Responsive Photonic Arrays

Prof Louise Bradley
BRADLEL@tcd.ie

Funding information:
IRC application

Background
Over the past decade there has been enormous interest in the development of mechanochromic photonics crystals as visual sensors. There are typically three ways to produce colour; pigmentation, emission or structural colour. Mechanochromic structures exploit structural colour resulting from the interference of light. A general term of structures that can be used to manipulate colour in this way is photonic crystals. The reflected or transmitted colour depends on the materials and structure. The structures can be as simple as planar thin films or as complex as the features in the blue morpho butterfly wings or 3D opal crystals. Many structures are inspired by those occurring in nature. Mechanochromic structures use materials which swell in response to a stimulus (liquid, gas, chemical) or which can be stretched or compressed with a resulting changing in the observed colour. The extent of the colour change, the sensitivity to the stimulus and the response time are all critical parameters that must be considered depending on the specific application. Often the structures fabricated to date are relatively simple, such as multi-planar layers or a grating on a surface, and the range of colour tuning is quite limited.

Innovation
The innovation in this project is that we will investigate structures that can be fabricated via direct laser writing using two photon polymerization. The Florea group is developing a range of responsive materials that are compatible with direct laser writing. The combination of novel materials with 3D printing opens up new horizons for photonic crystals and responsive visual sensors. One can design for a hierarchy of optical properties based on more complex designs which can have greater sensitivity to particular stimuli, and operate in specific wavelength regions. Previously it had been reported that photonic structures made by direct laser writing would operate in the infrared spectral range due to their micrometer length scales. However, we have recently published a paper showing visible colour from grid structures fabricated using a vapour responsive hydrogel. The colour of the structures redshifts as the vapour concentration is increased and the response is sensitive to the different vapours. Visual sensors remove the need for complex equipment and trained personnel for monitoring and testing in many environments from point of care medicine, to chemical testing or environmental testing.

Collaboration
This project is in collaboration with Prof. Larisa Florea in the School of Chemistry. As it is a collaborative project it will offer lots of opportunity for discussion with the material scientists so that we can understand and balance what is possible from a materials perspective with what is required from a photonics perspective to achieve the optimal sensor response. Our contribution to the project is in the structure design, materials characterization, optical characterization of the laser printed structures and simulation of experimental results to understand the material changes and how the sensors can be further optimized. The project is also in collaboration with Dr. Radislav Potyrailo, General Electric Research, USA.

Objectives and methodology
The objective of the objective of this project will be to develop solution based chemical sensors. A bulk hydrogel has a refractive index close to that of water, and will not be so visible. This project will explore the use of hydrogel with incorporated nanomaterials such that the material has a modified effective index and/or becomes a layer material. These nanomaterials can be dielectric or metallic. The first aspect of the project will be the investigation of photonic crystal designs such as grids, pillars, woodpile, and opal structures using these novel materials. This will determine the volume concentrations of the nanomaterials, the layer spacings within ordered materials and the optimum structures for visual sensors in solution environments. We will also numerically simulate the swelling to investigate the sensitivity of the sensor. The numerical modelling will be carried out using a combination of transfer matrix and finite difference time domain tools available in the Bradley group. The novel materials will be optically characterized using a ranged of techniques such as ellipsometry and dark field microscopy. Selected structures will be fabricated using the direct laser writing and will be characterized using custom built optical testbeds. The angle dependent reflection and transmission spectra will be measured as the structures experience a rage of stimuli of varying concentrations. Simulation of the experimental results provides a feedback loop with the design to understand the level of swelling and refractive index changes that occur in response to the various stimuli in the solution. The PhD student will undertake all elements of the simulation and characterization. They will be fully involved in all aspects of the project.

**Essential/Desired abilities**

The ideal candidate will have an interest in understanding how new materials and fabrication processes can be exploited to create novel visual sensors for chemical, medical, mechanical and thermal applications. The project will have a combination of numerical simulation, design, fabrication and characterization. So the ideal candidate will be someone who is interested in learning a broad range of skills. The candidate must have a 1.1 in their third year exams with a good expectation of a 1.1 final degree classification.

**Reference**