Fabrication of an 18-layer 3D Woodpile Photonic Crystal via Stacking of Pre-Patterned Free-Standing Membranes

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3D photonic crystals (3D PhCs) have many desirable attributions due to their abilities to confine light in all directions. The major challenge is to fabricate 3D micro/nano-structures with high yield and fast turn-around time, especially when the number of layers is large. Layer-by layer technique allows arbitrarily-shaped 3D structures to be fabricated and takes advantages of well-established integrated circuit processing techniques. Nevertheless, the complicated and lengthy procedure, in addition to roughness and/or incidental damages on the final structure by frequent dry etching, polishing, and heating, make it difficult for prototyping novel multilayer structures.

Here we present a new approach to form 3D structures by transferring and stacking pre-patterned, free-standing silicon membranes and demonstrate the process by fabricating an 18-layer woodpile 3D PhC, which has a complete 3D photonic band gap, and relatively simple structure. It consists of layers of dielectric rods in air, with the rods in each layer rotated by 90°, and shifted by half of the lattice period relative to the layer below (fig 1a). As a preliminary demonstration, the minimum feature size was set to 1.2 μm, and consequently the rod width, lattice constant, and layer thickness were 1.2 μm(w), 4.2 μm(Δa), and 1.6 μm(h) respectively. Figure 1b and 1c show cross-sectional view and details of an 18-layer stacked silicon woodpile, respectively.

Overall fabrication process is depicted in Figure 2. The woodpile pattern was first etched in the top layer of an SOI wafer and then released from the substrate with HF wet etch. The released membrane was then transferred on top of a PMMA film separated from a Si substrate by a PVA film. Dipping the Si wafer in water dissolves PVA and floats the PMMA film with woodpile membrane attached. Then the PMMA/woodpile film was again mounted on a handling Si wafer with an opening at the center where the woodpile structure will be located. This handling wafer will be flipped with the PMMA/woodpile facing down and then aligned and stacked onto a substrate with previously transferred woodpile layers. After dissolving PMMA layer in acetone, more woodpile layers can be stacked on.

This fabrication process is faster, simpler and more cost effective than previous 3D PhCs methods, making it ideal for the fabrication of a variety of optical, chemical, and electronic devices. This technique does not require high-temperature processes and is independent of, or at least flexible on the material used. This result can be the starting point for the introduction of cavities and/or waveguides for device applications.

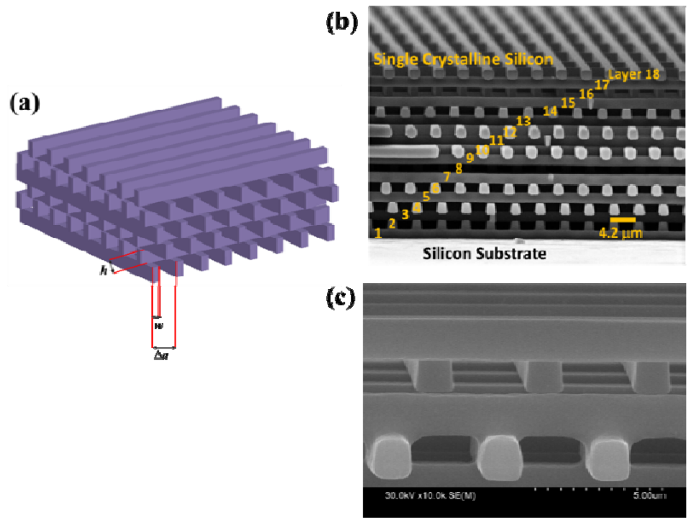

Fig. 1: Schematic view and SEM images: (a) The woodpile structure with critical lattice parameters denoted, w: 1.2 µm, : 4.2 µ m, and h: 1.6 µ m respectively. (b) Cross-sectional view and (c) magnified view of the 18-layer Woodpile.

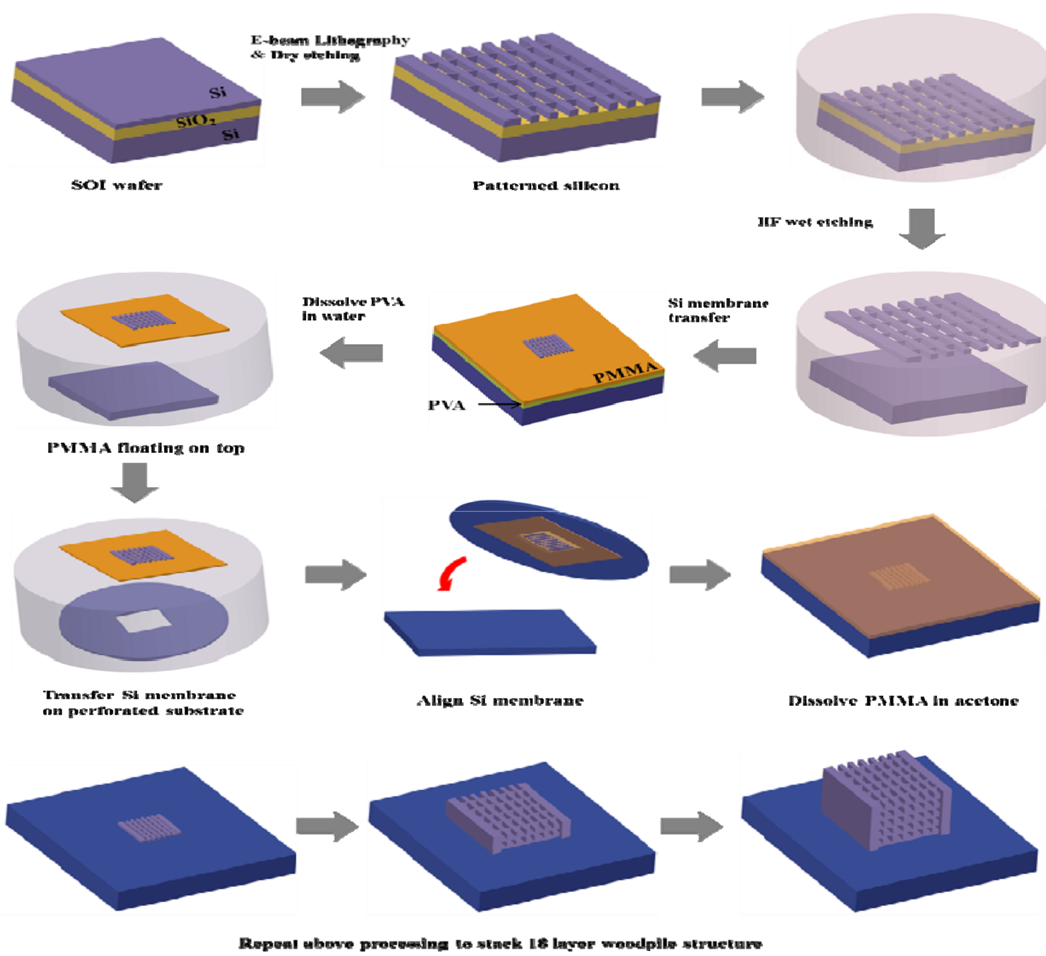

Fig. 2: Schematic of the silicon membrane transfer method.