Fabrication of 3 Dimensional Photonic Crystals with Waveguides for Visible Light

S. Dhuey, A. Testini, N. Borys, M. Melli, P.J. Schuck, C. Peroz

S. Cabrini

Molecular Foundry, Lawrence Berkeley National Lab, Berkeley, CA

Photonic crystals are structures in which the refractive index is periodically modulated. If the length scale of the modulation is comparable to the wavelength of light, it opens up a photonic band gap which will prevent propagation of that wavelength of light. A defect in the crystal will allow transmission at specific wavelengths, thus allowing light confinement or guiding. Much work has been done with two-dimensional photonic crystals, where the periodic variation is in two axes, thus preventing propagation of one wave vector. Three-dimensional photonic crystals (3D PhC) have a periodic variation in three axes, this allows the effect to operate at all angles of incident light and allows for more complex light confinement within the crystal. Limited work has been done for 3D PhCs, including waveguides, mostly at infrared wavelengths [1]. Preliminary work has been done in the visible regime without waveguides [2]. Work demonstrating 3D PhCs is limited by the complexity of the fabrication, where many layers are required, necessitating planarization of each layer, and sub-100nm alignment between layers, particularly for visible light. Also, the very limited number of materials with high refractive indices that are transparent to visible light complicates fabrication of 3D PhCs in this regime.

In this work we demonstrate a 3D PhC for visible wavelengths fabricated with a woodpile structure (Figure 1a), with the wires made of silicon nitride with an refractive index (n) around 2.20 that are separated by an interstitial nanoporous resist material with n = 1.17 [3]. The fabrication steps include patterning of a silicon nitride layer with electron beam lithography (EBL), then plasma etching to produce 90nm wires at a pitch of 270nm. Next, a film of low n resist is spin-coated as planarization and spacer layer without additional etching. A second silicon nitride layer is then deposited and patterned by EBL with precise alignment to the first layer and subsequently etched to form the second layer. With this method we created an 8-layer 3D PhC with sub-10nm overlay between layers (Figure 2b). Some crystals also included defects where perpendicular wires were removed from succeeding layers of the woodpile (Figure 1b) to allow for light confinement and waveguiding.

Preliminary measurements of the 3D PhCs over a narrow range of angles demonstrate the photonic band gap has opened for more than one angle. Future measurements will attempt to demonstrate waveguiding in the crystals.

References:

[1] Ishizaki K., Koumura M., Suzuki K., Gondaira K., Noda S.: Realization of three-dimensional guiding of photons in photonic crystals, Nature Photonics, Vol. 7, pp. 133-137, (2013)

[2] Subramania G., Lee Y., Fischer A.J., Koleske D.D.: Log-Pile TiO2 Photonic Crystal for Light Control at Near-UV and Visible Wavelengths, Advanced Materials, Vol. 22, pp. 487-491, (2010)

[3] http://www.sbamaterials.com/technology

A)

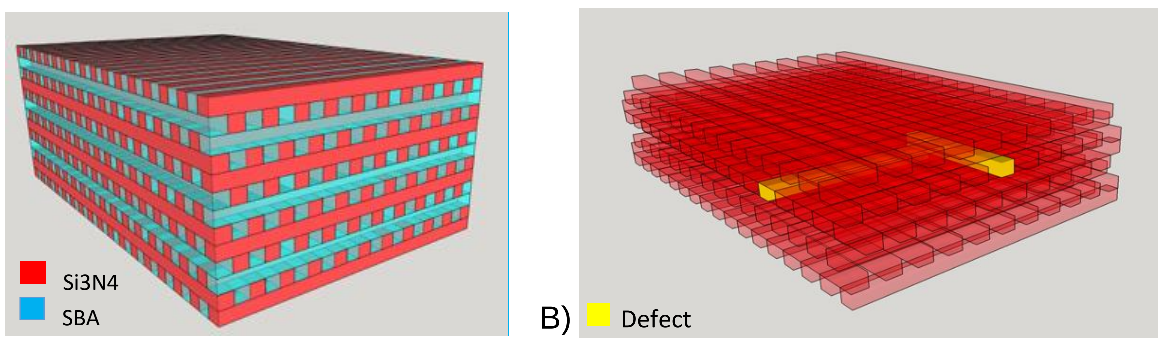

Figure 1: A) Schematic of the basic woodpile structure of the 3D PhC with silicon nitride beams and SBA interstitial material. B) An example of a programmed defect in the crystal, partial perpendicular lines are removed on two succeeding layers, so the light can be injected in one side and exit through the other side.

A)

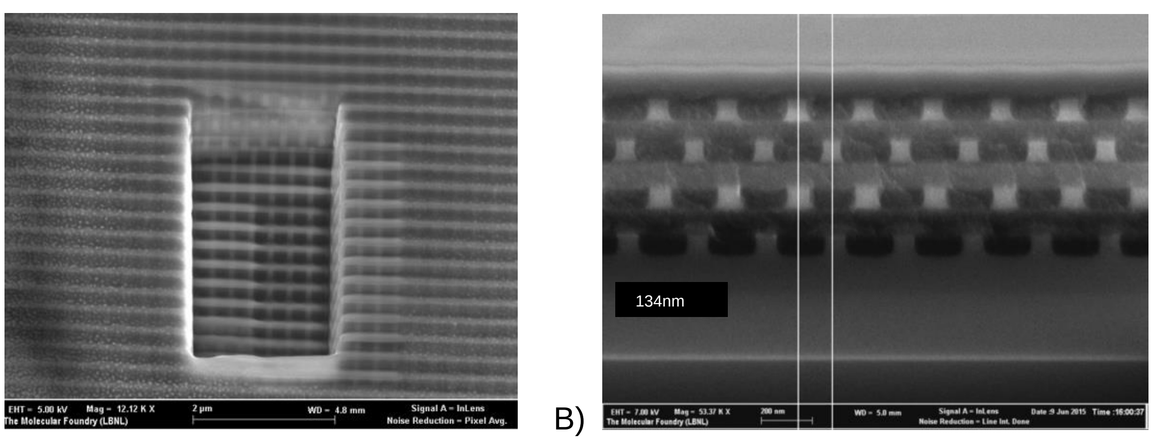

Figure 2: A) Top down SEM image of the 3D PhC with a portion milled away with a focused ion beam show the structure. B) Cross-section of the 3D PhC showing alignment between the layers.