PATTERN DEFINITION IN SELF-ASSEMBLED PHOTONIC CRYSTALS

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Introduction

Colloidal self-assembly has been widely explored as a route to photonic materials. Theoretical work has demonstrated that a three dimensional photonic band gap can be generated from an inverse FCC structure if fairly rigorous dielectric contrast conditions are met.[1,2] It is because of this finding that a multitude of research groups are investigating the self-assembly of colloidal particles followed by high dielectric constant replication strategies as a route to photonic band gap materials. The formation of low dielectric contrast three-dimensional nano- and microperiodic structures through colloidal templating is now relatively straightforward, but fabrication of high dielectric contrast structures as required for three-dimensional photonic band gap materials remains quite challenging. Furthermore, the functionality of self-assembled photonic crystals will be greatly enhanced if complex nanoscale features including wave guides and optical cavities are defined within the interior of photonic crystals. It is structures such as these that will be necessary for the integration of photonic crystals into optical and optoelectronic devices.

Experimental

The infilling of the colloidal crystals was accomplished via a range of strategies. Titania infilling was accomplished by adding a concentrated mixture of titania nanoparticles in water to a polystyrene colloidal crystal. The water was evaporated, and the polystyrene removed by calcinations at 500°C (Fig. 1). The melt imbibing of selenium was accomplished by first placing the colloidal crystal in a vial and then laying 5g of selenium powder above the crystal.[3] Then the vial was placed in an autoclave, evacuated, heated to 275°C, and pressurized. After quenching, with ice water, the pressure was released. Electrodepostion of semiconductors was performed either gavanostatically or potentiostatically, see reference for details.[4,5]

Figure 1. Photonic crystal created by imbibing nanocrystalline titania into a polystyrene colloidal template.

Pattern formation in the colloidal crystal was performed using a mode locked Ti:Sapphire pulsed laser (Spectra-Physics, Tsunami, pulse width < 80 fs, repetition rate = 82 MHz) operating at a wavelength of 780 nm with an average power at the objective of 50 mJ. Multi-photon polymerizations were performed on a LSCM (Leica DM IRBE) with an oil-immersion objective lens (63X, 1.32 N.A.). Features were defined using the region of interest software included with the microscope and an electro-optic modulator (Linos LM0202) was used to regulate the laser beam intensity.

Results and Discussion

We have now discovered routes to address both these issues. First, we developed a range of materials chemistry routes which operate within the three dimensional void space of a colloidal template to form high dielectric contrast three dimensionally periodic structures including imbibing of nanocrystalline titania, melt imbibing of chalcogenide glasses, and electrodeposition of II-VI semiconductors and conducting polymers. Second, we developed several promising approaches based on multiphoton polymerization of monomers contained within the interstitial space of the precursor colloidal crystal to write buried polymer wave guides and optical cavities with nanoscale precision within the self-assembled photonic crystals. Colloidal templates containing the polymerized features are compatible with infilling with a high dielectric constant material following the above procedures, which should result in integrated photonic band gap waveguides and optical cavities. Preliminary studies on the optical properties of these patterned nano- and microscale structures are underway.

Multiphoton polymerization strategies appear to have the potential to create features with an edge resolution of 100nm, and a bend radius of 1 micron (Fig. 2). This should fulfill the requirements for creating embedded waveguides in a photonic crystal. Alone this will not be sufficient to create a photonic band gap based waveguide, but if a high dielectric constant material can be embedded around the waveguide, the result should be a low-loss waveguide with a bend radius orders of magnitude smaller than possible with conventional fiber based waveguides.

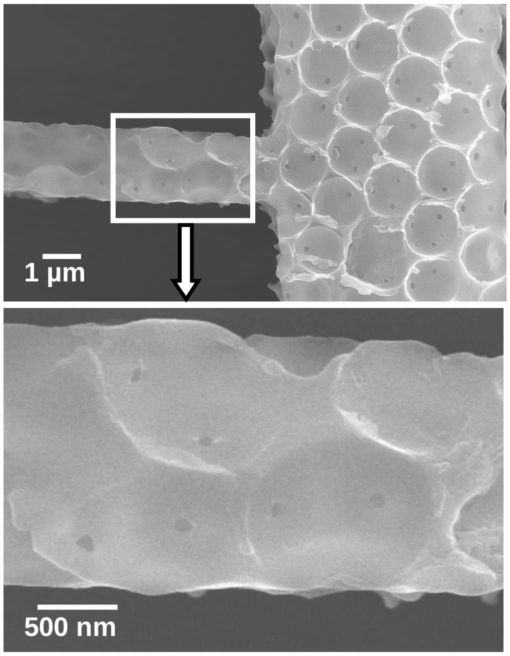

Figure 2. SEM micrograph of polymer feature formed through three-photon polymerization within a silica colloidal crystal. The silica has been removed with HF, exposing the polymer.

Conclusions

Integration of features within photonic band gap materials should result in devices with much greater sophistication than simple self-assembly. One promising route to creating such integrated features is multiphoton polymerization followed by high index replication.

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References

(1) Busch, K.; John, S. *Phys. Rev. E* **1998**, *58*, 3896.
(2) Biswas, R.; Sigalas, M. M.; Subramania, G.; Ho, K-M. *Phys. Rev. B* **1998**, *57*, 3701.
(3) Braun, P.V.; Zehner, R.W.; White, C.A.; Weldon, M.K.; Kloc, C.; Patel, S.S.; Wiltzius, P. *Advanced Materials* **2001**, *13*, 721.
(4) Braun, P.V.; Wiltzius, P. *Nature* **1999**, *402*, 603.
(5) Braun, P.V.; Wiltzius, P. *Advanced Materials* **2001**, *13*, 482.

Polymer Preprints **2002**, *43(1)*,26