

Natural means of producing photonic crystals

★ Current methods of producing photonic crystals are extremely energy-intensive and environmentally harmful. We spoke to **Dr Tore Brembu** and **Dr Martin Lopez-Garcia** about their innovative work in genetically engineering diatoms, which could potentially provide a natural alternative to existing methods of producing photonic crystals.

A lot of energy is typically required to fabricate photonic crystals, while the process also involves the use of highly toxic and contaminating solvents. As part of their work on a project funded by the Research Council of Norway, Dr Tore Brembu and Dr Martin Lopez-Garcia are investigating the possibility of using diatoms, or microalgae, to help produce photonic crystals (PhCs) in a more environmentally friendly way. "The structure we have found in these diatoms is actually very similar to those that we see in the PhCs currently fabricated in clean rooms. As the structure is similar, we believe that we can remove at least some of the steps required to produce PhCs in a clean room environment, simply by using natural bioproducts from diatoms," explains Dr Lopez-Garcia. The project's research focuses largely on two diatom species – *Coscinodiscus granii* and *Coscinodiscus wailesii* – both of which have PhC properties in part of their cell wall. "*C. granii* has a square lattice, while *C. wailesii* has a hexagonal lattice. They provide quite different properties with respect to PhCs, but both of them are very interesting," says Dr Brembu.

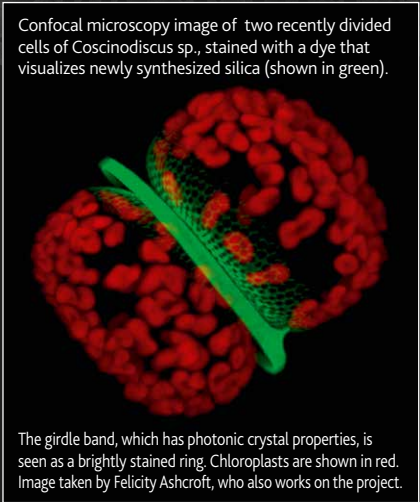
Diatom properties

The three most important diatom properties with respect to their potential in producing PhCs are their patterning, periodicity and pore size, which are regulated by genetic factors. It is the frustule, a unique, silica-based part of the cell wall in these diatoms, that has properties of interest in terms of producing PhCs. "The frustule is silica-based, and that's what gives it certain quite specific properties. Each diatom has a very intricate shape and pattern of pores, reaching from the micrometer down to the nanometer level," explains Dr Brembu. The regularity of the pore pattern is critical to the optical properties of the diatom, and Dr Lopez-Garcia says it's also important that this pattern is well preserved over a relatively large area,



Scanning electron microscopy image of a diatom frustule showing several sections of the exoskeleton. The girdle band is the belt shaped thin membrane that surrounds the inner nanometric patterned shape known as valve.

meaning tens of microns. "The pore pattern is very regular and well-preserved in these species, so we know that we are always going to obtain the same pattern, and it is only going to vary by a few nanometres between different cells," he outlines. "These two species of diatom are very periodic, in mathematical terms. We can define that lattice and that periodicity mathematically, and we will always obtain the same result."



The girdle band, which has photonic crystal properties, is seen as a brightly stained ring. Chloroplasts are shown in red. Image taken by Felicity Ashcroft, who also works on the project.

Researchers in the project are now working on engineering the genetic composition of both the two diatom species, with a view to using them to produce natural PhCs. This research is highly multi-disciplinary in scope, bringing together scientists from a variety of fields, which Dr Lopez-Garcia says is a real strength of the project. "We are mixing physics, materials sciences and biology," he says. On the biology side, Dr Brembu plans to use the CRISPR-Cas system and other methods as part of his work in genetically editing and transforming the diatoms. "A number of methods are available to genetically transform diatoms. We are going to use micro-injection techniques, similar to those used in IVF, to inject genetic material into a cell," he outlines. "We generate single guide RNAs (sgRNAs) specific for the genes that we will want to target. We aim to identify promising target genes experimentally, with interesting enzymatic properties that will make them promising targets, that affect the patterning, size or periodicity of the frustule."

The goal in this work is to generate different mutants and propagate them, then Dr

Brembu and his colleagues in the project will look to investigate the structure of the cell walls. "We purify the cell walls and observe them, usually using electron microscopy, which is a very commonly-used method with diatoms. With an electron microscope, we can take images, make measurements, and look for any changes," he says. Researchers hope to identify specific genetic factors that can be manipulated, through which the photonic properties of the diatoms can then be modified, opening up further possibilities. "Biosilica has huge technological potential, and it's already being used for

paramount consideration in this respect, particularly given wider concerns around the use of genetically modified organisms (GMOs). "In many countries these engineered diatoms might be considered as genetically modified organisms (GMOs)," acknowledges Dr Brembu. "This opens up certain ethical and societal questions, and we will hold several workshops with different stakeholders to look into these issues, and to get feedback on how society, industry, NGOs and governments view them. We aim to encourage communication with and between different stakeholders."

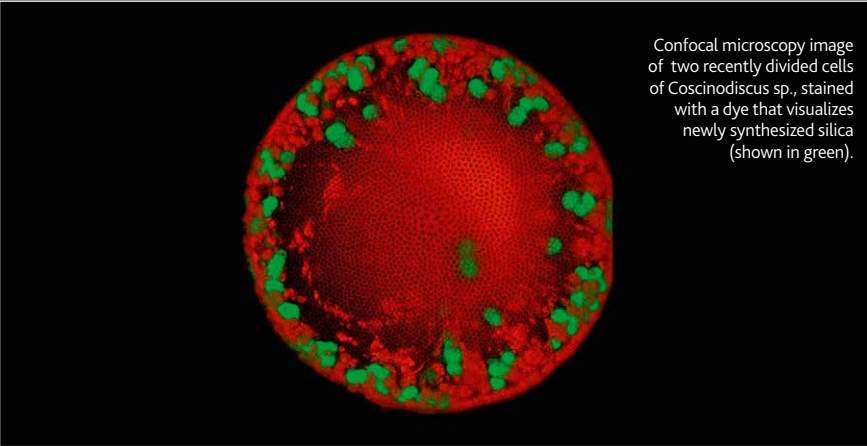
"The structure we have found in these diatoms is actually **very similar to those** that we see in the **photonic crystals currently fabricated in clean rooms**. As the structure is similar, we believe we can remove at least some of the steps required to produce PhCs in a clean room."

certain applications. If we can control the nanostructuring, then that opens a up whole new realm of possibilities," says Dr Lopez-Garcia. "If we reach our objectives by the end of this project, many other applications will open up beyond the photonics field. We could potentially see direct applications in fields like energy generation for example, through photocatalytic processes."

Early stage research

This research is still at a fairly stage however, with Dr Brembu looking to address several interesting basic research questions around how the frustule and the biosilica are genetically organised in diatoms over the course of the project. This could then provide solid foundations for researchers to explore potential applications in future. "We are working at a fairly low technology readiness level (TRL) in this project, but in future we hope to move in a more applied direction," outlines Dr Brembu. Safety is a

The diatoms will not be used in foodstuffs, so will not be regulated in the same way, yet other safety considerations may need to be considered. This is the focus of a great deal of attention in the project, with researchers examining different safety considerations around the genetic manipulation of diatoms. "Our partners at NORCE are looking at issues around responsible research and innovation (RRI). Stringent regulations are in place in Norway, which are currently in the process of being updated," says Dr Brembu. Close communication with stakeholders will help guide the future direction of research and ensure it is widely accepted, with the project team looking to develop a viable alternative to the current means of fabricating PhCs. "Currently PhCs are being fabricated with some toxic materials in an environmentally harmful way. We are trying to use natural systems instead," explains Dr Lopez-Garcia.



Confocal microscopy image of two recently divided cells of *Coscinodiscus* sp., stained with a dye that visualizes newly synthesized silica (shown in green).

ENIGMA

Enabling natural photonics through genetic manipulation of diatoms

Project Objectives

The ENIGMA project aims to tailor the photonic properties of the silica-based cell walls of diatoms by gene editing techniques, achieving spectrally tuneable photonic platforms for specific applications. If successful, this project will enable the substitution of current environmentally unfriendly photonic crystal production with bio-sourced nanomaterials.

Project Funding

The ENIGMA project is funded by the Research Council of Norway (NRC) (Grant no. 342255).

Project Partners

- Norwegian University of Science and Technology (Norway)
- The Spanish National Research Council, (Spain)
- NORCE (Norway)

Contact Details

Project Leader,
Dr. Tore Brembu
Department of Biology
Norwegian University of Science and Technology
T: +47 97 505 808
E: tore.brembu@ntnu.no
W: <https://www.digitallifenorway.org/projects/enigma/index.html>

Martin Lopez-Garcia Tore Brembu



Martin Lopez-Garcia is a researcher at the Institute of Optics of the Spanish National Research Council in Madrid. His investigations focus on discovering and understanding the role of photonic nanostructures in nature. He is also interested in the applications of these biotic photonic systems in energy harvesting technologies.

Tore Brembu is a researcher at Department of Biology at Norwegian University of Science and Technology. His work focuses on molecular biology of diatoms, lately focusing on the molecular mechanisms underlying diatom cell wall biomineralization.

NORCE

NTNU

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Funded by
The Research
Council of Norway