

Bioinspired photonics for tomorrow's technological applications

Sébastien R. Mouchet

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



University
of Exeter

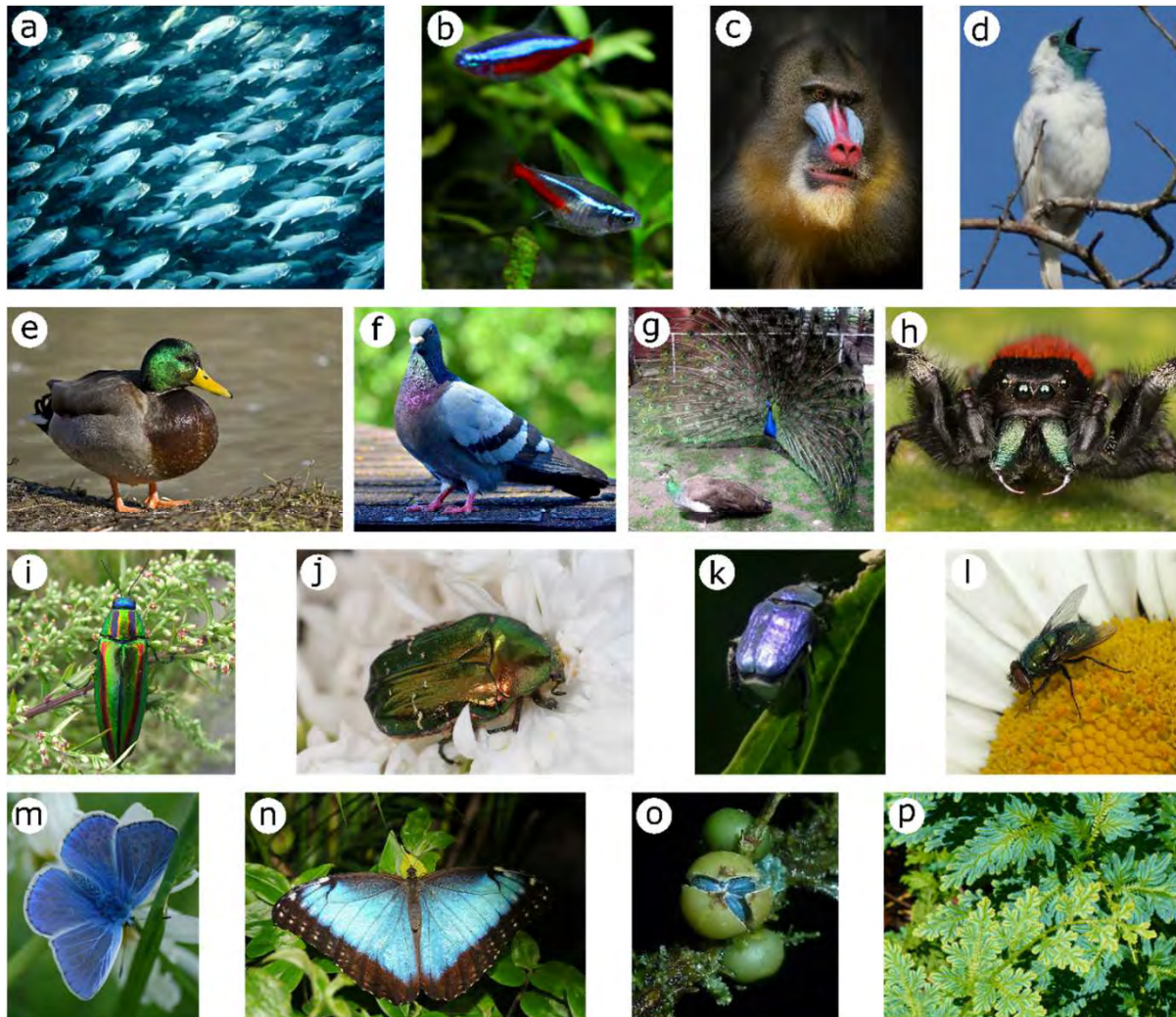


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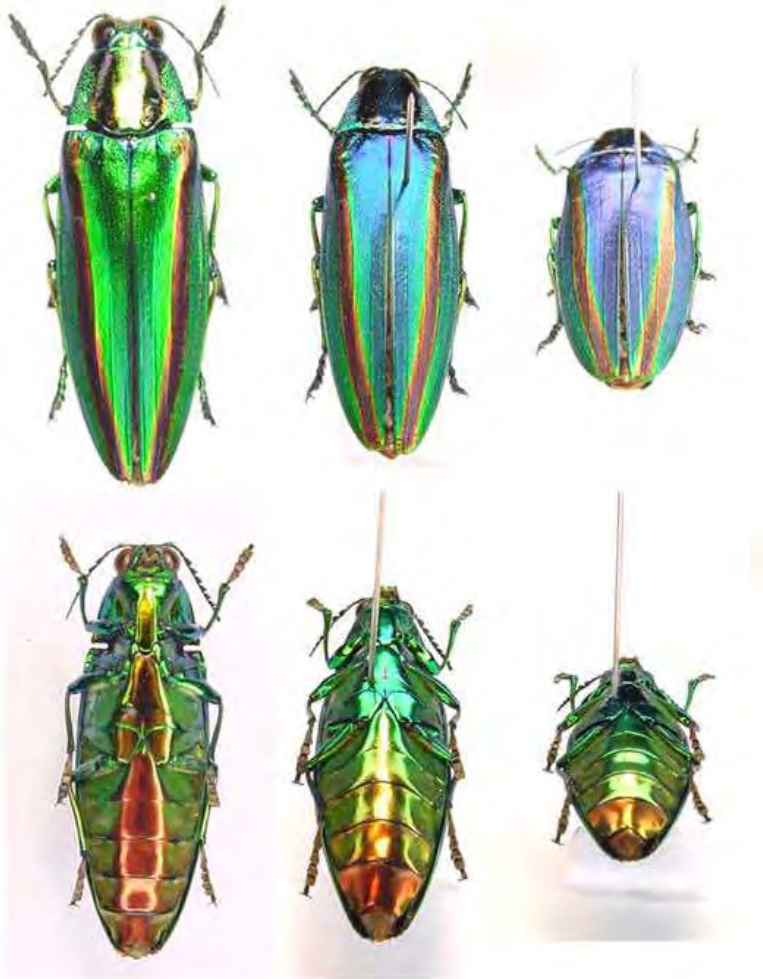
Structural colours in natural organisms



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

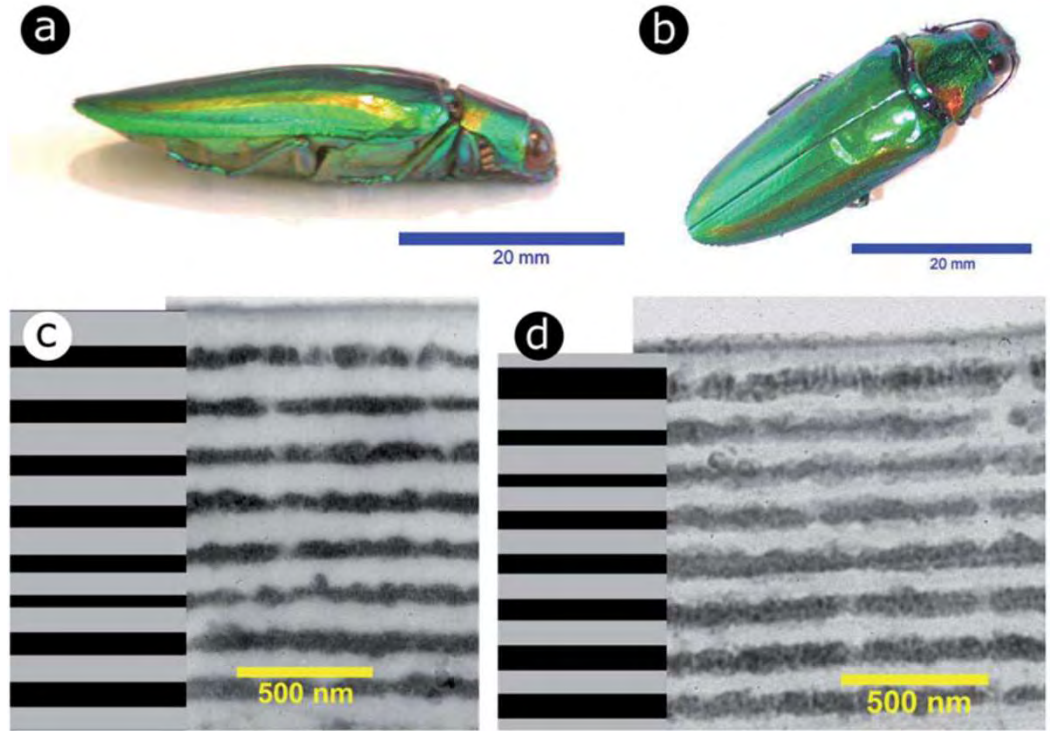
Properties of natural photonic structures

Iridescence



Properties of natural photonic structures

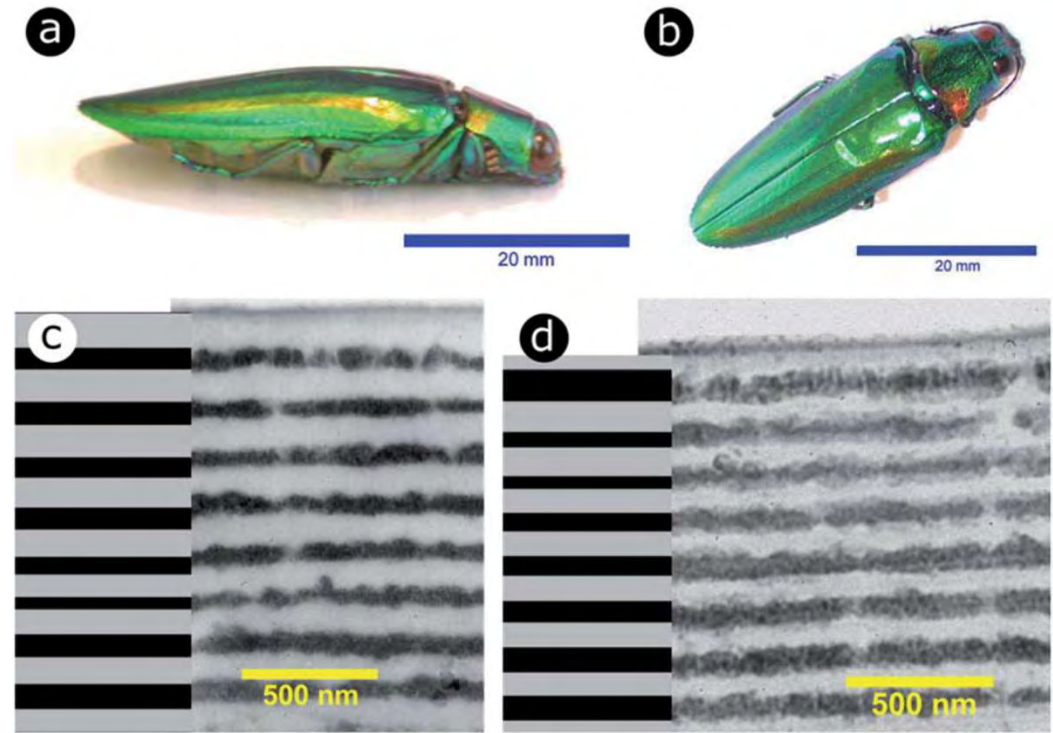
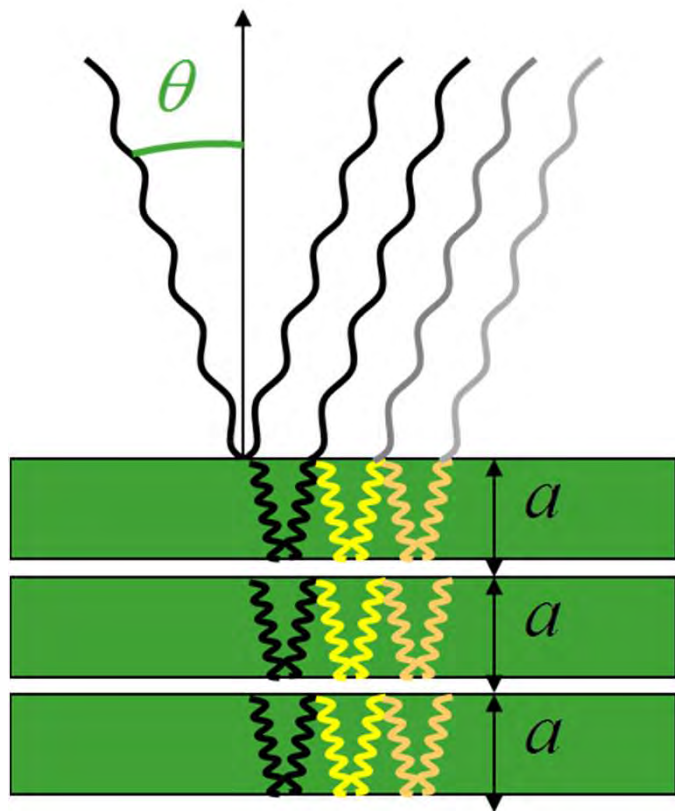
Iridescence



Natural photonic structure!

Properties of natural photonic structures

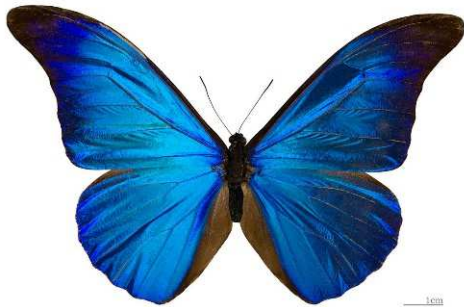
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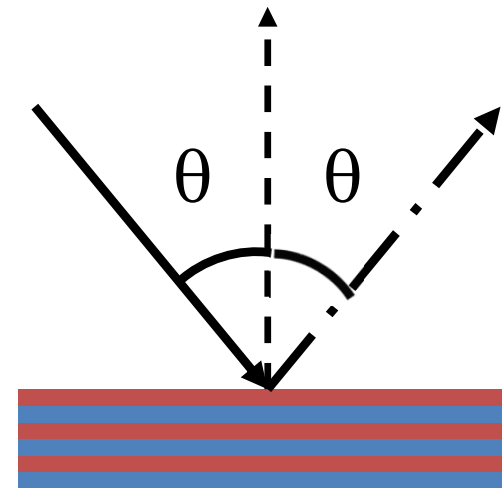
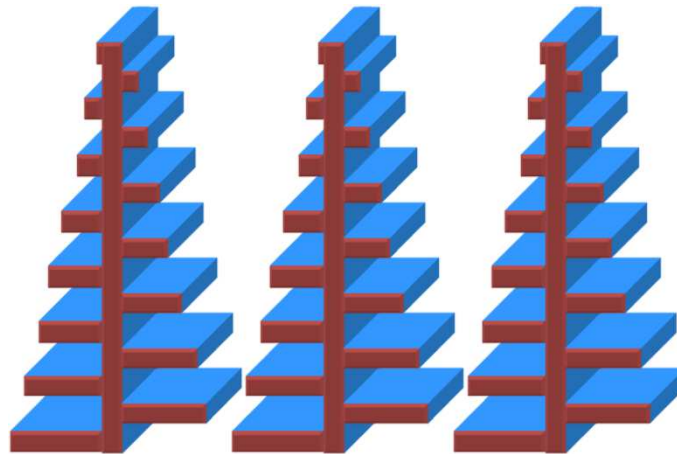
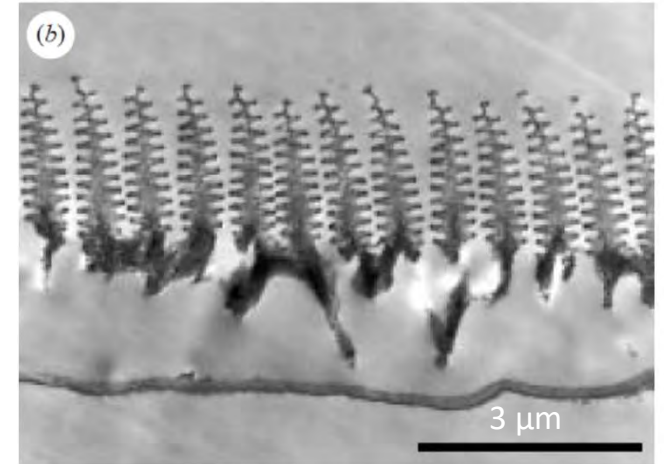
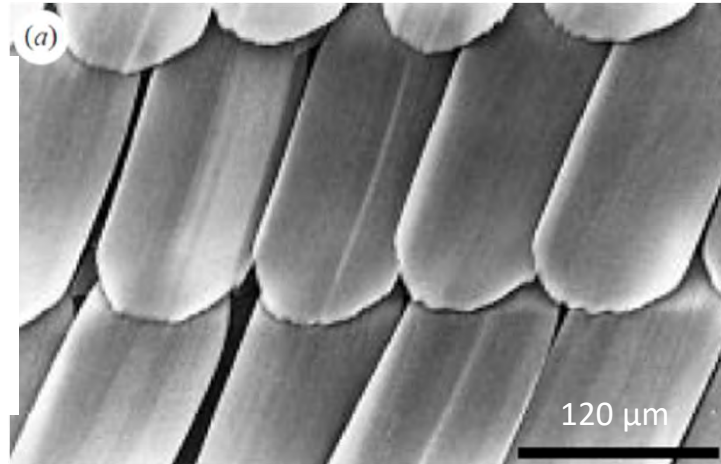
Natural photonic structure!

Properties of natural photonic structures

Iridescence



M. rhetenor

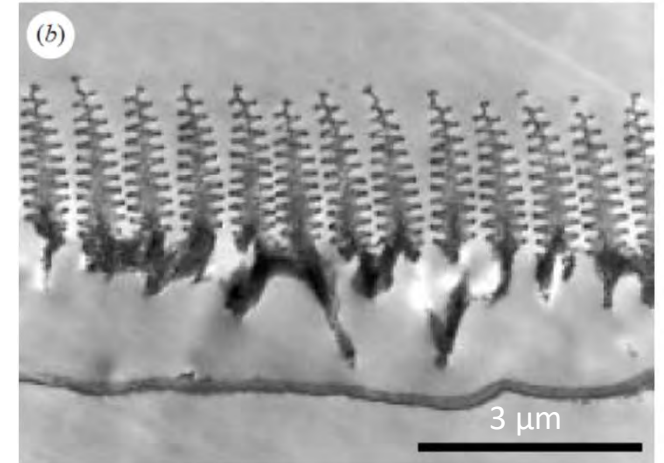
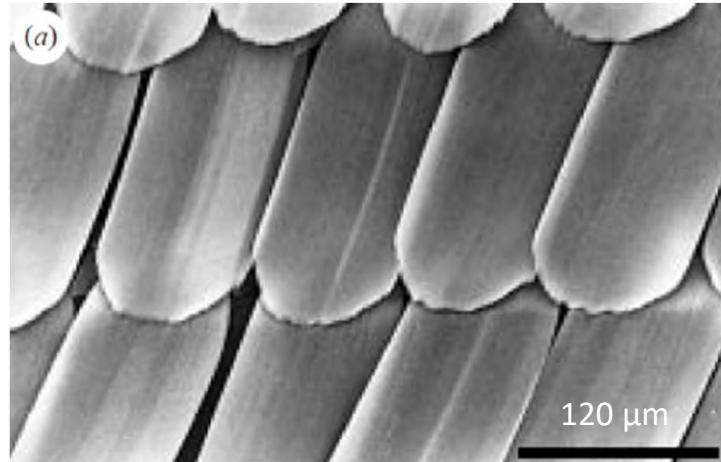


Properties of natural photonic structures

Iridescence



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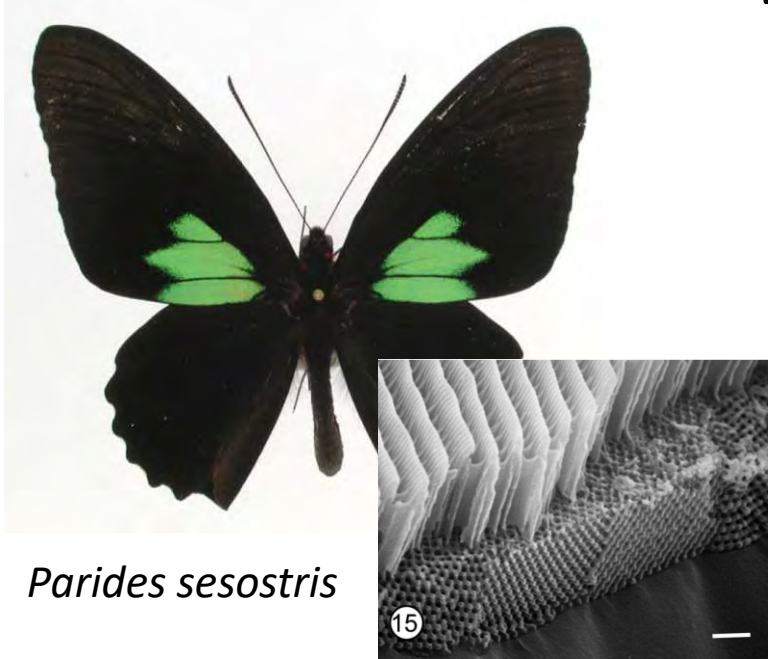


Liquid-induced colour change

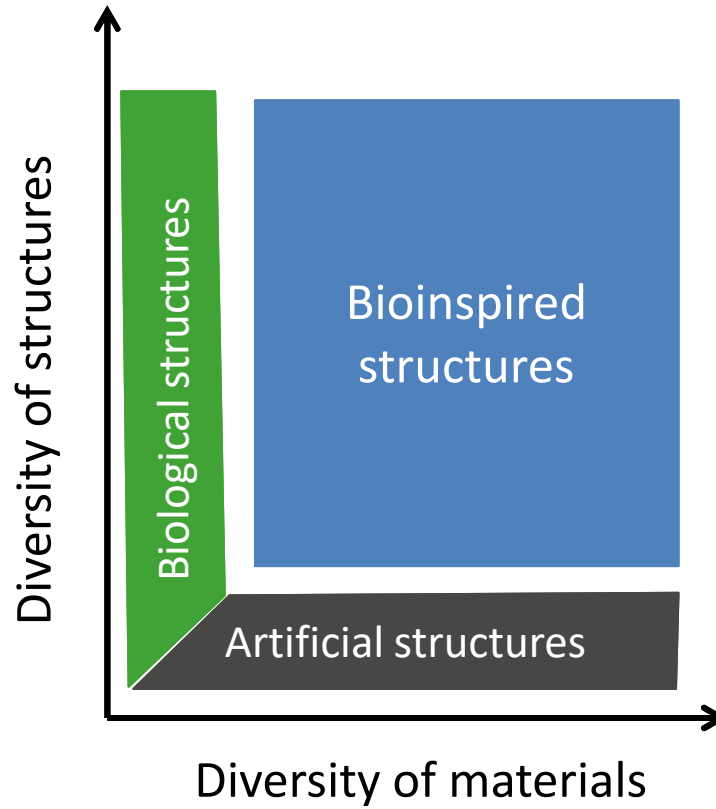


All these lepidopteran photonic structures are generally open to air, the surrounding environment.

Bioinspiration



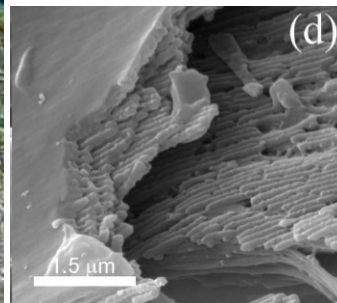
Parides sesostris



Morphotex fabric
Teijin Limited



Pavo cristatus



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

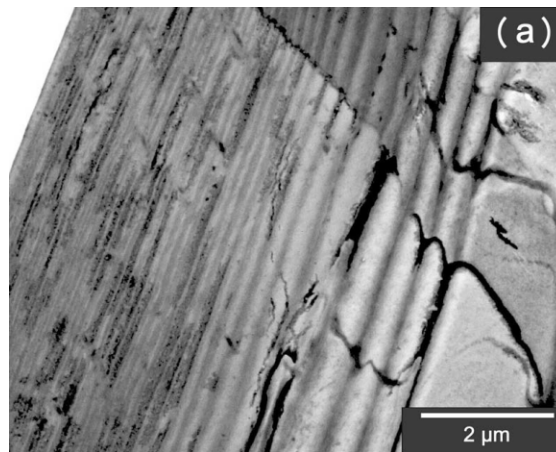
www.unamur.be

Liquid-induced colour change

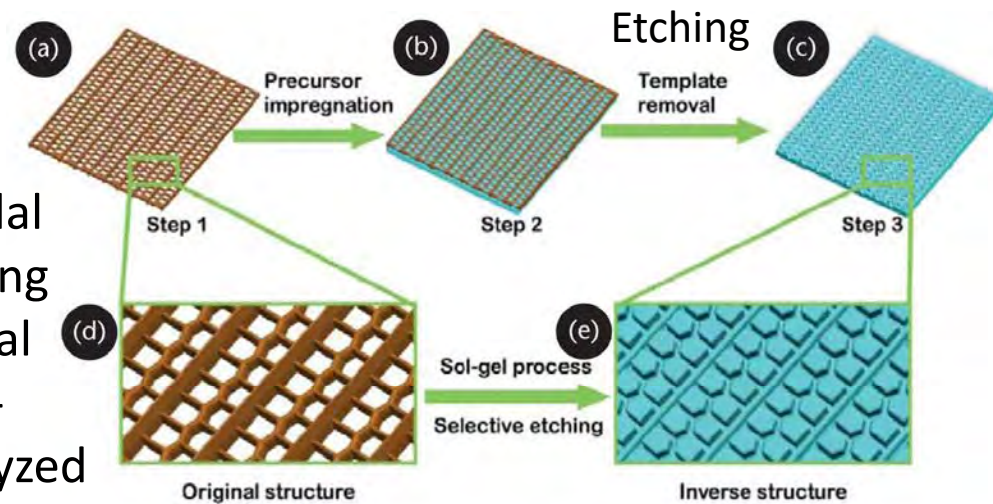
Charidotella egregia



Chirped Bragg mirror

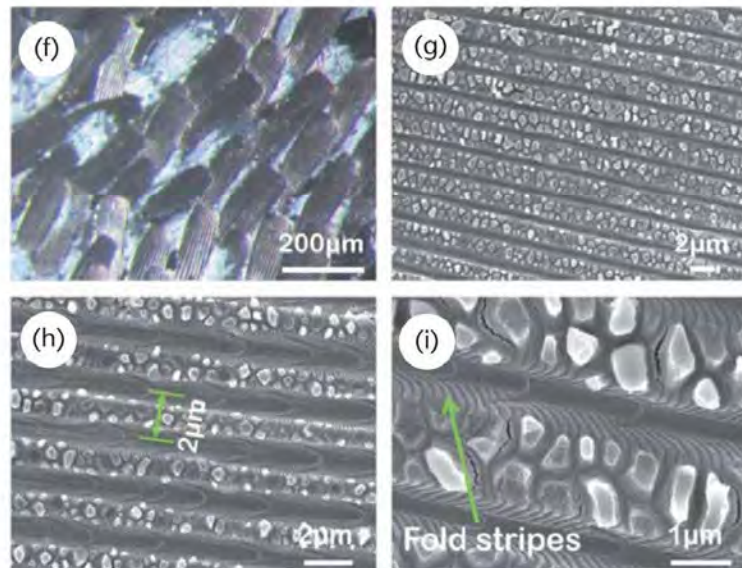


Sol-Gel Methods



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

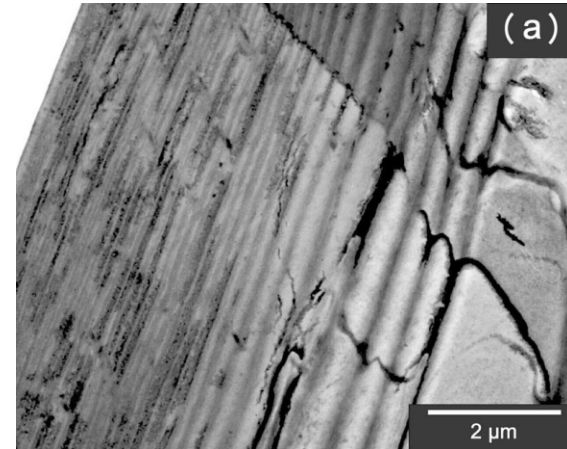
Deposition of SiO_2 , TiO_2 or Al_2O_3



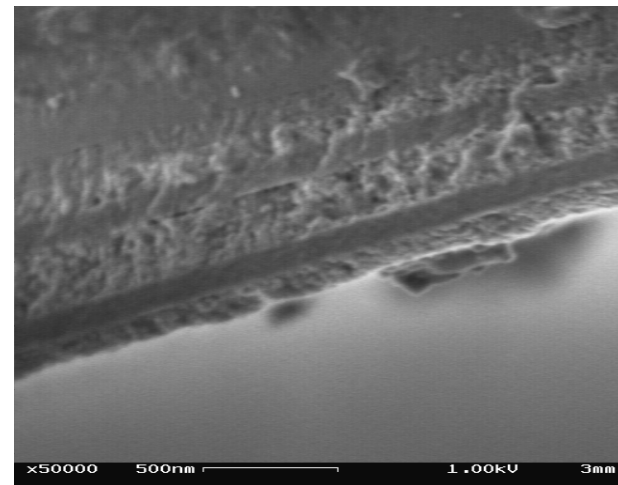
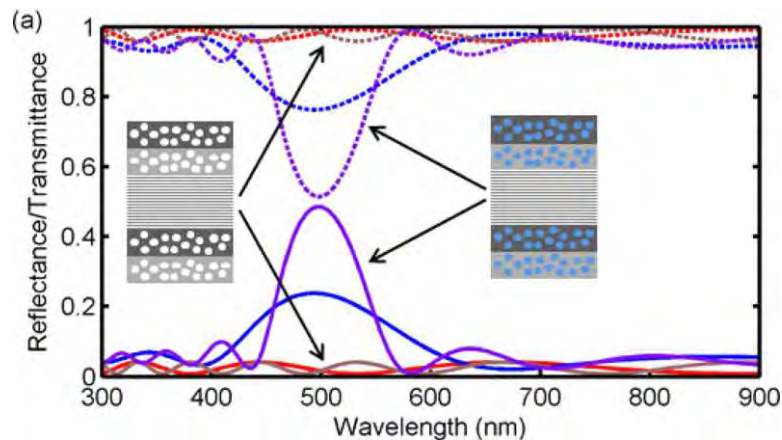
Inverse replica of butterfly wing

Bioinspired smart glass coatings

Charidotella egregia



Vigneron *et al.*, PRE 76, 2007

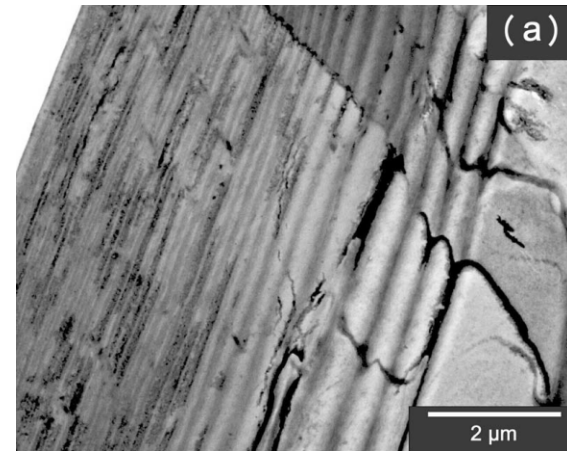


- Glass slide coated with mesoporous oxide Bragg layer stack
- Mesoporous oxides (L_1 layers: $x\text{TiO}_2(1-x)\text{Al}_2\text{O}_3$, L_2 layers: SiO_2) were synthesised by sol-gel method
- Molar ratio x of mixed oxide layers was adjusted in order to get a transparent Bragg mirror in dry condition

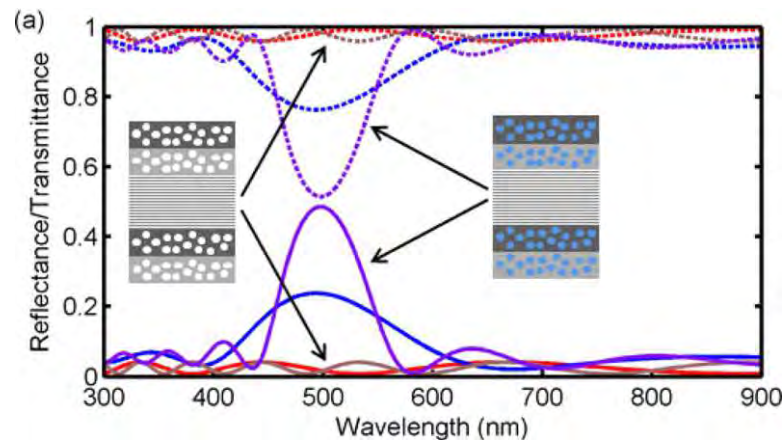
Deparis, Ghazzal, Simonis, Mouchet *et al.*, APL 104, 2014

Bioinspired smart glass coatings

Charidotella egregia



Vigneron *et al.*, PRE 76, 2007

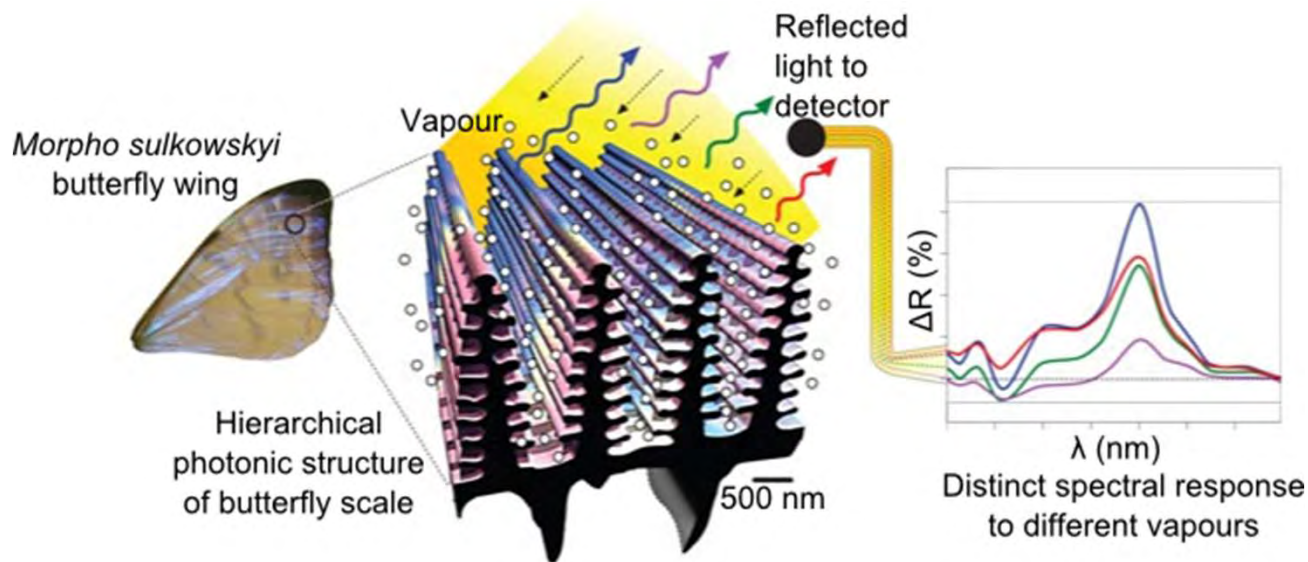


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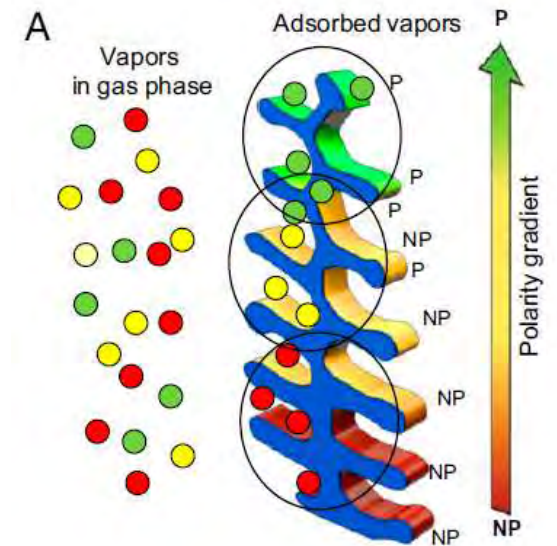


Deparis, Ghazzal, Simonis, Mouchet *et al.*, APL 104, 2014

Gas/vapour-induced colour change



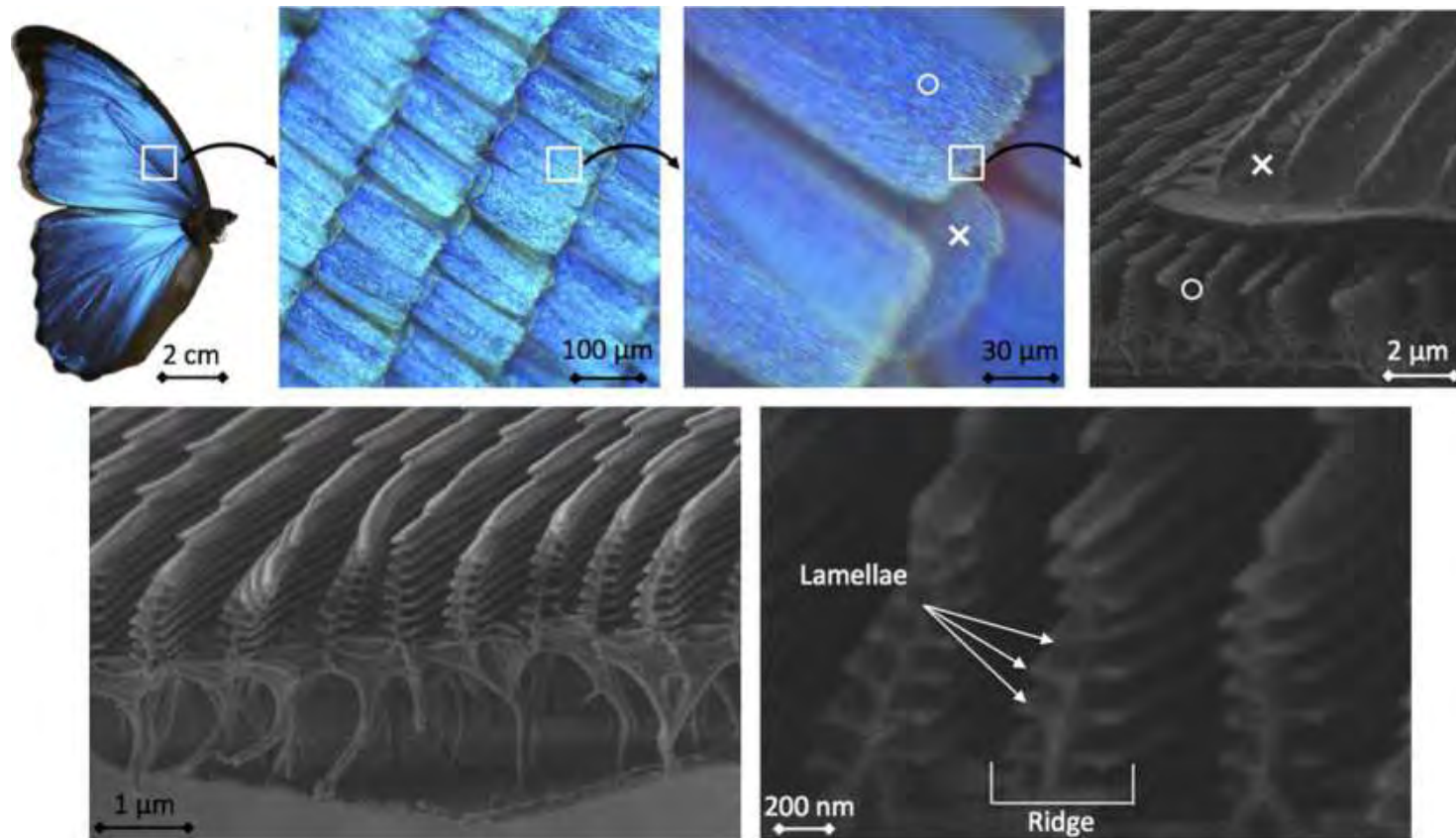
Potyrailo, R. A., *et al.*, Nat. Photonics 1, 2007.



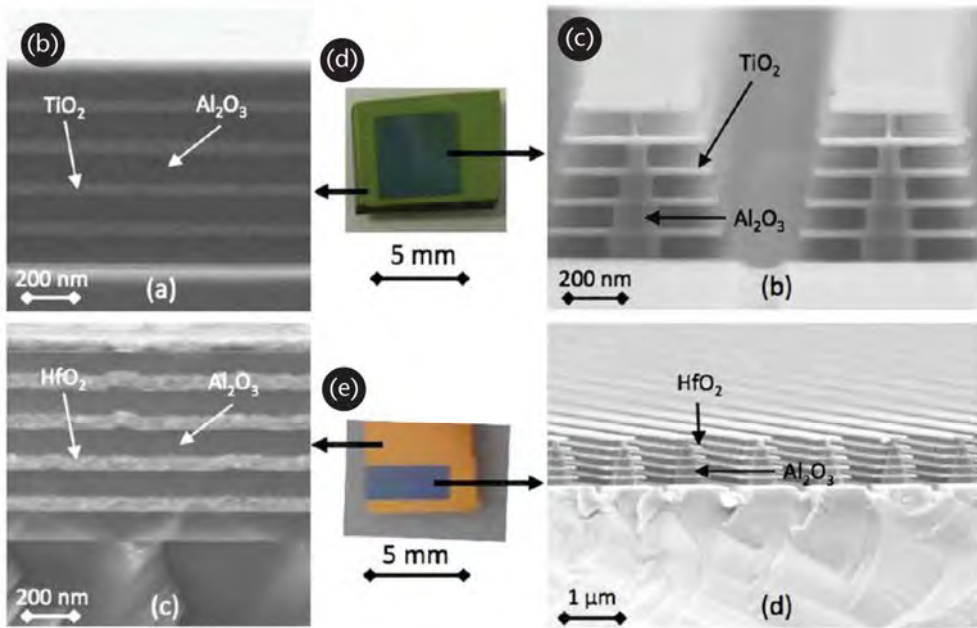
Potyrailo, R. A., *et al.*, PNAS 110, 2013.

Bioinspired photonic gas/vapour-sensors

Morpho godarti

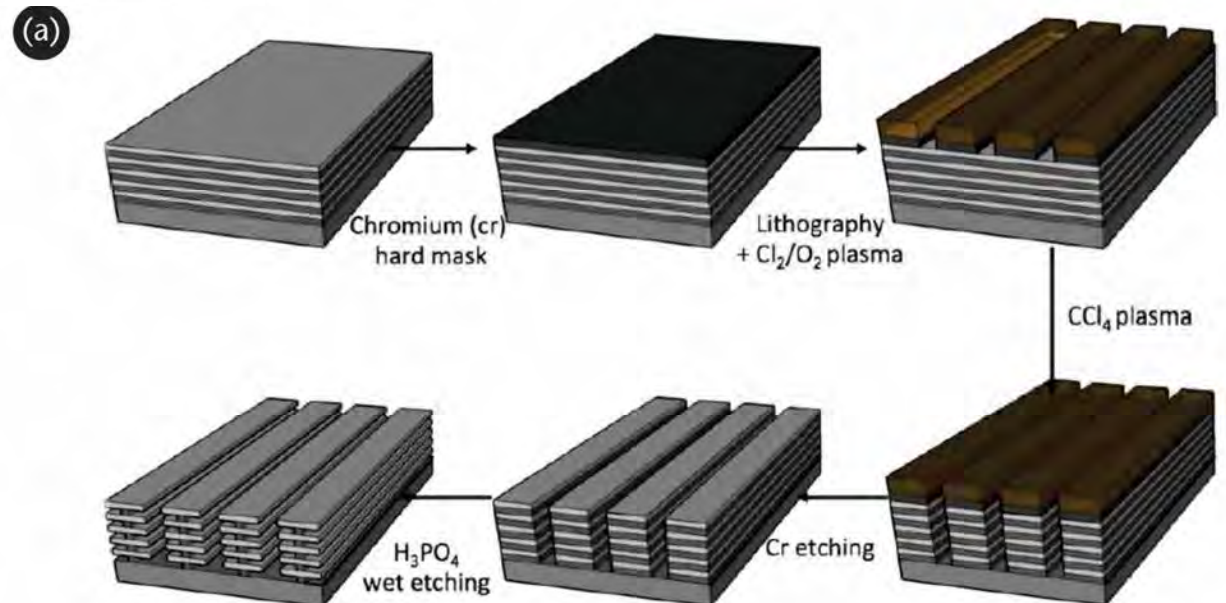


Bioinspired photonic gas/vapour-sensors



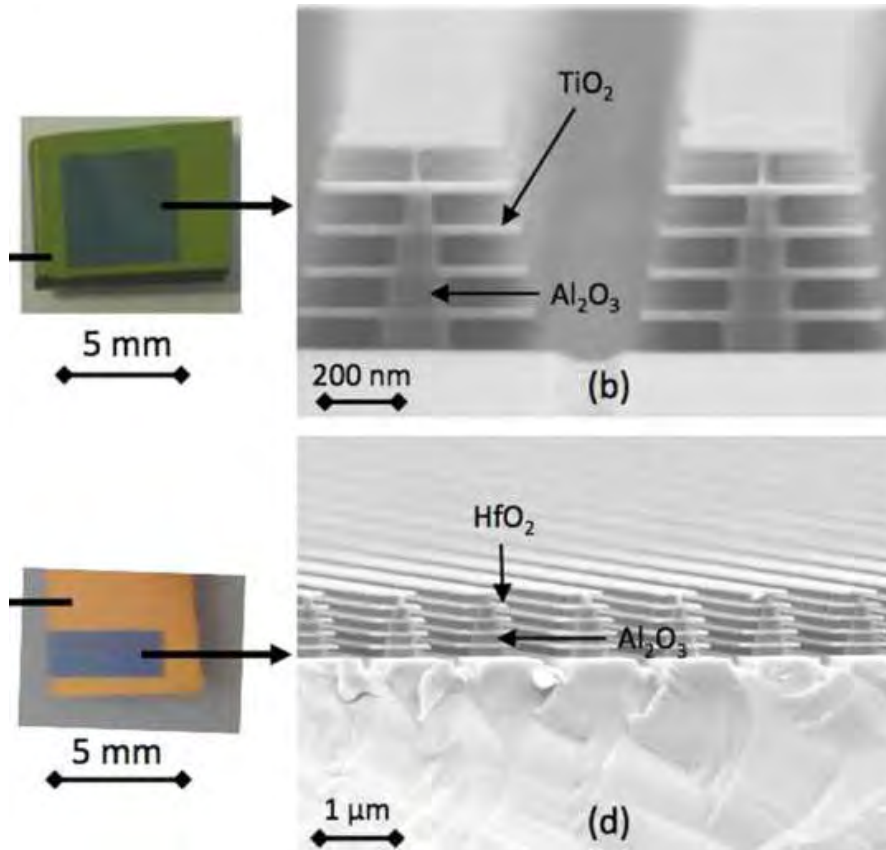
Atomic Layer Deposition

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

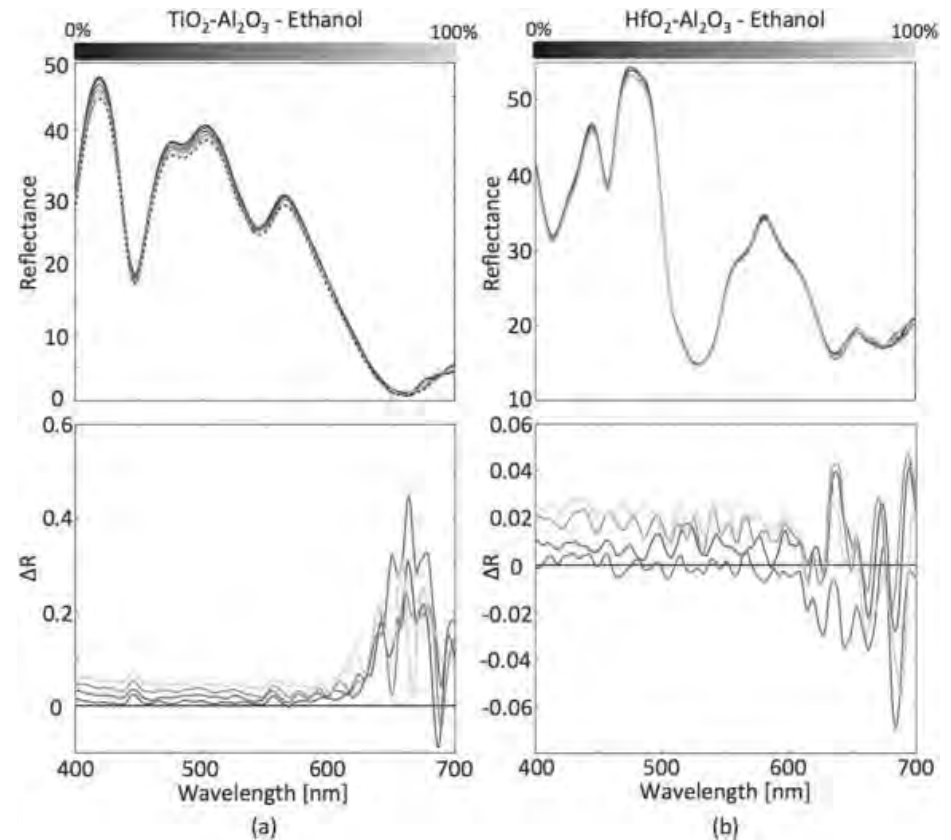


Bioinspired photonic gas/vapour-sensors

Morpho godarti

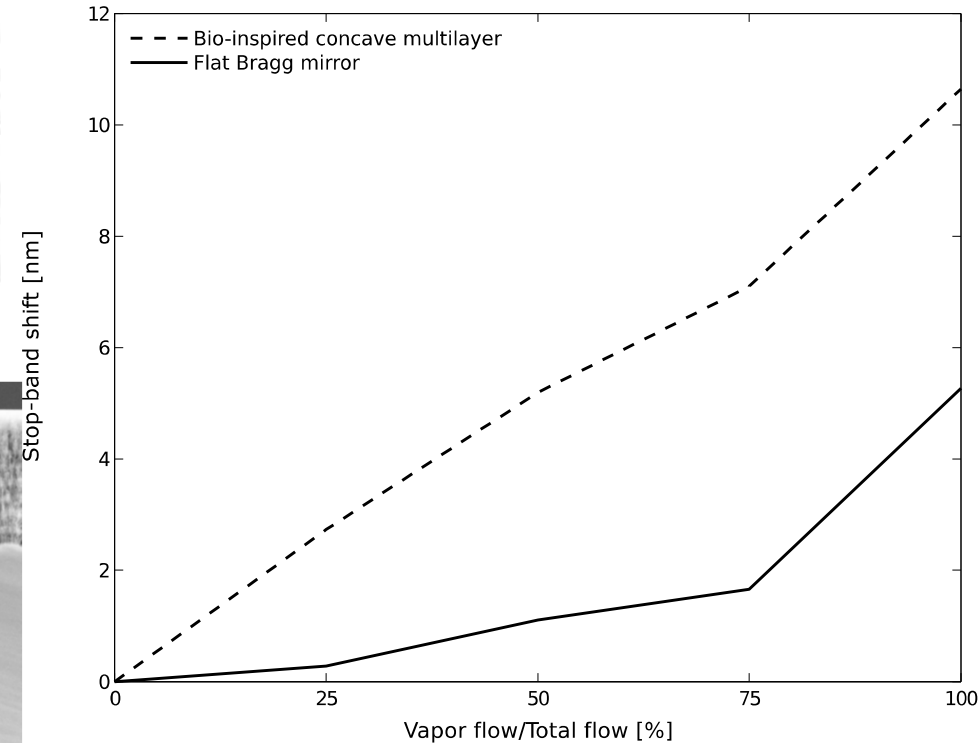
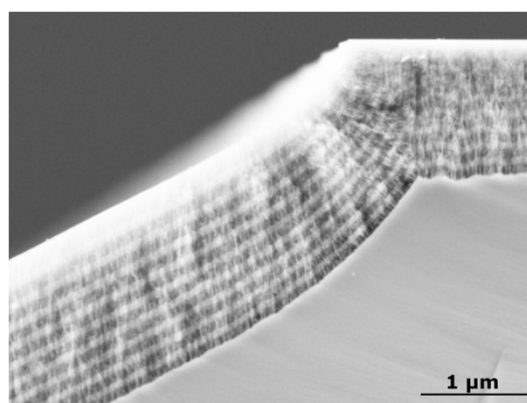
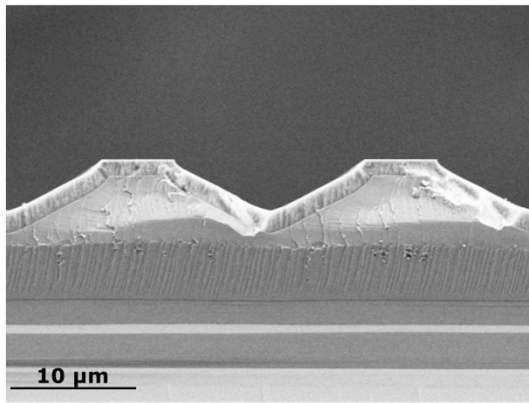
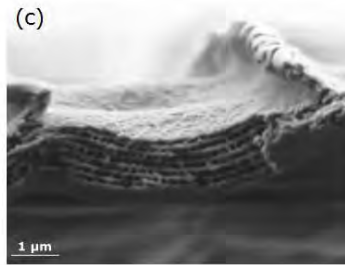
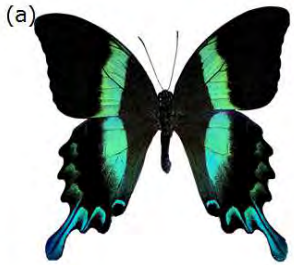


ALD Bragg mirrors of $\text{Al}_2\text{O}_3/\text{TiO}_2$ or $\text{Al}_2\text{O}_3/\text{HfO}_2$
nanostructured by etching



Bioinspired photonic gas/vapour-sensors

Papilio blumei



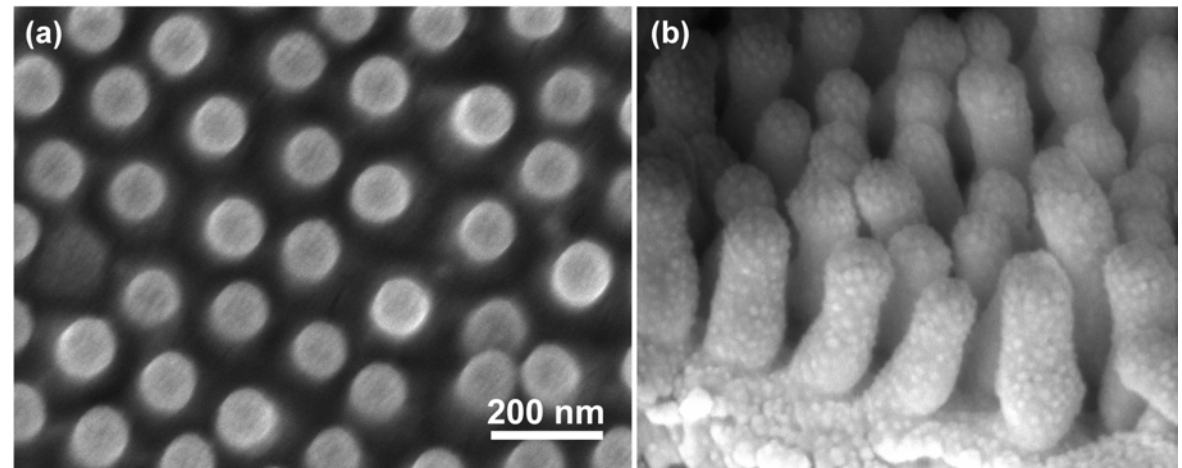
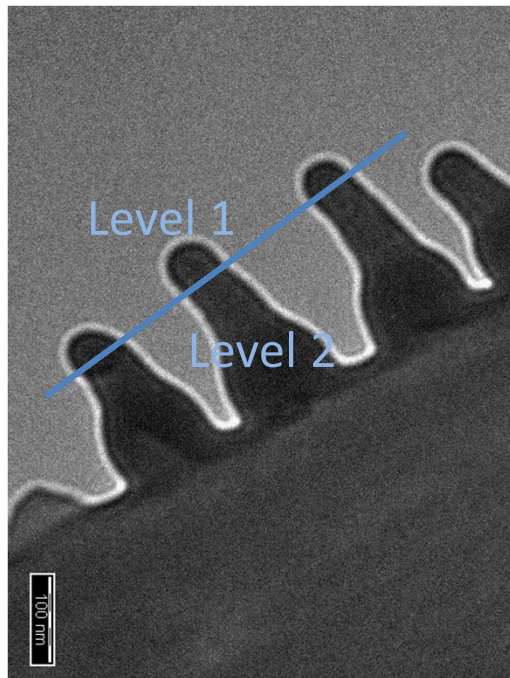
Concave porous silicon multilayer synthesised by photolithography and etching

Multifunctional nanostructures on the wings of *Cicada orni*

Transparent wings with

- antireflection effect and
- hydrophobic properties

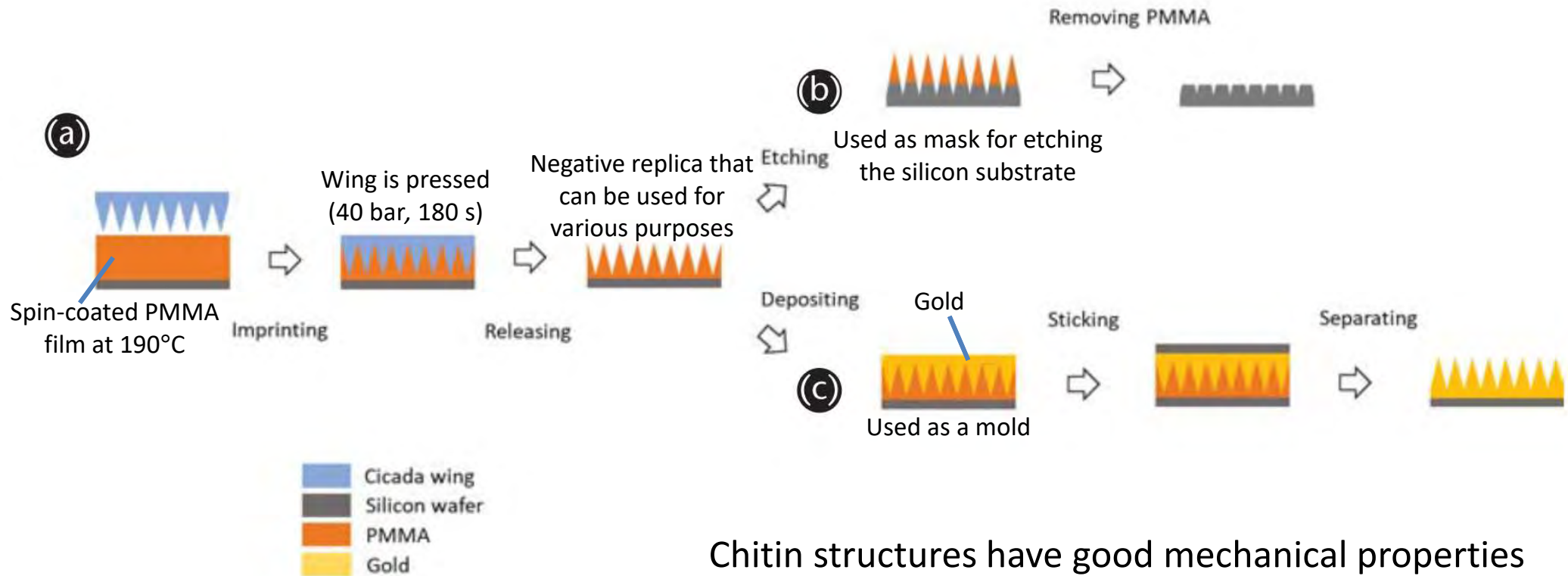
due to a quasi-periodic arrays of hexagonally close-packed protrusions



Dellieu *et al.*, JAP 116, 2014

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

Nanoimprint lithography & cicada wing nanostructures

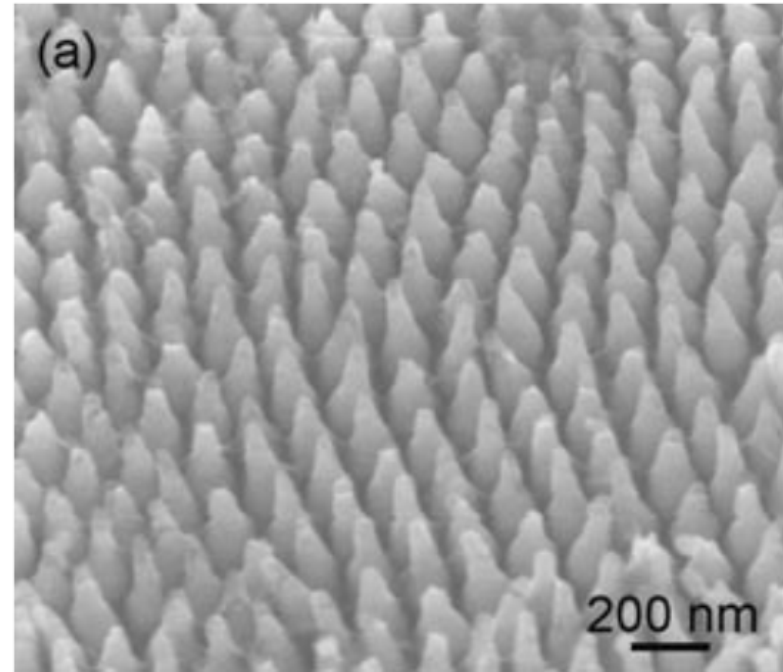
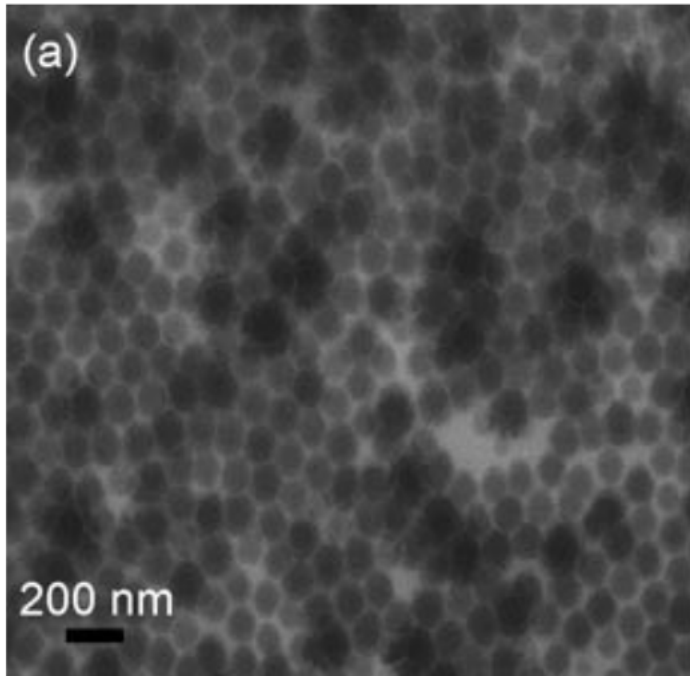


Chitin structures have good mechanical properties and chemical stability allowing them to withstand imprint process and are reusable

Mouchet & Deparis, Natural Photonics and Bioinspiration, 2021

Zhang *et al.*, Small 2, 2006

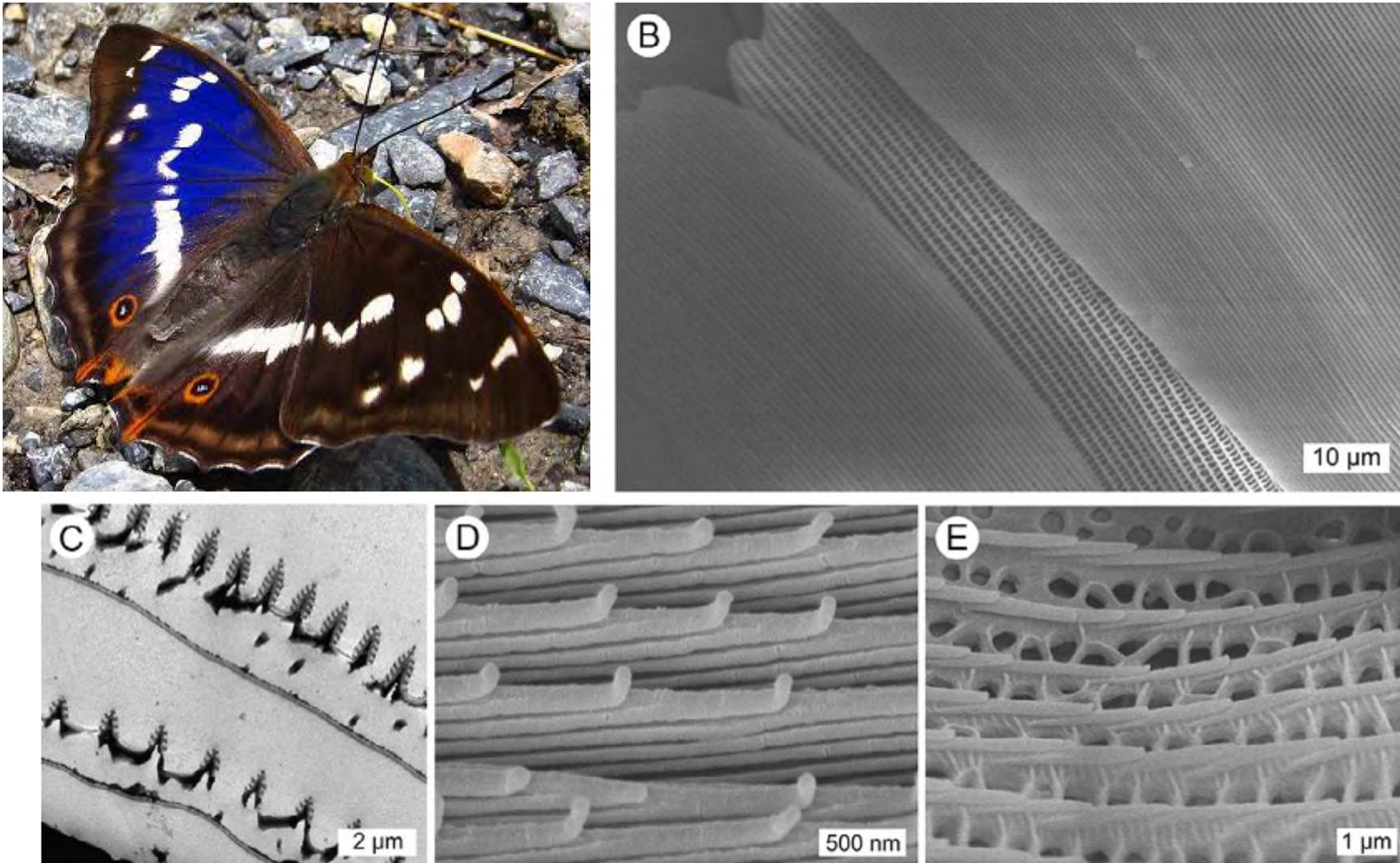
Nanoimprint lithography & cicada wing nanostructures



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



J. Newton, 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

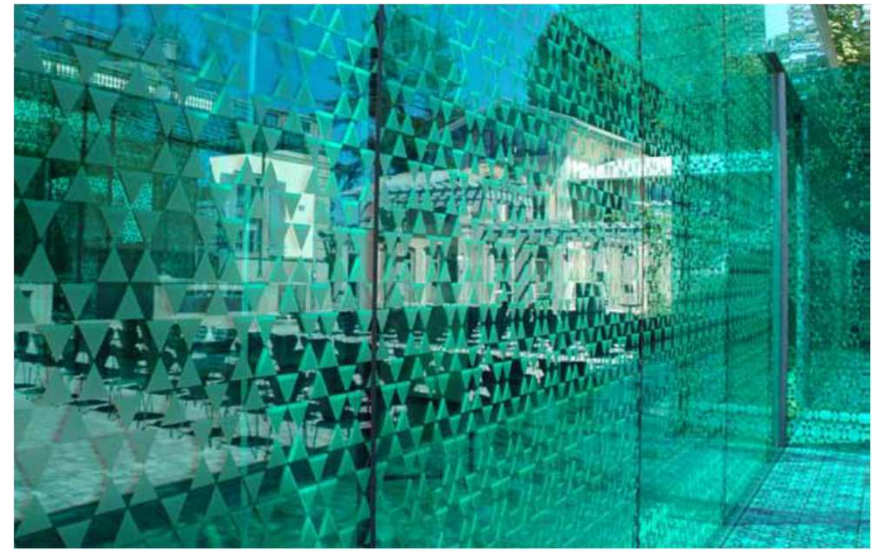
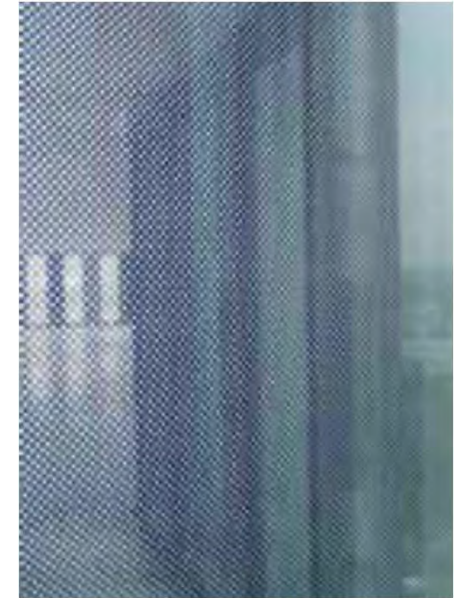


Collision between birds and windows



tuchodi, https://commons.wikimedia.org/wiki/File:Mirrored_Aggression,_bird_2.jpg
Schmid, Oiseaux et vitres : éviter les collisions, 2016

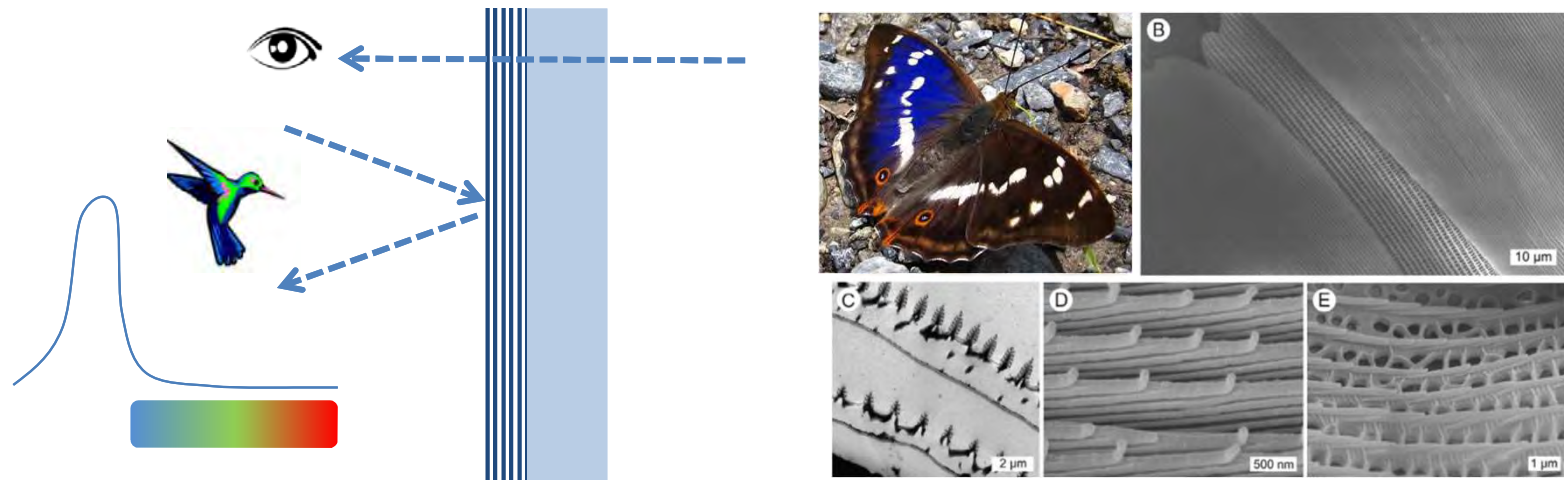
Existing solutions



Nets, stickers, curtains, screens, grids, etc

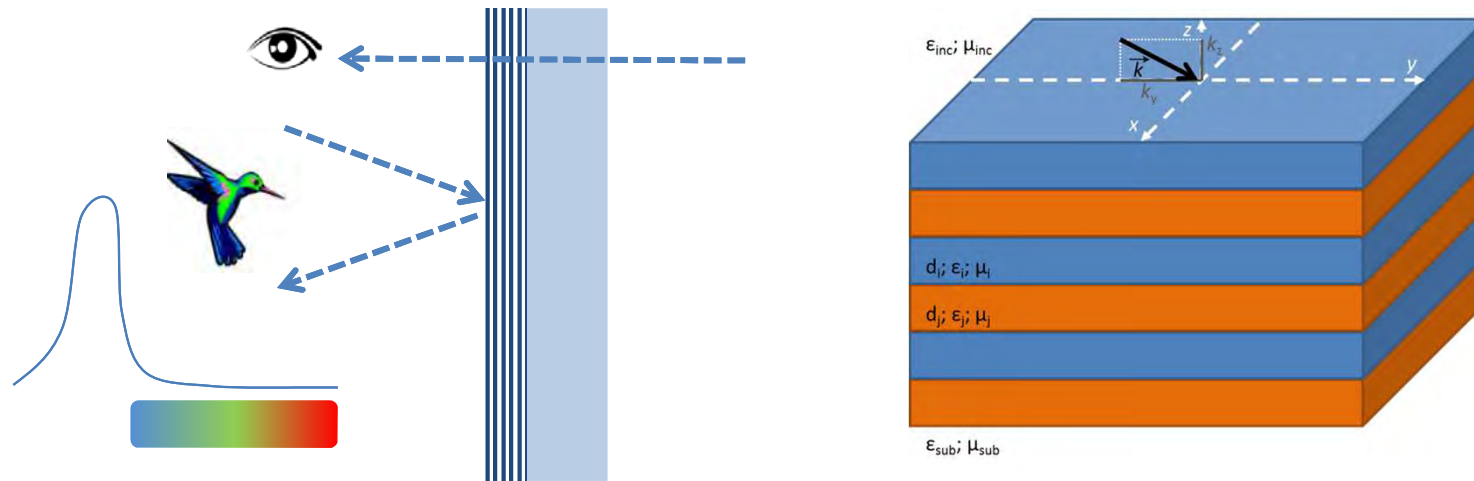
Sheppard, Bird-Friendly Building Design, American Bird Conservancy, 2011

Bioinspired bird-safe windows



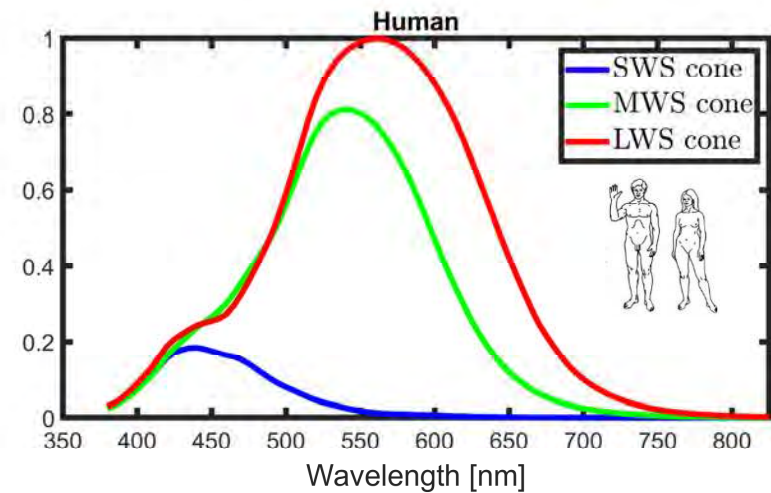
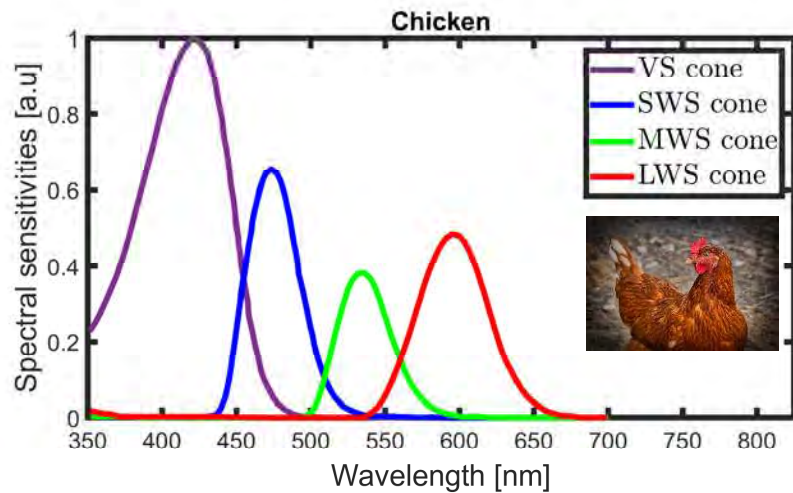
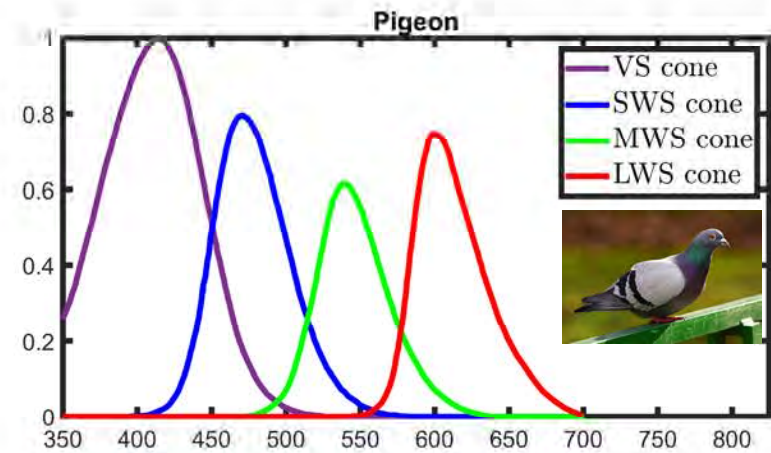
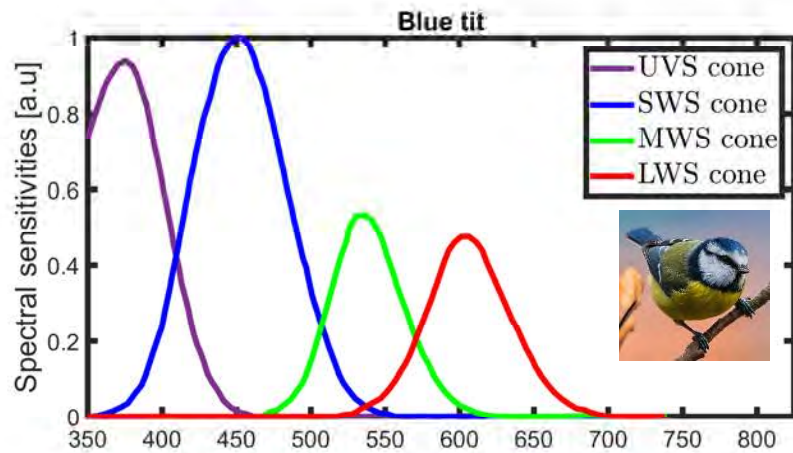
Optimisation of the optical response wrt the layer materials and thicknesses, taking into account the human and avian colour perception

Bioinspired bird-safe windows



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

Bioinspired bird-safe windows



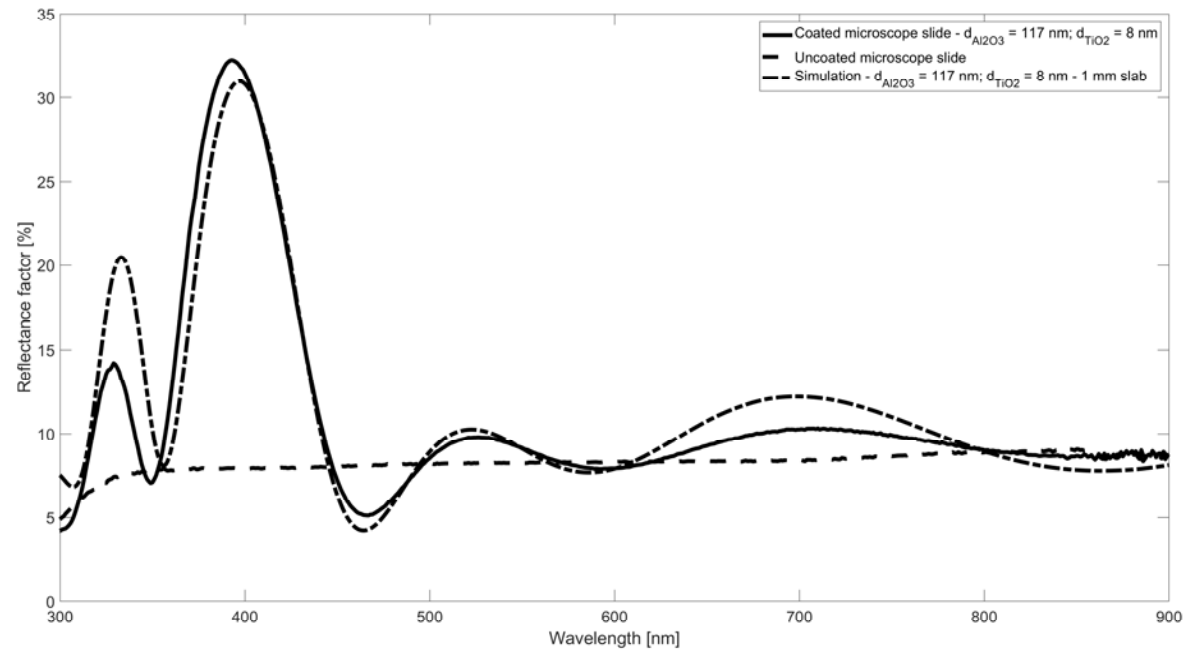
Mouchet *et al.*, in preparation

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

Bioinspired bird-safe windows



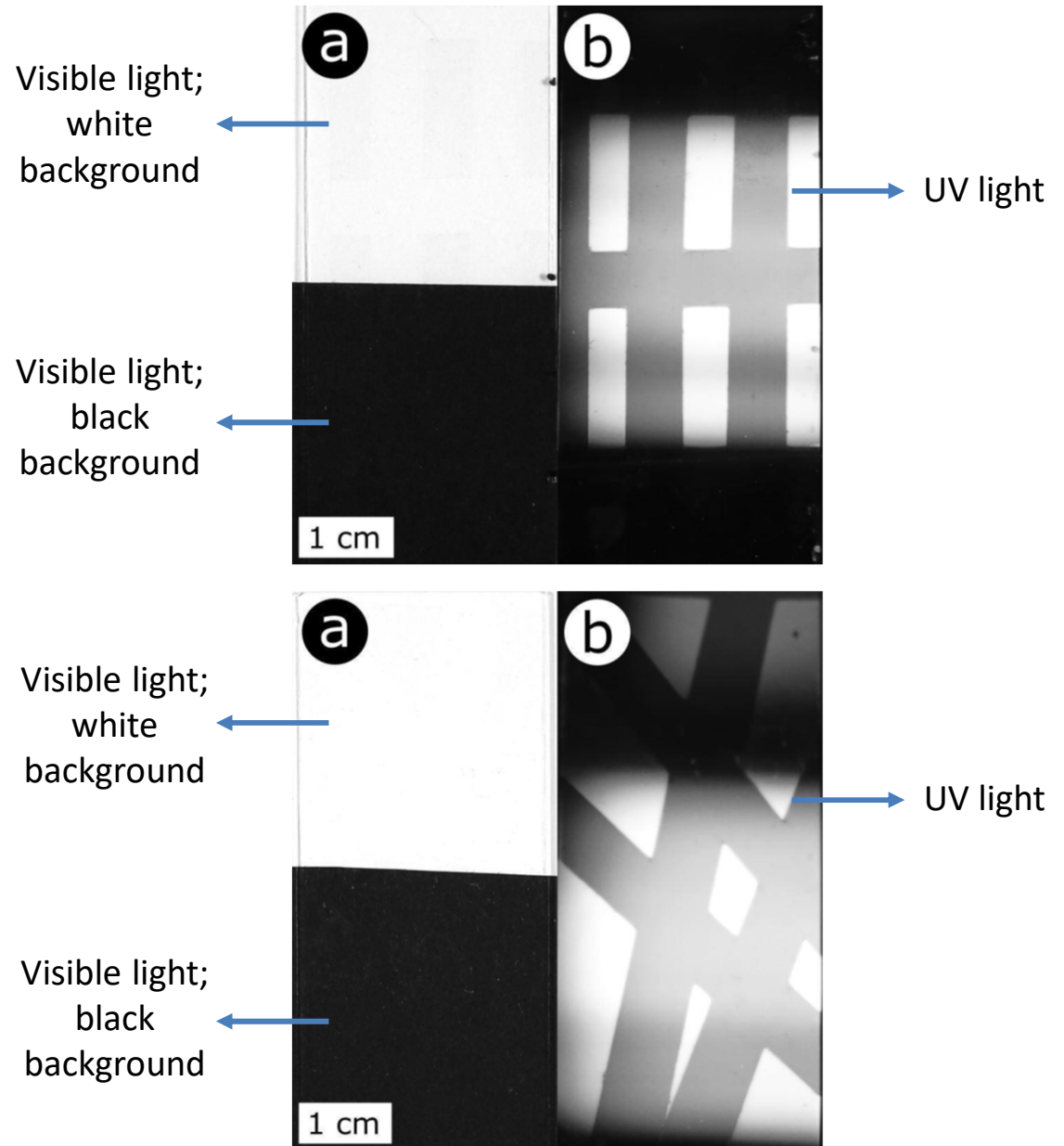
Deposition by Physical Vapour
Deposition

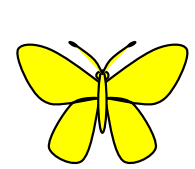


Bioinspired bird-safe windows



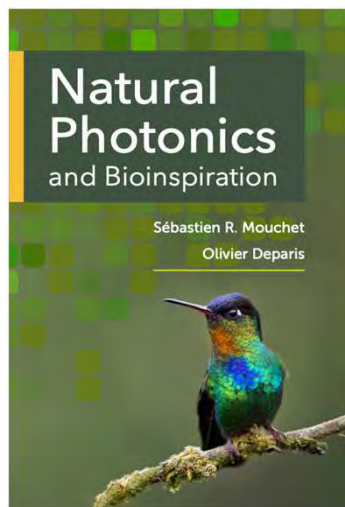
Deposition by Physical Vapour
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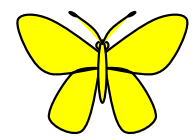


Conclusion

- **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... 😊



Belgium Wallonia
REsearch Fellowships



MARIE CURIE



UNIVERSITÉ
DE NAMUR



Namur Institute of Structured Matter



Institute of Life, Earth and Environment



Thank you for listening
Any questions?

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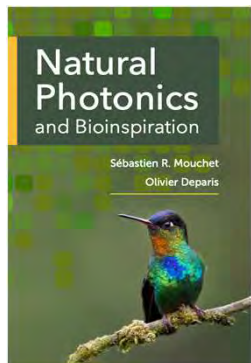
s.mouchet@exeter.ac.uk



Acknowledgements

- Prof. Jean-Pol Vigneron (†), University of Namur (BE)
- Prof. Olivier Deparis, University of Namur (BE)
- Prof. Pete Vukusic, University of Exeter (UK)
- Prof. Laurent Francis & Dr Olivier Poncelet, Catholic University of Louvain (BE)
- Prof. Nawfal Ghazzal & Prof. Eric Gagneaux, Catholic University of Louvain (BE)

- BEWARE Fellowships, Walloon Region (Belgium)
& Marie Skłodowska-Curie Actions



Further reading... 😊

BTS team



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