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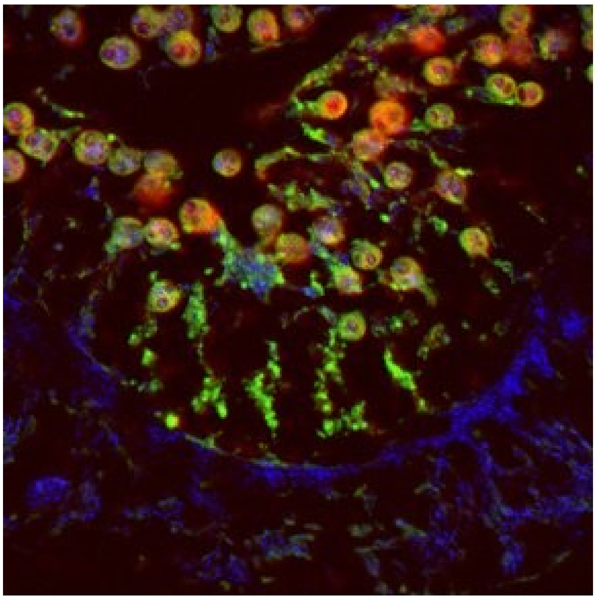
Bioeconomy BW

Learning from corals' virtuoso handling of light

There are research projects where the development of a hypothesis is as exciting as the final results. A project at the Ulm-based institute ILM that is being funded under the "Molecular Bionics" programme, is one of such projects. This immediately becomes clear when Raimund Hibst, ILM director and project coordinator, refers to it as a risky and ambitious project. If everything goes according to plan, the ILM will be able to improve photovoltaic plants and bioreactors, create optical construction materials and provide protection against short-wave UV light.

The ILM's engineers and scientists are investigating the symbiotic community of corals and algae. Hibst explains that bionic researchers who focus on the investigation of light tend to model photosynthesis. However, the researchers from Ulm are pursuing a completely different, and until now, unique path. They are centring their investigations on the step that precedes photochemical conversion and hope to be able to find an answer to the question as to whether the structure of a material that is illuminated by (sun) light has an effect on the degree to which sunlight is utilised.

Two key departments are involved in the project



Three-channel fluorescence picture reveals the algae incorporated into a stone coral. © ILM

Two key departments of the Institute of Laser Technology in Medicine and Metrology are working on a project entitled "Strategies for optimised light management using marine symbionts as an example". The departments involved are the Department of Material Optics headed up by Alwin Kienle and the Department of Microscopy headed up by Angelika Rück. The project will last two years and ends at the end of this year. The ILM has been equipped with numerous aquaria where special lamps imitate sunlight in order to mirror the high UV irradiation at the equator.

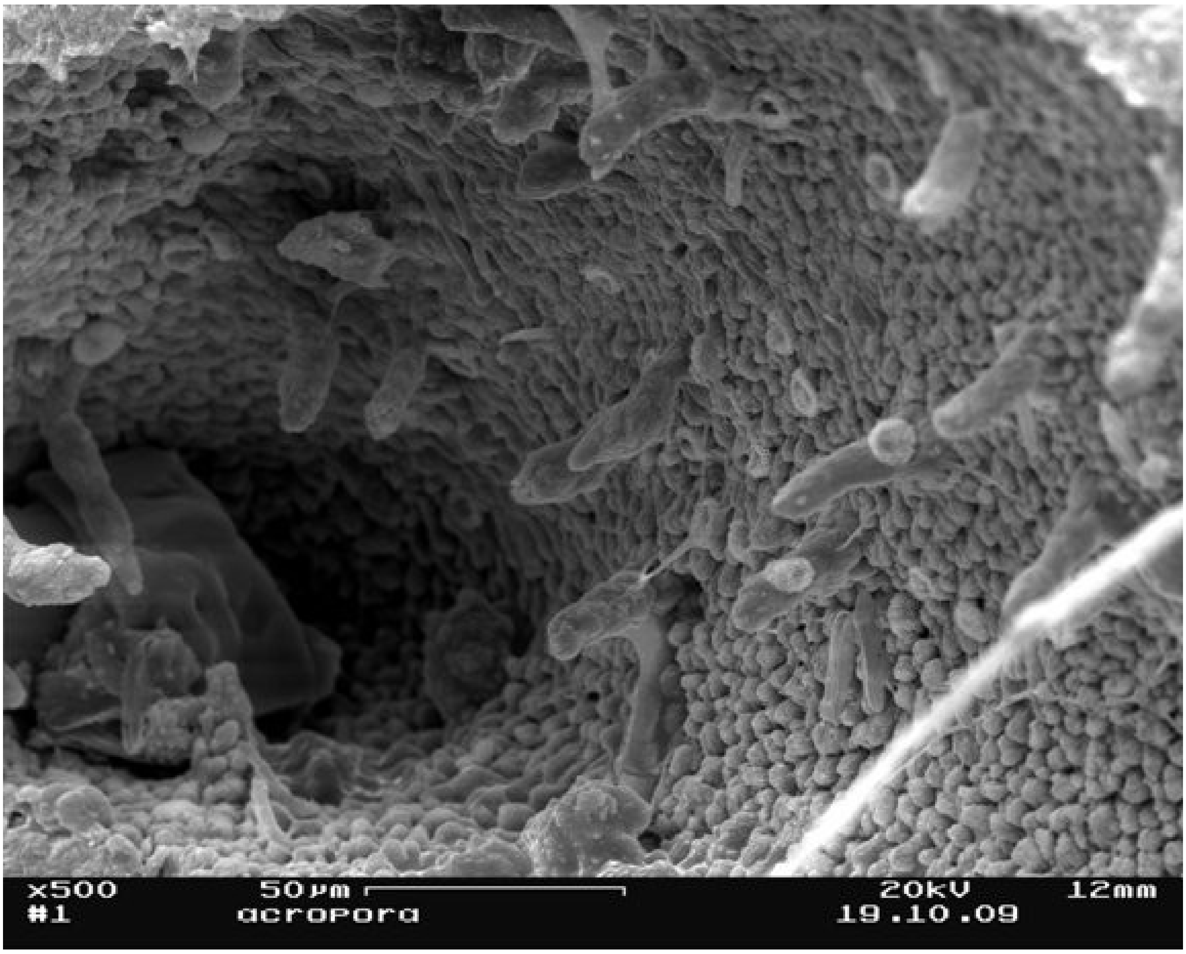
The project started with the investigation of the light conductance effects of a dentine cube, continued with the observation of the same phenomenon on the fur of polar bears and is now focusing on the symbiotic community of corals and algae. The Ulm researchers assume that cnidarians pursue some kind of intelligent light management for the benefit of the algae, which convert light into chemical energy. In turn, the corals benefit from the algae's activities as they live on the metabolic products of the algae.

How does light propagate in scattering tissue?

The project makes use of findings obtained by the ten doctoral students and their supervisor, the physicist Alwin Kienle in the ILM's largest department. Kienle and his colleagues are investigating the propagation of light in scattering tissues and its correlation with the tissues' optical properties. How does light propagate? Why does it travel in different directions? How does the scattering probability depend on the microstructure of the material? These questions, which initially touch on medical issues, can be transferred to many other technical fields of application, said Raimund Hibst.

If it is known how light spreads and how much light is absorbed by a certain material, it is then possible to glean information about the material and its properties. This information can then be used, for example, to localise tumours (although this requires a lot of computing capacity).

Nowadays, it is known that many tissues such as the human skin have an anisotropic structure, which scatter light in a specific direction, rather than inhomogeneously. The material scientists led by Alwin Kienle use objects such as spheres and cylinders to carry out experiments for the investigation of light scattering.



The electron microscope image presents the diverse morphology of corals. © Paul Walther, University of Ulm

The starting point: dentine

Kienle's investigations were triggered by the search for dental filling material that would give fillings a natural appearance. When light strikes a tooth's surface it is not reflected off until it hits the dentine, which is located below the dental enamel. When Kienle tried to find out the reasons for this, he found that the dentine had a fairly anisotropic structure and he thus discovered something that can now be taken as the starting point for bionic investigations: if light strikes a dentine cube, the light is emitted at a certain angle as it is scattered from the tiny dentinal tubules (fine, hair-like tubes that radiate outward through the dentine from the pulp to the exterior enamel border). Therefore, the light is not guided through the dentinal tubules, but along the cylindrical scatterers.

This led to the idea, which has since been patented, of guiding light through a series of cylindrical scatterers. Further research led the ILM researchers to discover similar effects in polar bears. Researchers also assume that polar bear fur performs like fibre optics. White hair is very inefficient in capturing the sun's energy. It is therefore assumed that the sunlight is diverted by the hairs so that it is applied directly to the polar bears' black skin, thereby insulating the body as well as preventing the bears from losing too much heat.

Whilst reading the relevant literature, one of Kienle's colleagues found that corals somehow protected symbionts, i.e. algae, against UV light. Algae mainly require red light for photosynthesis, while corals live on algal metabolic products. The researchers therefore assumed that this observation would help them develop new anti-UV protectants.

Nature is an ingenious builder

Corals (the photo shows an endoscopic image) appear to convert light for use by the algae. © ILM

As the Ulm researchers learned more about the corals' ability, they found that corals in deep-sea regions ensured that the algae were exposed to sufficient amounts of light. The ILM researchers therefore concluded that the corals conducted some kind of light management on behalf of the algae. Further research substantiated their hypothesis that the corals are very creative in handling light. For example, they found that corals had fluorophores that differed from those of corals exposed to strong sunlight. For example, corals living around the equator at a depth of around ten metres, need to protect their symbiotic partners by producing proteins that absorb damaging short-wave ultraviolet light. Some researchers assume that at greater sea depths, specific fluorophores convert blue light into red light, which the algae then use for photosynthesis.

The Ulm project consists of two parts; one focuses on material optics and the other on microscopic aspects. The researchers are seeking to find out whether corals have light-conducting structures. On the microscopic level, the researchers want to find out whether the corals make use of intelligent light management, and if so, do they have special fluorophores that are able to convert short-wave light into longer wavelength light?

Risky, but attractive

The project coordinator, Raimund Hibst, is well aware that his team are out on a limb. The approach is risky but a successful outcome would open up applications in many different areas. The researchers envisage the possibility of altering the surface of a thin-film cell by applying a layer with a specific microstructure, which would reduce the reflection of energy-rich sunlight. They further assume that this would enable them to guide sunlight to active elements. Another option is to adapt the wavelength of light by using fluorophores that are more effective in utilising UV light. Sunlight could thus be used more effectively in bioreactors.

At present, Raimund Hibst is unable to say whether the coral-algae symbiotic community will provide them with ideas as to how sunlight can be effectively used for technical applications. He expects that the best conclusions will come when the project ends in late 2011.

Simulating the propagation of light with Monte Carlo simulations

The researchers have in the meantime been able to produce high-resolution three-dimensional CT images, which are used for the voxel-based Monte Carlo simulation developed at the ILM. Kienle explains that the Monte Carlo simulation can be used to calculate the propagation of light in the entire coral at different wavelengths and help the researchers characterise the coral's light management. For example, the researchers can investigate whether light conductance effects occur as a result of the corals' microstructure.

Using a broad range of different investigational methods, including endoscopic methods, the ILM researchers have investigated the versatile morphology and dynamics of light propagation in corals. They have already collected initial findings on the complex miniature organisms and their interaction with algae (zooxanthellae).

The ILM researchers are using laser scanning microscopy to determine structures up to a limit of optical resolution of 200 nm; an integrated software combines the images obtained with confocal microscopes into a closed three-dimensional body. Using electron microscopy (Paul Walther, University of Ulm), the researchers are also able to clarify the different crystallisation forms of the coral skeleton.

The ILM researchers are using confocal fluorescence microscopy to investigate the interaction of fluorescent particles and pigments as well as the optical properties of living tissue in living animals. They document this information in a space-resolved, spectral-resolved and time-resolved manner and are able to identify certain processes on the molecular level.

Detection of rapid molecular energy transfer

The monitoring of processes over time enables the researchers to identify the dynamic processes of organisms during irradiation, for example the reorganisation of particles of tissue components. On the other hand, a time slot of only a few nanoseconds between two laser pulses enables the researchers to detect the point in time that energy is transferred from one fluorescent molecule to another.

Using absorbent or fluorescent molecules, the researchers hope that when the project comes to an end in late 2011 they will be able to show how light is conducted or scattered as a result of particular nano- or microstructures.

Article

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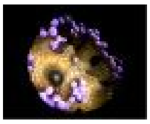

Molecular bionics – inspirations from the microworld for the macroworld