Natural and bio-inspired photonic materials

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This project will open a new interdisciplinary field of research: natural photonics. The project combines different disciplines and techniques in order to obtain from one side low cost, editable, sustainable photonic materials and on the other to answer fundamental questions about the biological significance, the assembly and the role of disorder in cellulose-based natural photonic structures. Although structural colour in the animal kingdom has been studied and mimicked previously, only very recently plants have also been shown to develop intense and strong structural colours. They achieve this using a simple and very interesting material: cellulose. Cellulose micro-fibrils, found in several types of cells and in a wide variety of plants, form a chiral multilayer structure, which provides a strong and colour-selective reflection of light. The mechanism by which these structures are naturally formed in plant cell walls remains an unresolved problem in developmental biology. Biomimetics with cellulose-based architectures is key to understand biological processes at work during the growth of these structures in cell walls. Importantly it also enables us to fabricate novel photonic structures using low cost materials in ambient conditions since cellulose is the most abundant polymer available on the planet.

Inspiration from nature

Pollia condensata fruits reveal the first example of multilayer-based strong iridescent colouration in plants. The colour is caused by Bragg-reflection of helicoidally stacked cellulose microfibrils, which form multilayers in the cell walls of the epicarp. Uniquely in nature, the reflected colour differs from cell to cell, as the layer thicknesses in the multilayer stack vary, giving the fruit a striking pixelated or 'pointillist' appearance. Because the multilayers form with both helicoidities, optical characterisation reveals that the reflected light from every epidermal cell can be polarised either circularly left or right, never previously observed in the same tissue.

Biomimetic structures: cellulose photonics

Cellulose nanocrystals can spontaneously assemble in a chiral nematic liquid crystalline phase in water, that can be retained in dry conditions, giving rise to strongly coloured films.

Cellulose assembly in plants

Cellulose from different species of plants, that show different assemblies of cellulose, in the same genus (Pollia japonica and Pollia condensata) at different stages of growth will be extracted. X-ray NMR and Fourier Transform Spectroscopy will indicate the exact composition of the cellulose micro-fibrils. Once the cellulose fibrils are extracted from the different parts the self-assembly will be tested in water.

Disorder in Nature

Another aspect I worked on in collaboration with LENS and University of Florence is the optical response of white beetles. We investigated the optical properties of these scales, which have shown that they are able to scatter light more efficiently than any other biological tissue known, which is how they are able to achieve such a bright whiteness. Animals produce colours for several purposes, from camouflage to communication, to mating and thermoregulation. Bright colours are usually produced using pigments, which absorb certain wavelengths of light and reflect others, which our eyes then perceive as colour.

The ultra-white Cyphochilus produces this colouration by exploiting the geometry of a dense complex network of chitin. The nano-structured chitin network have optimised in order to produce maximum white with minimum material. This nano-network is directionally-dependent, or anisotropic, as it makes them lighter. Over millions of years of evolution the beetles have developed a compressed network of chitin filaments. This network is directionally-dependent, or anisotropic, which allows high intensities of reflected light for all colours at the same time, resulting in a very intense white with very little material.