Replication of Holographic Photon Crystals via Atomic Layer Deposition

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Introduction

Photonic Crystals (PCs) are structures that exhibit a spatially periodic modulation of dielectric constant. As a result, these materials have several very unique optical properties. Certain wavelengths of light may be restricted from propagation through the material in some or all directions. This can be used to create specialized filters, or, through the introduction of defects where light can propagate, high precision waveguides. PCs can also exhibit negative refractive indices, allowing for devices such as flat lenses, free of the spherical aberrations associated with curved lenses. In general, PCs are useful in a plethora of devices all allowing for tremendous control of light.

One technique for PC fabrication is holographic lithography. Similar to classical lithography, it employs the use of multiple laser beams, whose interference allows more complex three-dimensional exposure patterns and thus more complex three-dimensional structures. This technique is ideal for creating plastic structures with periodically spaced air holes creating a 3D template for PC fabrication.

In this work, atomic layer deposition (ALD) was used in combination with etching procedures to modify the structure and increase the dielectric contrast of PCs created via holographic lithography.

Procedures

A holographic PC (HPC) was annealed at 50°C for 90 minutes. It was then filled with 100 nm of Al_2O_3 via ALD, using trimethylaluminum and water vapor as precursors. The sample was ion milled for 30 minutes, to obtain access to the coated polymer network. The polymer template was then removed via oxygen plasma etching. The sample was then coated in 5 nm of TiO_2 via ALD using $TiCl_4$ and water vapor as precursors. The sample was then coated in 50 nm of GaP via ALD, using trimethylgallium and tris-dimethylaminophosphine as precursors. The sample was then etched in 2% HF to remove the Al_2O_3 lattice. Reflectance measurements and SEM images were acquired between each step.

Results and Discussion

Through the employed processing technique, the original HPC structure could be replicated in GaP, a material exhibiting a much higher dielectric constant than the polymer lattice (3.3 vs. 1.6). The resulting structure was a replicated shell of the original lattice, with the shell structure resulting from the conformal nature of ALD film growth.

The optical and structural changes were observed in both the shifting of the Bragg peaks (the result of constructive interference between light reflecting off the periodic lattice) and in the SEM images. The sample reflectance at each processing stage is shown in Fig. 1.

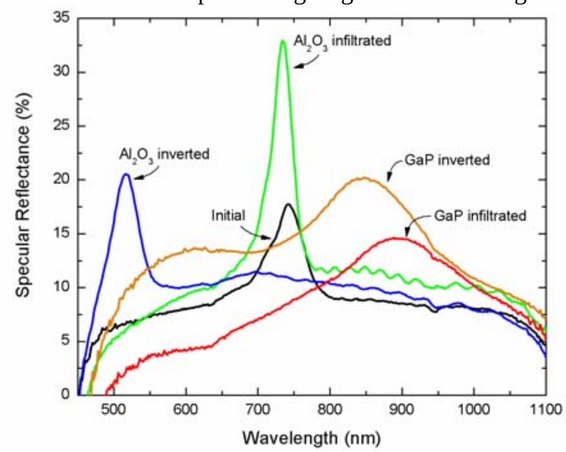

Fig 1. Sample reflectance throughout processing of HPC.

Figure 2 shows SEM images of the initial holographic lattice and the replicated GaP lattice. The image reveals near perfect replication of the lattice, although ion-milling has affected the top surface.

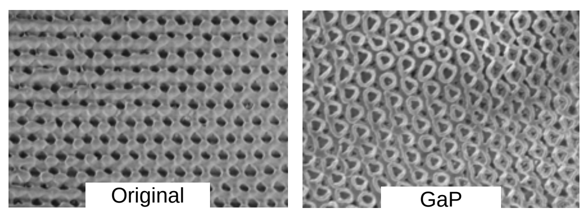

Fig 2. SEM images of the original HPC and the GaP replication.

Conclusions

Multi-material, multi-stage ALD was used successfully to modify the structure and dielectric constant of 3D holographically-defined polymer PCs and in particular to invert and replicate structures in other materials. Using this technique, a high index contrast GaP replica was fabricated and offers the potential to form a full photonic band gap in the visible with enhanced opto-electronic properties.

References

1. Graugnard, King, Gaillot, Summers. *Adv. Func. Mat.* **2006,** *16*, 1187.
2. King, Gaillot, Graugnard, Summers. *Adv. Mat*. **2006**, *18*, 1063.