Formation of high index three-dimensional inverse woodpile photonic crystals by single infiltration

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As a promising candidate for the next generation communication and information systems, photonic crystals (PCs) have received intensive research interests in the past few years. To explore the advanced functionalities of PCs, three-dimensional (3D) structures with a complete bandgap are crucial. To this end, materials of high refractive index contrast have to be employed to fabricate 3D PCs. Several approaches have been proposed to form 3D PCs in high index materials, for example using semiconductor lithography, generating inverse structures in self-assembled opal lattices and direct writing in chalcogenide glasses. Semiconductor lithography has been proved to be an efficient and precise way to fabricate two-dimensional (2D) PCs, but for 3D structures, this method is too expensive, complicated and time-consuming. A complete bandgap has been demonstrated in titanium inverse opal structures only for a limited geometry, thus lacking of designing flexibility. Direct laser writing in high index chalcogenide glasses on the other hand involves a complicated aberration problem when the fabrication depth increases, leading to 3D structures of insufficient periodicities.

Recently two-photon polymerization (2PP) technique has been applied in the fabrication of 3D PCs in low index polymer materials [1]. This approach is inexpensive, simple, fast, and accurate. It enables arbitrary 3D PC geometries with controllable defects that add functionalities. Although it is impossible to achieve a complete bandgap with such an approach due to the insufficient index contrast, the 3D polymeric PCs provide a template for high index inverse 3D replica. In this paper, we demonstrate a novel method to achieve high index inverse 3D PCs with arbitrary geometries formed by a simple sol gel process, which only involves a single step infiltration of the TiO_2 precursor into 3D polymeric templates generated by 2PP and a subsequent calcination.

In our experiment, 3D woodpile templates with a face-centered cubic (fcc) geometry (Fig. 1a) were fabricated using a commercially available photosensitive resin SU-8 (MICROCHEM) by the 2PP technique. Fig. 1b presents a scanning electron microscope (SEM) image of a fabricated 33 layer PC, which has a periodicity of 700 nm and a rod width of 150 nm, enabling a partial bandgap in the near infrared (NIR) range. To form the inverse structure, a solution of the precursor titanium propoxide $Ti(OR)_4$ was used as infiltration liquid, which was then transferred into TiO_2 through a sol-gel process. The composite was heated to completely remove the polymer template. A refractive index of high than 2.2 was expected for the final replica. Fig. 1c shows a confocal image of the resulted inverse structure. The preliminary measurement shows a bandgap with a 20% suppression ratio in transmission (Fig. 1d) in the NIR (~2 μm) region. Refining the fabrication process will lead to a complete bandgap.

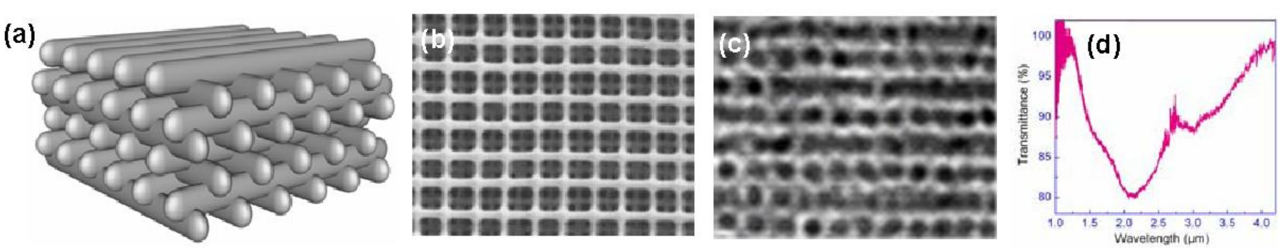

Fig. 1 (a) Schematic for woodpile structures. (b) SEM image of 3D polymeric woodpile template. (c) Confocal image of 3D high index reverse woodpile structure. (d) Transmission spectrum of the 3D inverse woodpile PC showing a suppression ratio of 20%.

Reference

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