FABRICATION OF 3-D OPAL AND INVERSE-OPAL STRUCTURES FOR PHOTONIC-CRYSTAL DEVICES

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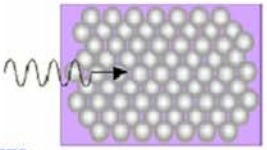
ABSTRACT

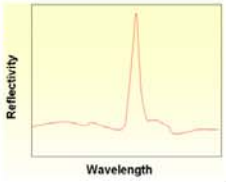
A new process based upon a combination of centrifugation and spin-annealing has been developed for the fabrication of high-quality three-dimensional opal and inverse-opal photonic crystals with stop gaps in the mid-IR portion of the spectrum. Fourier-transform IR reflection spectroscopy has been used to characterize the samples; the results are in excellent agreement with band structure diffraction calculations.

BACKGROUND

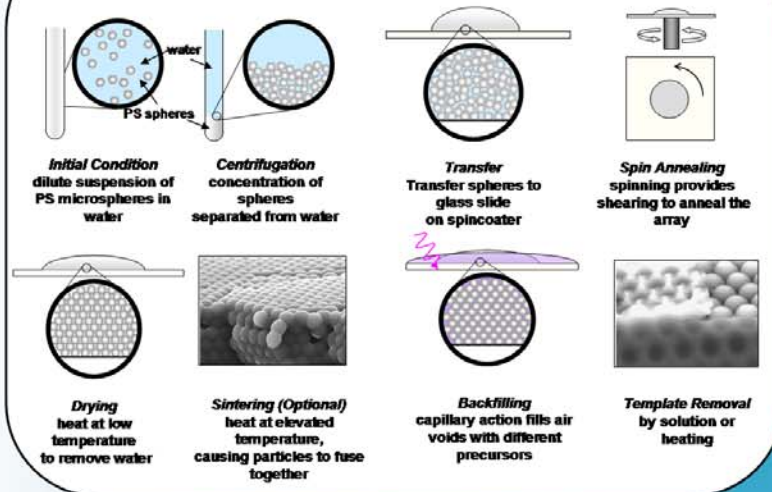
- PhCs are materials with periodic variation in dielectric properties
  - "Unusual" effects when the wavelength of the incoming radiation is comparable to the periodicity of the structure
  - Typically, the PhC will exhibit high reflectivity over a narrow frequency bandgap



- The bandgap reflectivity is enhanced by
  - High dielectric contrast between the phases
  - High structural regularity
  - Fully three-dimensional ordering

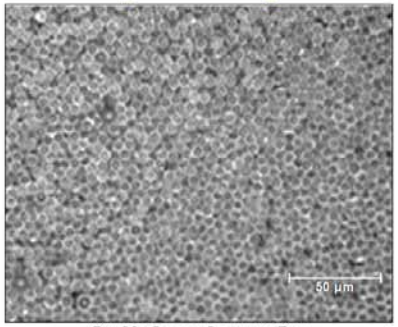


FABRICATION DETAILS

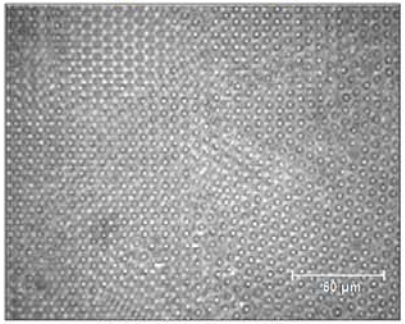


STRUCTURE OBSERVATION 1

- Spin-annealing is critical for achieving good ordering

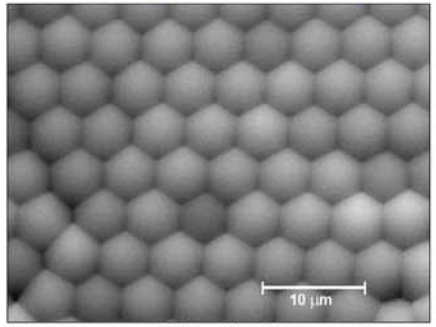


Opal before spin-annealing

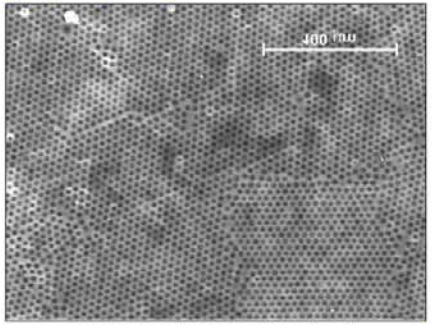


Opal after spin-annealing

- Opals and inverse opals of high quality are produced



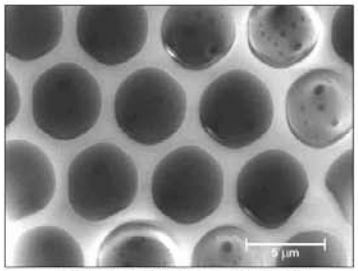
Sintered opal



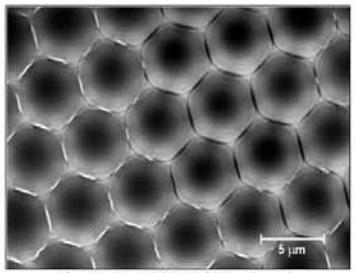
Inverse opal from unsintered opal

STRUCTURE OBSERVATION 2

- Sintering reduces inverse opal wall thickness, which enhances bandgap effect

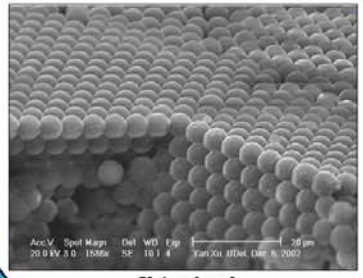


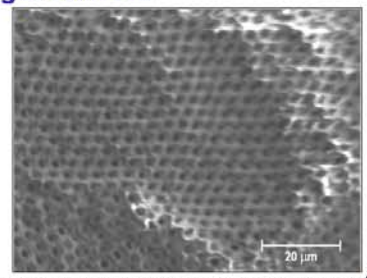
Inverse opal from unsintered opal



Inverse opal from sintered opal

- Full three-dimensional ordering is achieved

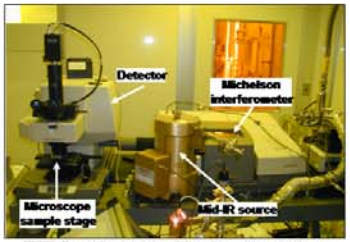

Sintered opal



Cross-section of inverse opal from sintered opal

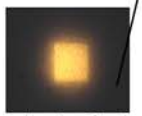
OPTICAL PROPERTIES

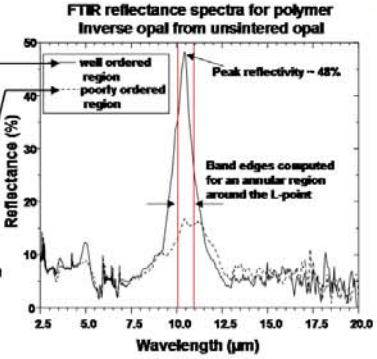
- Measure PhC reflectivitity as a function of wavelength
- Strong peak observed at $\lambda = 10.5\ \mu m$



FTIR Spectrometer with microscope stage

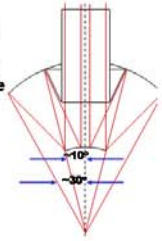

well ordered region

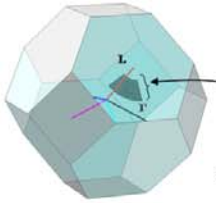

poorly ordered region



- Theoretical prediction of peak position
  - Compensate for range of angles probed by FTIR in calculated results
  - Good agreement with experimental results

The [111] direction (*L*-point) is normal to the sample surface, but the FTIR reflecting microscope objective does not illuminate from directly above





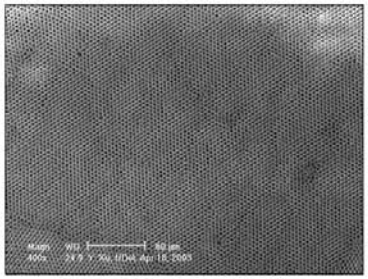
FCC First Brillouin Zone (BZ)

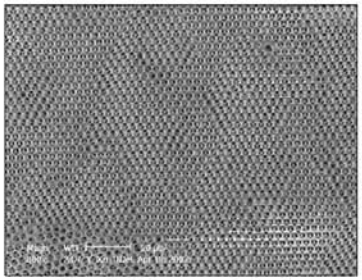
A more accurate representation is a range of *k*-vectors lying in an annulus around the *L*-point

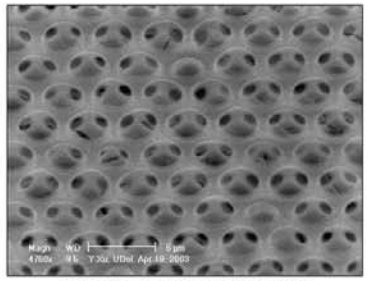
Average band-edge frequencies over these points on the irreducible BZ surface to obtain a more accurate estimate of the reflection band probed by the FTIR

FUTURE WORK

- Higher dielectric contrast between materials required to achieve wider stopgaps, higher reflectivity
- Replace polymer-air system with titania-air or zirconia-air system
- Approach
  - Sol-gel infiltration process
  - Remove carrier fluid by heating


Zirconia-air inverse opal structure


Zirconia-air inverse opal structure


Zirconia-air inverse opal structure

ACKNOWLEDGEMENTS

This work is supported by the Army Research Laboratory through the Composite Materials Research program.