Photonic Band Gap Materials

Colloidal Photonic Crystals - Artificial Opals and Related Materials

Photonic Band Gap (PBG) materials are materials which can influence the direction that light can travel via the operation of a combination of reflection, refraction and diffraction processes. Put more simply, some wavelengths of light are forbidden to exist for waves travelling within the material in specific directions and so these wavelengths are reflected back towards the eye of the observer. The resulting ‘iridescence’ or ‘opalescence’ (and natural opals are excellent examples of photonic band gap materials), gives rise to changing colours that are dependent on the angle at which the material is viewed. Often very colourful materials as demonstrated in the images above, the colour arises not from selective absorption of certain wavelengths but from structural effects, and as such these materials are said to exhibit ‘structural colour’.

PBG materials can be fabricated using a ‘top-down’ approach employing methods such as lithography developed for the electronics industry, where selective pieces of a material are removed so as to produce a regular grid type arrangement in both 2D or 3D, however this approach is both expensive and time-consuming.

Prof Pemble with two samples of flexible colloidal photonic crystals made in the laboratory of collaborator Dr Hiroshi Fudouzi of the National Institute for Materials Science, Tsukuba, Japan. Distorting these flexible materials alters the layer spacing between the colloidal particles that make up the film which then alters the perceived colour. Such materials are analogous to natural opal gemstones and certain iridescent butterfly wings and are said to be examples of ‘structural colour’.

An example of a colloidal photonic crystal waveguide
example of a colloidal photonic crystal waveguide such as might be used in the fabrication of optical interconnects, for chip-to-chip and board-to-board communication. The colloidal spheres that make up the material may clearly be seen. Note that the waveguide structure is surrounded by another colloidal photonic crystal which has been infilled so as to provide a contrasting refractive index medium to that of the waveguide itself.

At Tyndall we employ a different, so-called ‘bottom-up’ approach in which we mimic the natural processes that lead to the creation of opal gemstones, via exploitation of colloidal crystallisation. In this approach we synthesise colloidal particles of SiO$_2$ (as in natural opals) or polymer, and assemble these in to highly regular 2D and 3D arrays, so as to produce a series of naturally periodic structures - artificial opals and their various analogues.

Funded by Science Foundation Ireland and the European Union, we are working towards real device fabrication from these materials based on methods such as controlled evaporation and layer-by-layer assembly which we can achieve using our Langmuir-Blodgett methods. These include the roll-to-roll synthesis of colloidal photonic crystal thin films on flexible substrates which we have recently demonstrated.

Examples of free-standing chitosan membranes fabricated by PhD student Ms Catherine Ryan by infiltrating a chitosan based interpenetrating network around a colloidal photonic crystal architecture. Such materials alter their shape and colour with pH and as such have significant
potential for use in wound dressings and slow release drug patches.

Photonic crystal thin films made in this way can find application as light-trapping and anti-reflection media to enhance solar cell light capture, as intensifiers for LED emission and in a wide range of wave-guiding and light sensing applications. Additionally strain-induced changes in periodicity in the flexible materials depicted above have been deployed by our friends in Japan to act as simple strain gauges which can be attached to large structures that may suffer from seismic activity.

Lastly, since the observed colours of these materials depends upon the refractive index contrast within the material, immersing samples of colloidal photonic crystals into different liquids often results in dramatic colour changes that may also be exploited in a wide range of commercially important technologies.

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Related Publications

- **A bottom-up fabrication method for the production of visible light active photonic crystals**, *J. Mater. Chem. C* volume 2 issue 9 pages 1675 to 1682 (2014)
  Authors: Sibu C. Padmanabhan, Keith Linehan, Shane O'Brien, Syara Kassim, Hugh Doyle, Ian M. Povey, Michael Schmidt, Martyn E. Pemble

  Authors: Mikhail Parchine, Joe McGrath, Maria Bardosova, Martyn E. Pemble

- **Silica-based photonic crystals embedded in a chitosan-TEOS matrix: preparation, properties and proposed applications**, *Journal of Materials Science* volume 51 issue 11 pages 5388 to 5396 (2016)
  Authors: C. C. Ryan, J. A. M. Delezuk, A. Pavinatto, O. N. Oliveira, H. Fudouzi, M. E. Pemble, M. Bardosova
