Structural colour in the insect world

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What is structural colour?

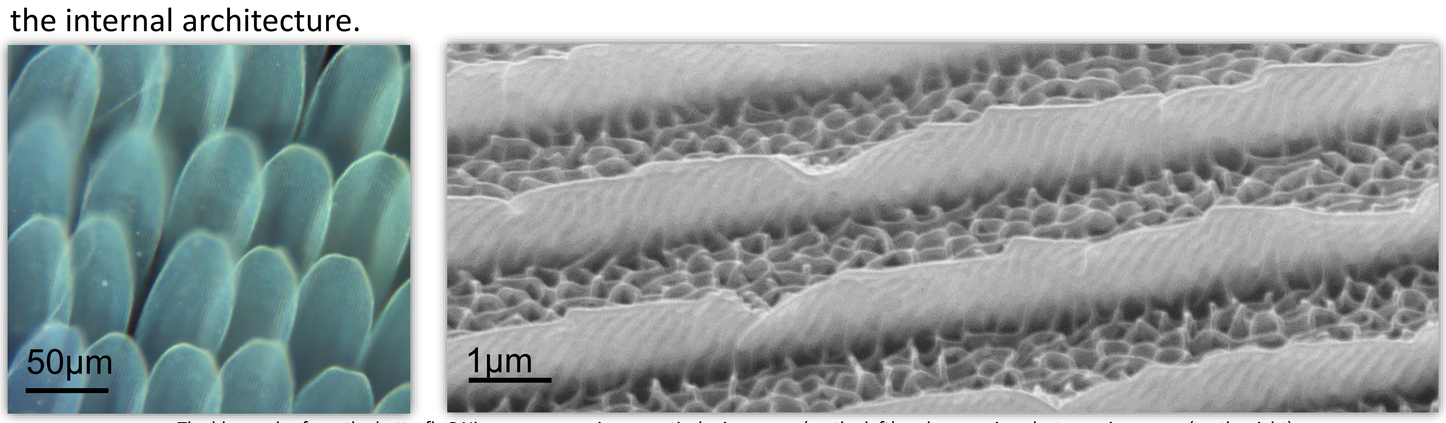
Structural colouration arises from the coherent interaction of light with photonic structures, as opposed to pigments.
A number of insects have evolved these nanostructures for mating, camouflaging, or signalling purposes [1].

AIMS

In vivo study: microscopical investigation the development of the photonic structures found in the green beetles *G. Viridula* to gain an insight into the uncharted field of nanostructuring.
Production of bio-inspired materials: fabrication of a novel highly-scattering material obtained by replicating the structure of the white beetle *Cyphochilus*.

Methods

In conjunction with spectroscopy, optical microscopy is a powerful tool to characterise the nanostructures. Electron microscopy and focused ion beam milling can be used to further investigate the internal architecture.



The blue scales from the butterfly P.Nireus as seen using an optical microscope (on the left) and a scanning electron microscope (on the right).

How does structural colour develop in nature?

The life cycle of the beetle G.Viridula. From top and clockwise: the egg stage, the larval stage, the pupal stage, and the adult stage.

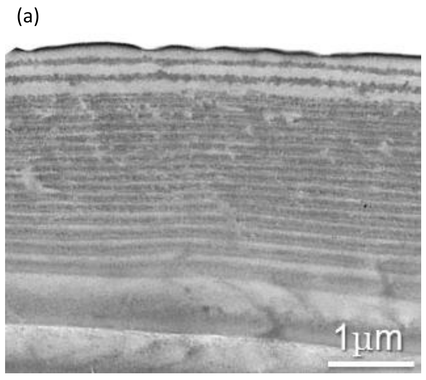
Scan the QR codes to get access to the videos

The *G.Viridula* beetles are utilised as a model to understand how self-assembly works in nature and how photonic structures develop.

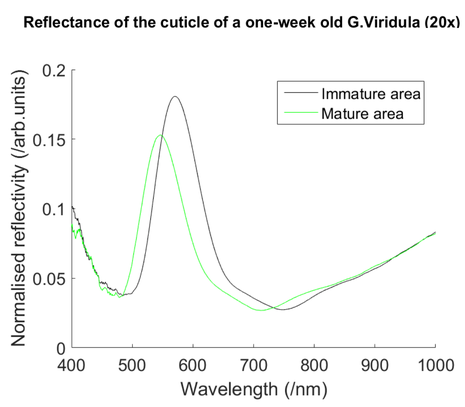
Their shiny green colouration arises from a melanin multilayer that can be found in the cuticle, as shown by TEM sectioning (a).

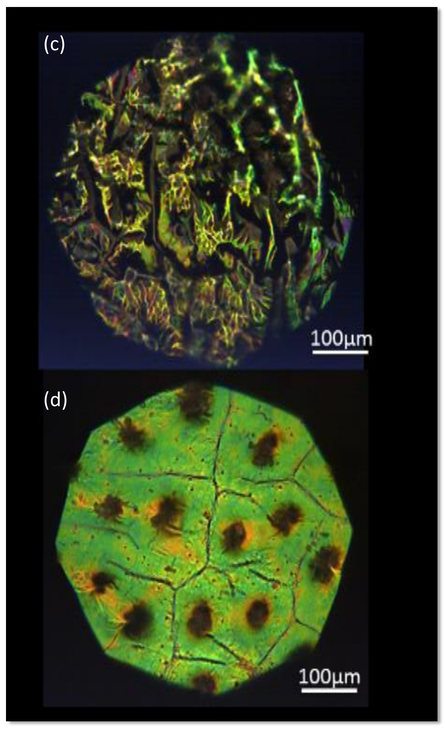
The reflectivity of the cuticle is seen to blueshift as the insects reach maturity (b) due to the stretching of the cuticle during the first week of adult life, from (c) to (d).

(a)

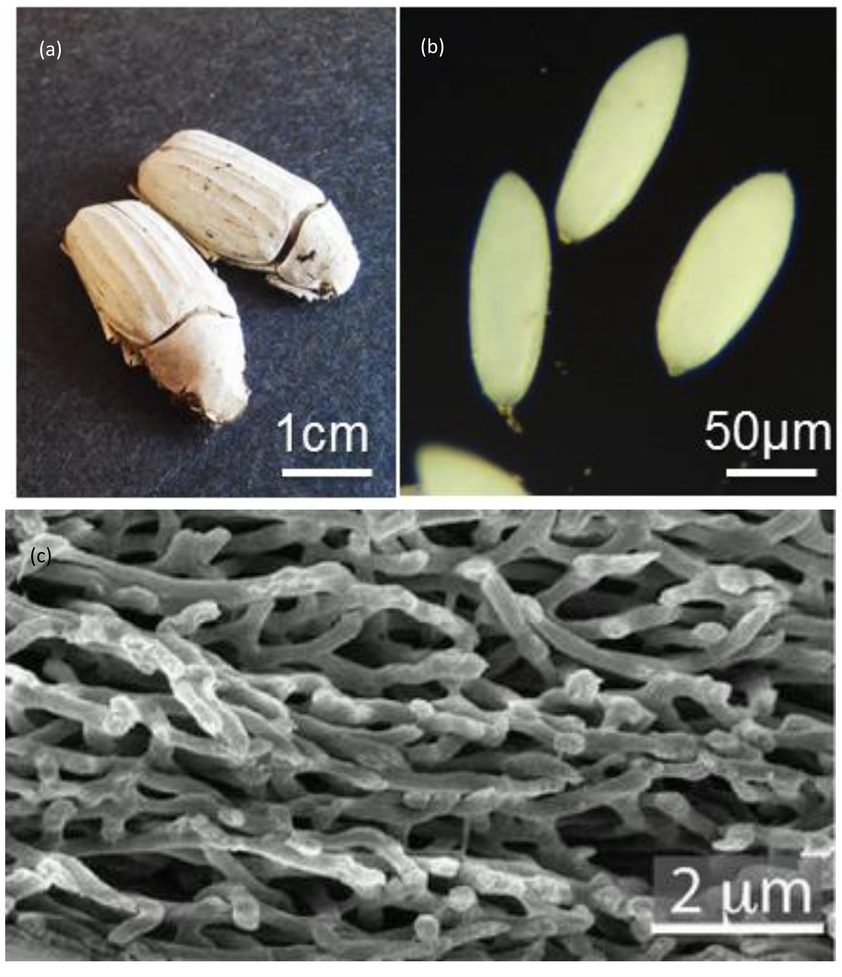


(b)





Bio-inspired photonic materials

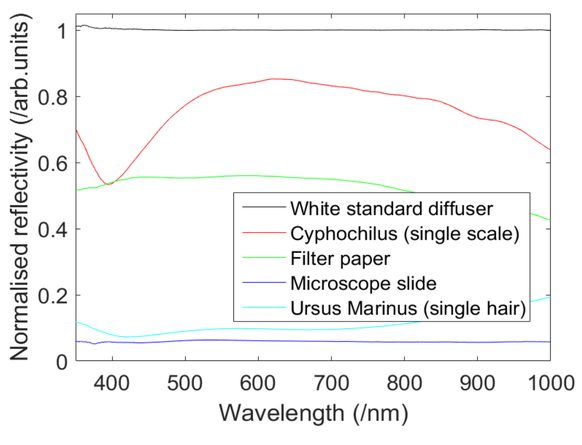


Each scale of *Cyphochilus* beetle scatterers light efficiently thanks to a random chitin network [2], as shown in figures (a), (b), and (c) from [2].

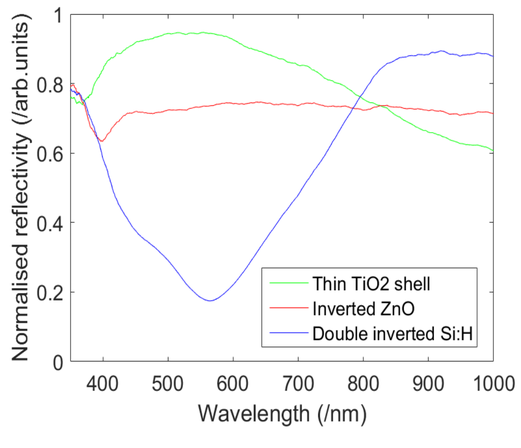
Can we use these scales as a template to produce a material showing strong scattering and localisation of light [3]?

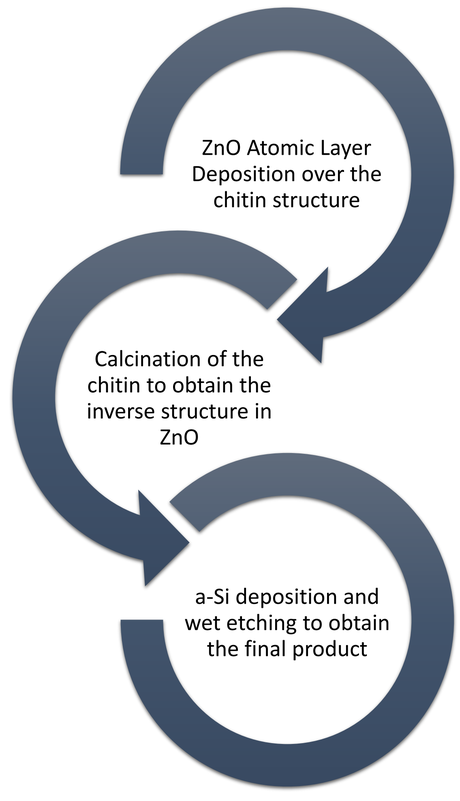
We are working on the production and characterisation of such material using a double-inversion method [4] for replication organic polymers using amorphous silicon (a-Si) and titania (TiO_2).

Reflectance of various white materials (50x, 1.2NA)



Reflectance of the produced samples (50x, 1.2NA)





In collaboration with Prof. F. Scheffold and N. Müller, University of Fribourg, Switzerland.

Outlook

Self-assembly in Nature: understanding the self-assembly of photonic structures using the beetle G.Viridula as a model to gain insight into bottom-up processes in Nature.

Fabrication of highly scattering materials: large-scale production of scattering materials whose application range from efficient paints to reflective coatings.

Acknowledgements

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References

[1] Vukusic, P. & Sambles, J.R. (2003), *Photonic structures in biology*. Nature, 424.
[2] Burresi, M., Cortese, L., Pattelli, L., Kolle, M., Vukusic, P., Wiersma, D. S., Steiner, U. & Vignolini, S. (2014), *Bright-white beetle scales optimise multiple scattering of light.* Scientific Reports, 4: 6075.
[3] Anderson, P. (1958), *Absence of diffusion in certain random lattices.* Physical Review, vol.109.
[4] Muller, N., Haberko, J., Marichy, C. & Scheffold, F. (2014), *Silicon hyperuniform disordered photonic materials with a pronounced gap in the shortwave infrared.* Advanced Optical Materials, 2: 115–119.