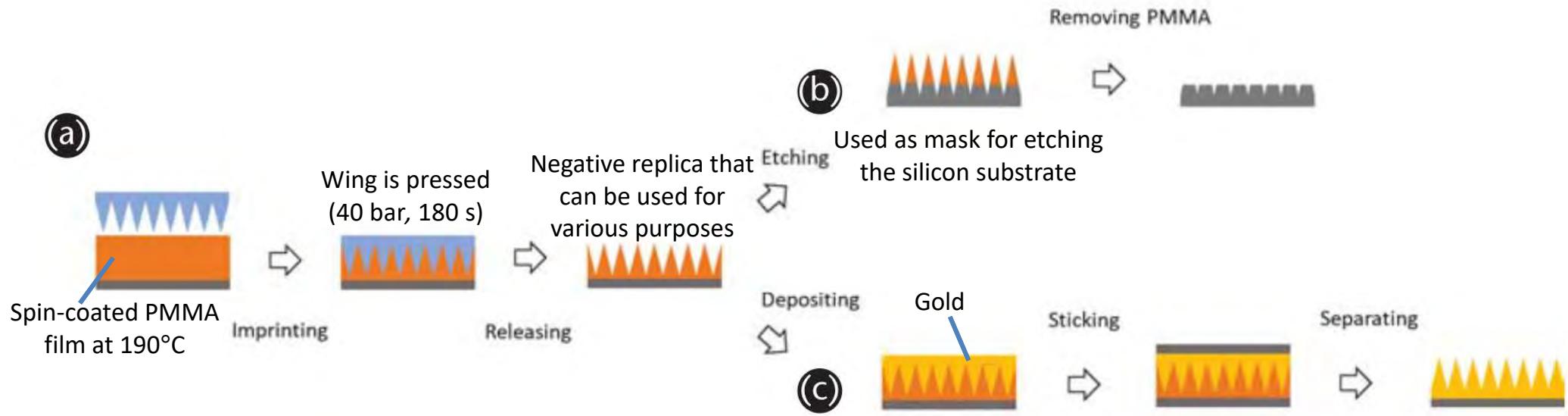
due to a quasi-periodic arrays of hexagonally close-packed protrusions



Dellieu *et al.*, JAP 116, 2014

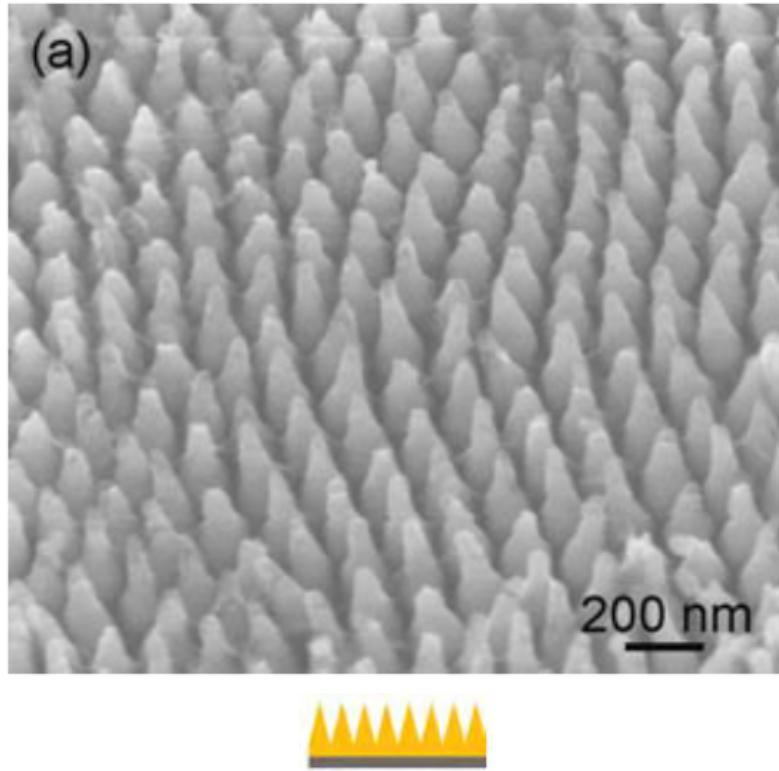
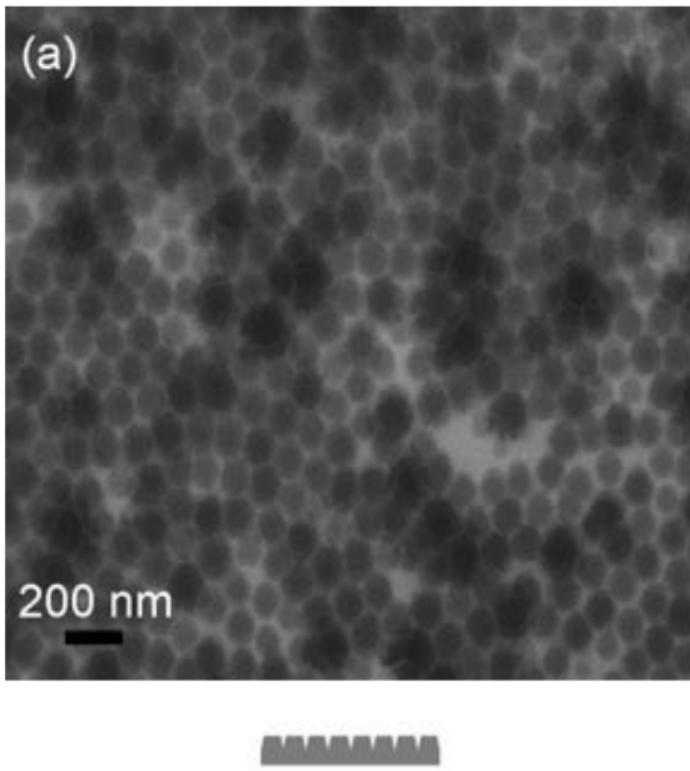
Deparis, Mouchet *et al.*, Mater. Today: Proc. 1S, 2014

# Nanoimprint lithography & cicada wing nanostructures



Chitin structures have good mechanical properties and chemical stability allowing them to withstand imprint process and are reusable

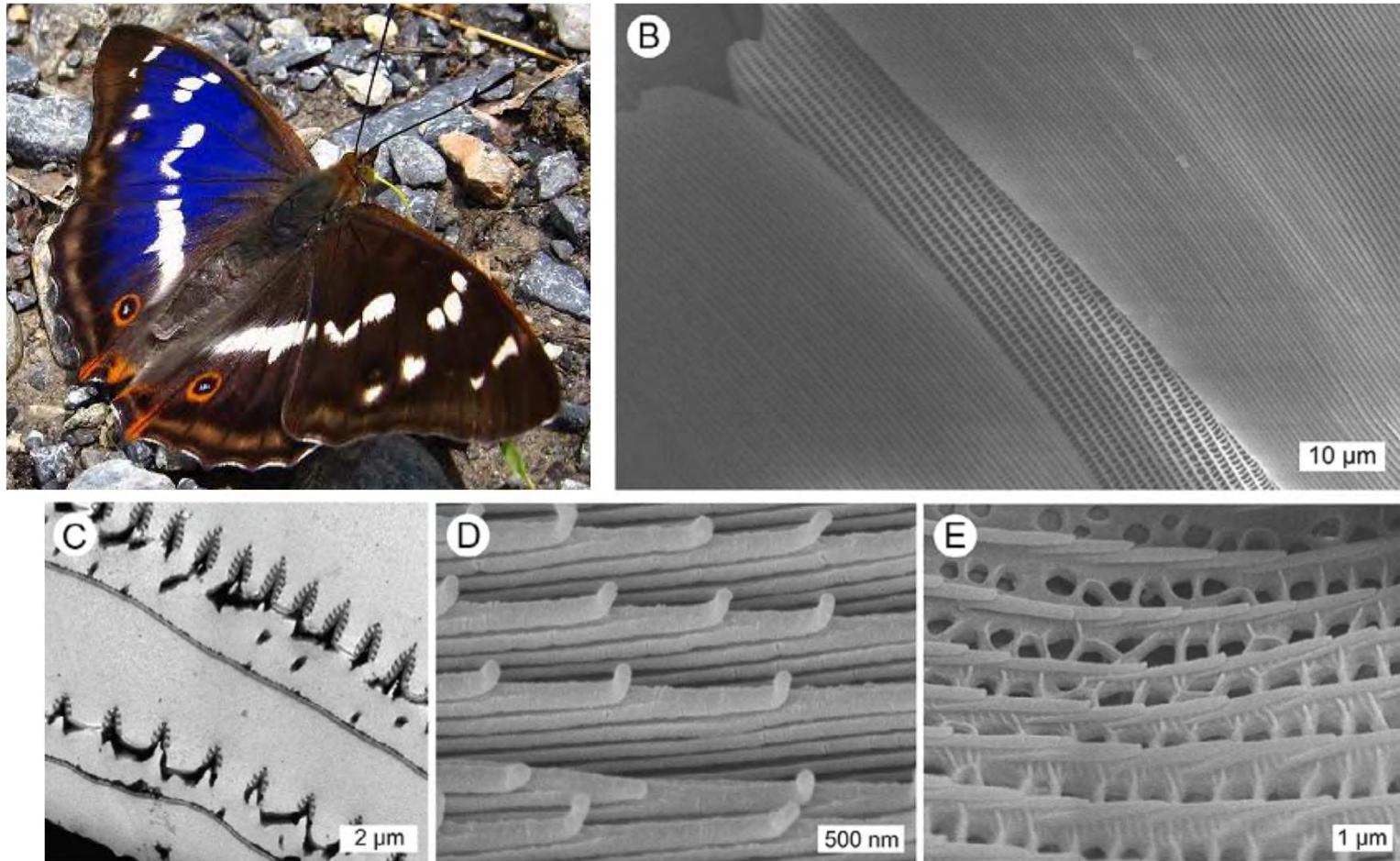
# Nanoimprint lithography & cicada wing nanostructures



Zhang *et al.*, Small 2, 2006

Mouchet & Deparis, Natural Photonics and Bioinspiration, 2021

# UV reflection from butterfly wings



Purple Emperor *Apatura iris* butterfly

Mouchet & Vukusic, Advances in Insect Physiology 54, 1-53, 2018  
Pantelić et al., Optics Express 19, 5817-5826, 2011



# Collision between birds and windows



J. Dielis, [https://commons.wikimedia.org/wiki/File:Pigeon\\_imprint\\_on\\_window.jpg](https://commons.wikimedia.org/wiki/File:Pigeon_imprint_on_window.jpg)



J. Newton, [https://commons.wikimedia.org/wiki/File:Bird\\_Splat.jpg](https://commons.wikimedia.org/wiki/File:Bird_Splat.jpg)



# Collision between birds and windows



US windows kill 100 million to 1 billion birds a year

Sheppard, Bird-Friendly Building Design, American Bird Conservancy, 2011

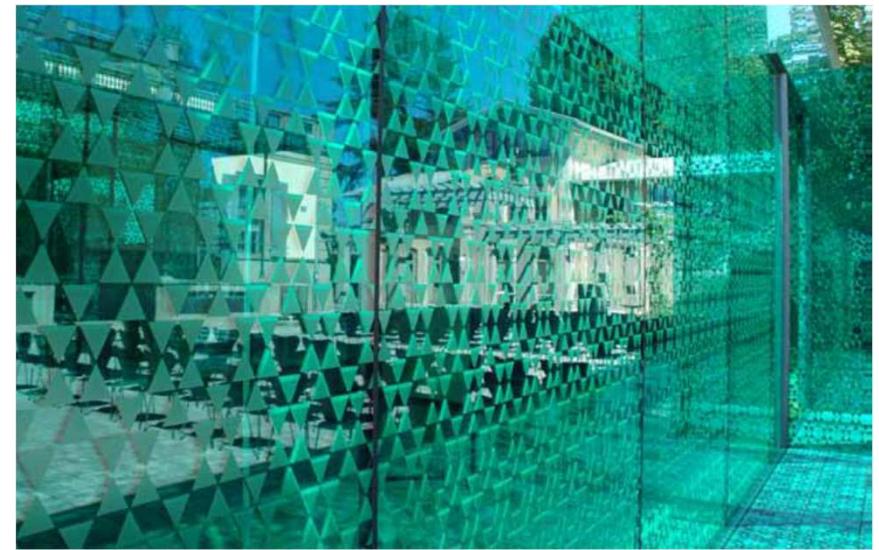


# Collision between birds and windows



tuchodi, [https://commons.wikimedia.org/wiki/File:Mirrored\\_Aggression,\\_bird\\_2.jpg](https://commons.wikimedia.org/wiki/File:Mirrored_Aggression,_bird_2.jpg)  
Schmid, Oiseaux et vitres : éviter les collisions, 2016

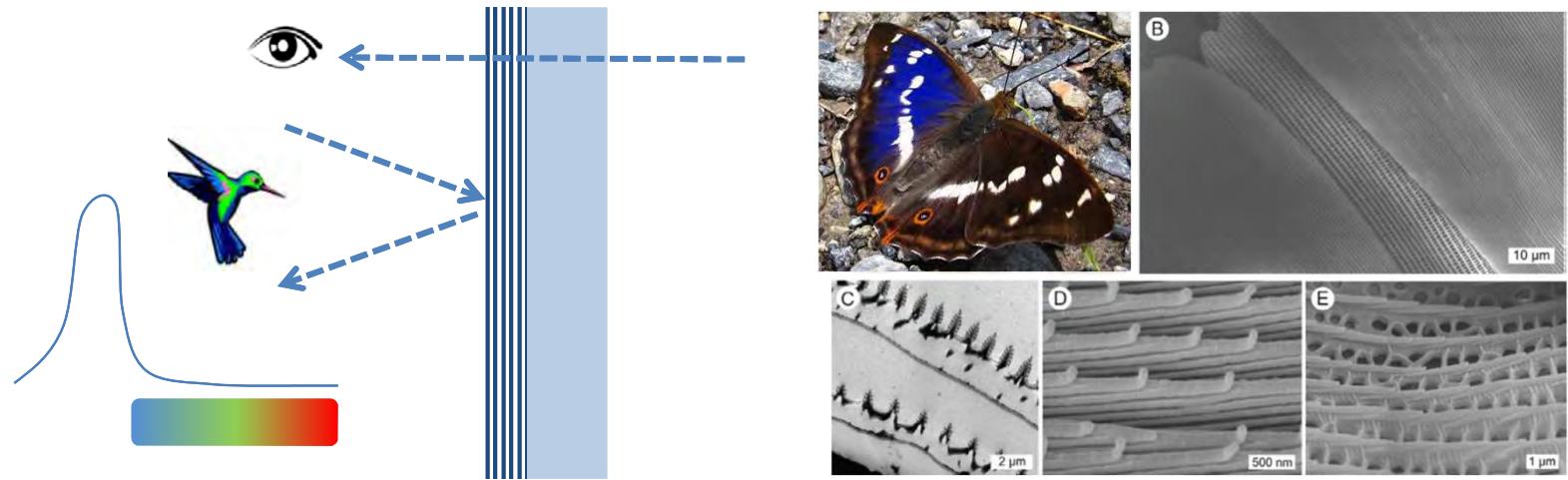
# Existing solutions



Nets, stickers, curtains, screens, grids, etc

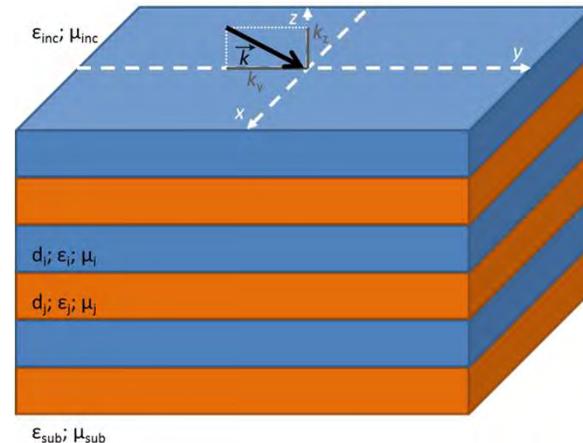
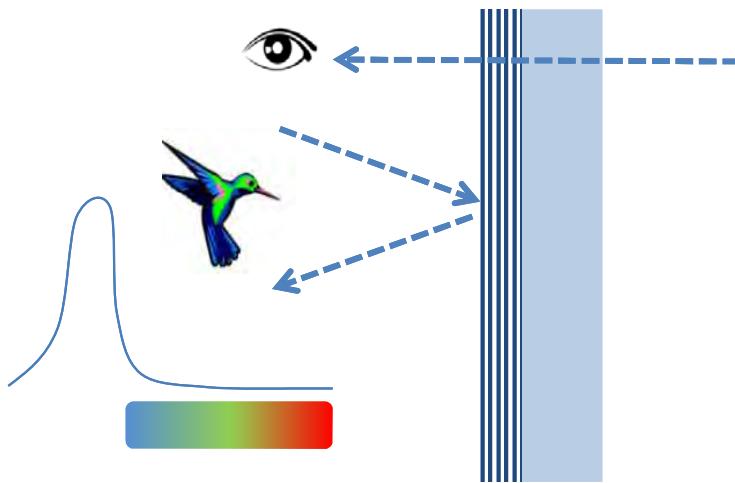
Sheppard, Bird-Friendly Building Design, American Bird Conservancy, 2011

# Bioinspired bird-safe windows



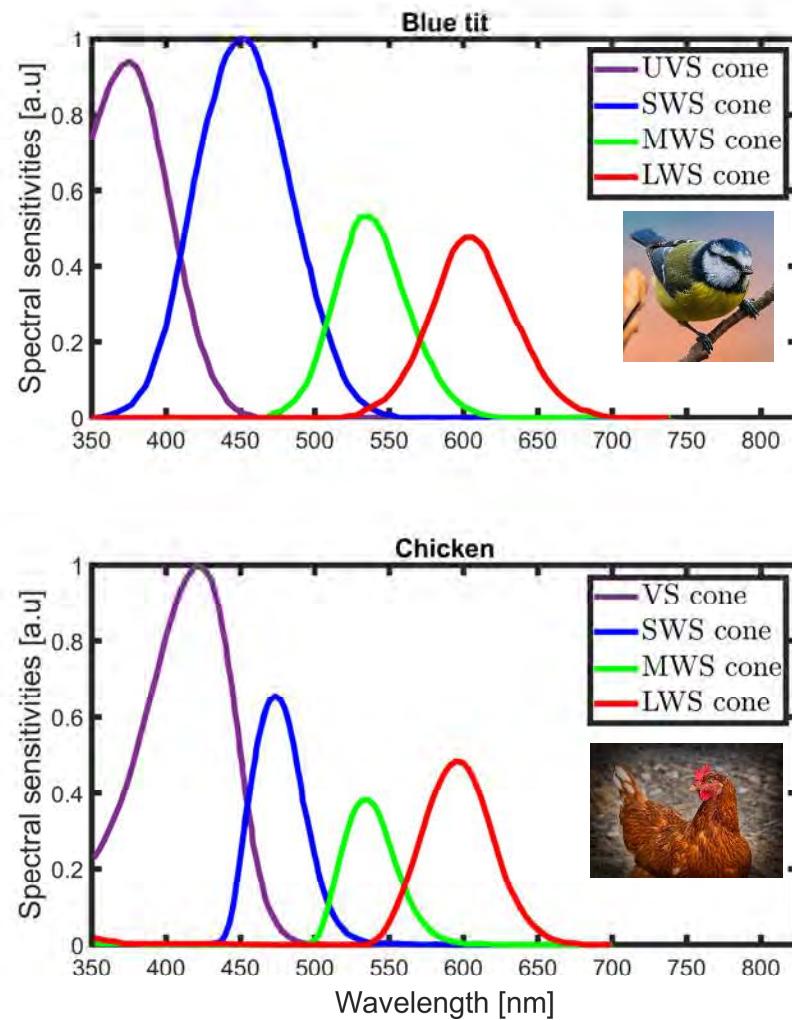
Optimisation of the optical response wrt the layer materials and thicknesses,  
taking into account the human and avian colour perception

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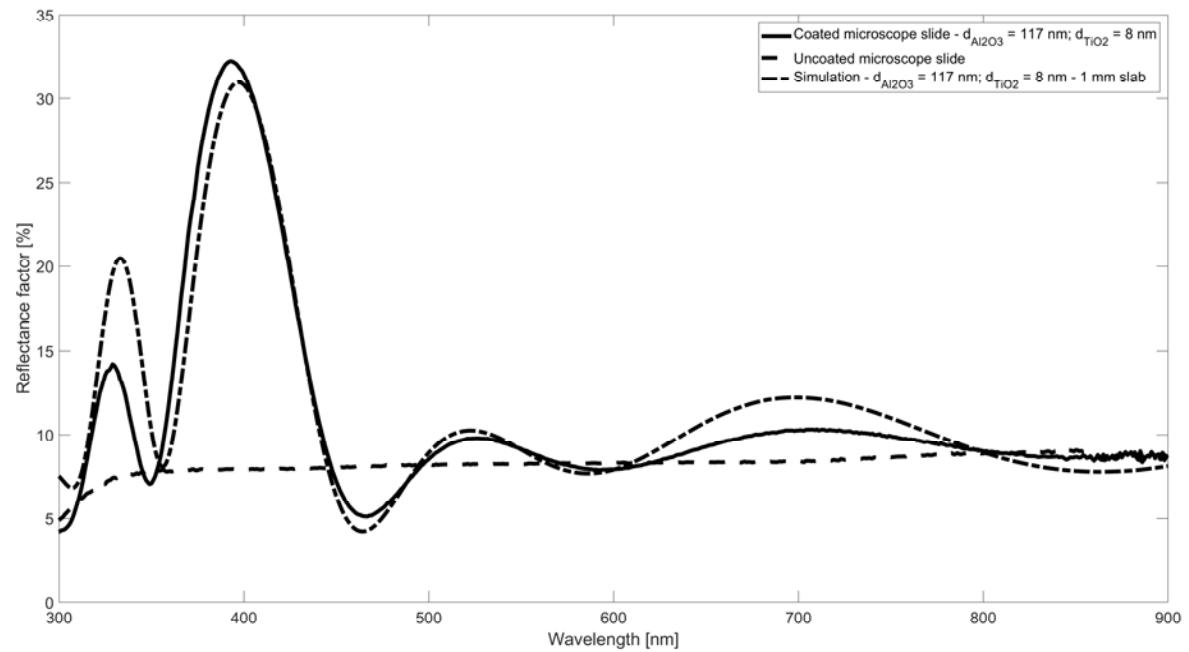
Mouchet *et al.*, in preparation

Data from Vorobyev, 2003; Vorobyev *et al.*, 1998; Wilby *et al.*, 2015; Smith and Pokorny, 1975

# Bioinspired bird-safe windows



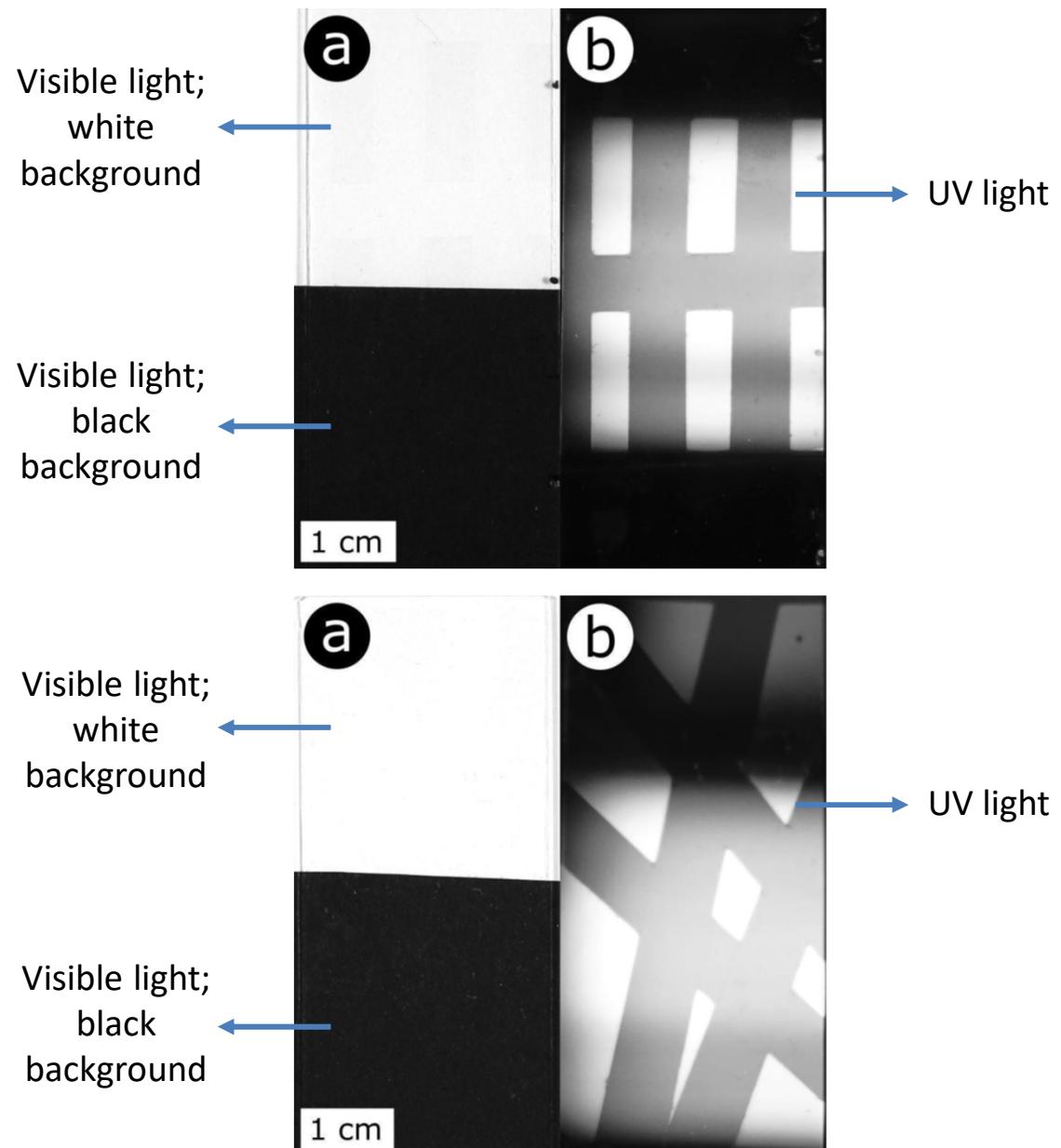
Deposition by Physical Vapour  
Deposition



# Bioinspired bird-safe windows



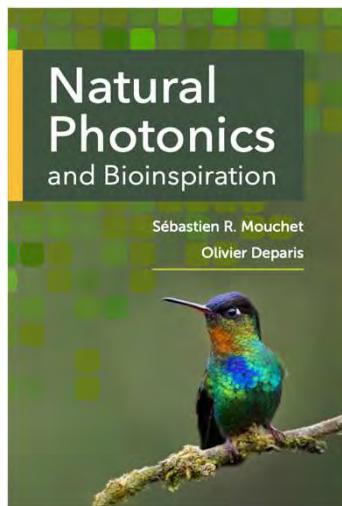
Deposition by Physical Vapour Deposition



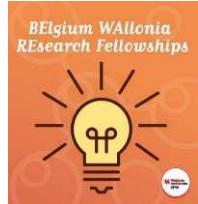


# Conclusion

- **Natural photonic structures** are **sophisticated materials** displaying a **large variety of optical effects**
- Interesting properties: liquid-induced colour change, gas sensitivity, antireflection, UV reflection...
- Studying them allows us to **develop new concepts and applications** through a **bioinspiration** approach that may rely on nanoimprint lithography



Further reading... ☺



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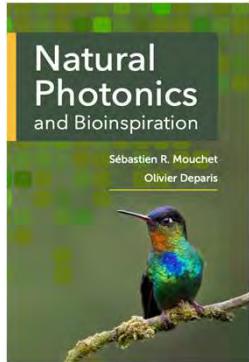
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- Prof. Nawfal Ghazzal & Prof. Eric Gaigneaux, Catholic University of Louvain (BE)
- BEWARE Fellowships, Walloon Region (Belgium)  
& Marie Skłodowska-Curie Actions



Further reading... ☺

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BTS team