Inverse Opals for Active Colour Tuning Devices

Diego Bracho García
(db14475@Bristol.ac.uk)

Annela Seddon, Richard Trask, Ian Hamerton

www.bris.ac.uk/composites
Presentation Outline

• Background
  – Structural colour and photonic crystals (PCs)
  – Examples of PCs in nature
  – Tuneable PCs

• Objectives

• Experimental

• Results
  – Self Assembly
  – Inverse opals

• Conclusions and future work
Photonic Crystals Fundamentals

- What are photonic crystals?
  - Periodically ordered structures
  - Built from dielectric materials
  - Periodicity in the scale of visible wavelength (200-700 nm)

- What is so special about them?
  - Photonic bandgap formation caused by diffraction and interference
  - They exhibit bright angle-dependant coloration

*Figure 1: Photonic structures (1D, 2D and 3D)*

1D multilayer (Bragg reflector)  
2D hexagonal lattice array  
3D photonic crystal (opal structure)
Structural Colour in Nature

- The most frequent form of colouration comes from light absorbent dyes
- However, several examples of structural colour are found in nature
  - Opal gemstone
  - Beetle shells
  - Butterfly wing
  - Peacock feathers
- Colour of these arises from the interaction of light with periodic structures

Figure 2: Photonic structures in nature: Opal gemstone (top), Japanese Jewel Beetle, and Blue Morpho Butterfly (bottom)
Tuneable and Responsive PCs

- The photonic bandgap can be tuned by adjusting one or more of the physical parameter of the PC structure

- Stimuli responsive materials can be used to create polychromatic devices
  - Sensors, adaptive camouflage, photonic tuning devices, etc.

- **Objective:** design and assemble composite PC structures by self-assembly of polymeric and ceramic colloidal suspensions, in order to study their optical response and photonic band-gap tuning.

*Figure 3: Schematic illustration of tuneable parameters in 3D photonic crystals*

Experimental

- Silica inverse opals are formed by co-assembly of polymer colloids in a solution containing a silica precursor. A silica inverse opal is obtained after removal of the polymer template and consolidation of the silica matrix during calcination.

\[ n \text{Si(OR)}_4 + 2n \text{H}_2\text{O} \xrightarrow{\text{H}^+} n \text{SiO}_2 + 2n \text{R(OH)} \]

**Figure 4**: Schematic illustration of inverse opal assembly by colloidal self assembly
Results

• Resulting species exhibit angle-dependant coloration characteristic of photonic structures.

• Face-centered cubic structure (FCC), with the (111) plane oriented at the surface of the structure.

Figure 5: SEM images from SiO$_2$ inverse structures templated from 500 nm colloids

• Optical properties of these devices can be tailored by changing colloidal template diameter

• Additionally, it was found that coupling a metallic silver layer on the surface of this structure, switches the optical response and enhances reflectivity.

Figure 6: Photographs of prepared silica inverse opals and silver coated silica inverse opals
Results

- Colour can be tuned by altering one or more physical parameters of the system
  - Lattice spacing, symmetry, induction of defects, etc.

- For example, colour changes from bright orange to dark blue when infiltrated with ethanol, which can be reversed by evaporation of the solvent
  - Refractive index contrast

Figure 7: Diffuse UV-vis spectra of silica inverse opals (φ=240 nm) coated with 15 nm Ag in air (a), and infilled with ethanol (b).
Conclusions and Future Work

• Silica inverse opals of different pore sizes were fabricated using a vertical deposition method in a single-step co-assembly of polystyrene colloids in a silica precursor solution.

• Prepared samples exhibit iridescent behavior characteristic of photonic structures.

• Coating of an absorbent metal layer induces other effects, such as plasmonic effects.

• Future work will include the integration of smart materials, such as thermo-responsive polymer gels and nematic liquid crystals, in order to tune the optic properties of the devices.
• Acknowledgements:

• Poster:

Inverse Opals for Active Colour Tuning Devices
Diego Bracho, Ian Hamerton, Richard Trask, Annela Seddon

Photic crystals are periodic ordered microstructures, built from dielectric materials, with a periodicity in the scale of visible light wavelengths (~200-700 nm). Through rational design and smart tuning of the PC periodicity it is possible to tailor the colour exhibited by these materials. The main objective of this work is to design and assemble photonic crystal structures based on colloidal self-assembly and silica sol-gel chemistry for active colour display devices.

Results
Polymer opals and silica inverse opals were prepared by colloidal self-assembly and sol-gel chemistry. The resulting structures exhibit angle-dependent colouisation characteristic of photonic structures (Fig. 1.a). These exhibit a face-centered cubic (FCC) structure, with the (111) plane oriented at the surface of the structure (Fig. 1.b).

The exhibited colour can be tuned by altering one or more physical parameters of the system, such as lattice spacing (Fig. 2), symmetry, induction of defects, and refractive index contrast (Fig. 3).

Conclusions and Future Work
- Direct and inverse opals of different pore sizes were fabricated using a vertical deposition method in a single-step co-assembly of polystyrene colloids in a silica precursor solution.
- Tunability of the photonic bandgap within the visible spectrum is interesting for potential applications in photonic and optical, such as colour display devices, active camouflage, sensors, etc. Future work will include the integration of smart materials, aiming for complete tunability within the visible spectrum.