Membrane Stacking; a New Approach for Three-Dimensional Nanostructure Fabrication

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The diffraction of light within periodic structures (so called "photonic crystals") offers a wide variety of opportunities for controlling and manipulating light[1]. Most research to date has focused on 2-dimensional (2D) photonic crystals, because highly developed planar-fabrication techniques (i.e., lithography followed by pattern transfer) are directly applicable. However, the full potential of photonic crystals in futuristic sensing, communication and computation systems is best achieved with 3-dimensional (3D) structures. The problem is that new methods of 3D fabrication need to be developed to achieve desired complex structures over large areas with low cost and high yield.

Interference lithography can produce periodic 3D structures in photosensitive polymers[2], but the introduction of deviations from perfect periodicity (i.e., waveguides and structures that constitute "devices" within the periodic matrix, so-called "defects") is highly problematic. Moreover, it's not clear that backfilling 3D polymeric structures is applicable to a suitable range of materials. Layer-by-layer methods enable the controlled introduction of defects[3], but to date fabrication is tedious, slow, low yield, and covers impractically small areas (e.g., <100 μm on edge).

We describe a novel approach in which the 3D structure is fabricated by assembling membranes that are patterned in advance using conventional planar methods (Figure 1)[4]. This approach minimizes the yield problem because membranes can be inspected and selected before assembly, and the desired waveguides and devices, can be introduced at any level. When brought into contact, membranes that are free of particulate and other contamination will bond spontaneously by Van der Waals or other mechanisms.

We report progress to date using low-stress SiN_x membranes as the test vehicle. 2D periodic structures have been etched into-free standing membranes (Figure 2), and nonaligned stacking carried out (Figure 3). We do not consider precise alignment of layers a potential problem since light diffracted from the structures during assembly will provide a built-in, reliable alignment signal. We believe the major problem facing the membrane assembly approach will be ensuring freedom from particles and other contamination. Si membranes, with their higher refractive index, are more desirable and will be used in the next stage of our research.

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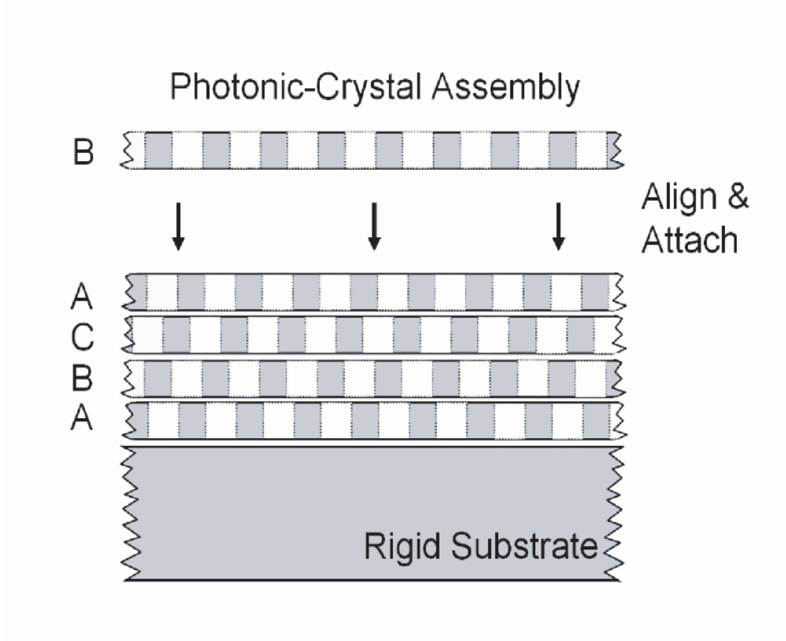
[1] J.D. Joannopoulos, P. Villeneuve, S. Fan, Nature. 386, 143(1997).
[2] M. Campbell *et al.*, Nature. 404, 53(2000).
[3] M.Qi *et al.*, Nature. 429, 538 (2004).
[4] K. Aoki, App. Phys. Lett. 17, 3122 (2002)



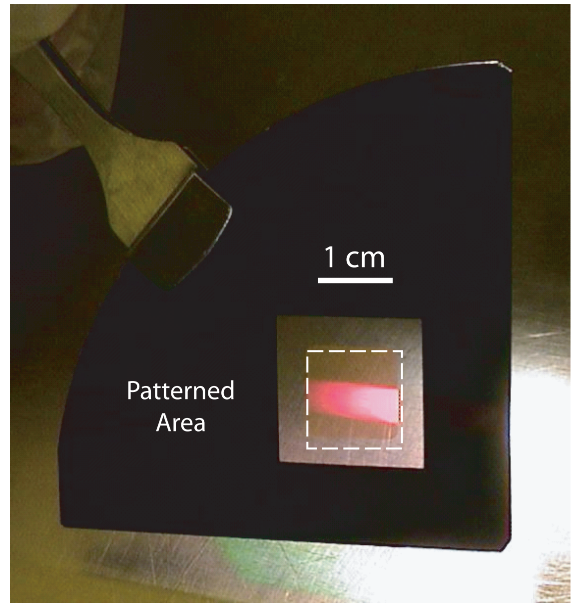


Figure 1: Depiction of the layer-by-layer stacking approach to the fabrication of 3D photonic crystals. All of the layers are fabricated in parallel and inspected prior to assembly.

Figure 2: Single layer of 3D photonic cyrstal (holes of 600nm pitch) etched into a free standing SiNx membrane, 350nm thick. Interference Lithography used for patterning.

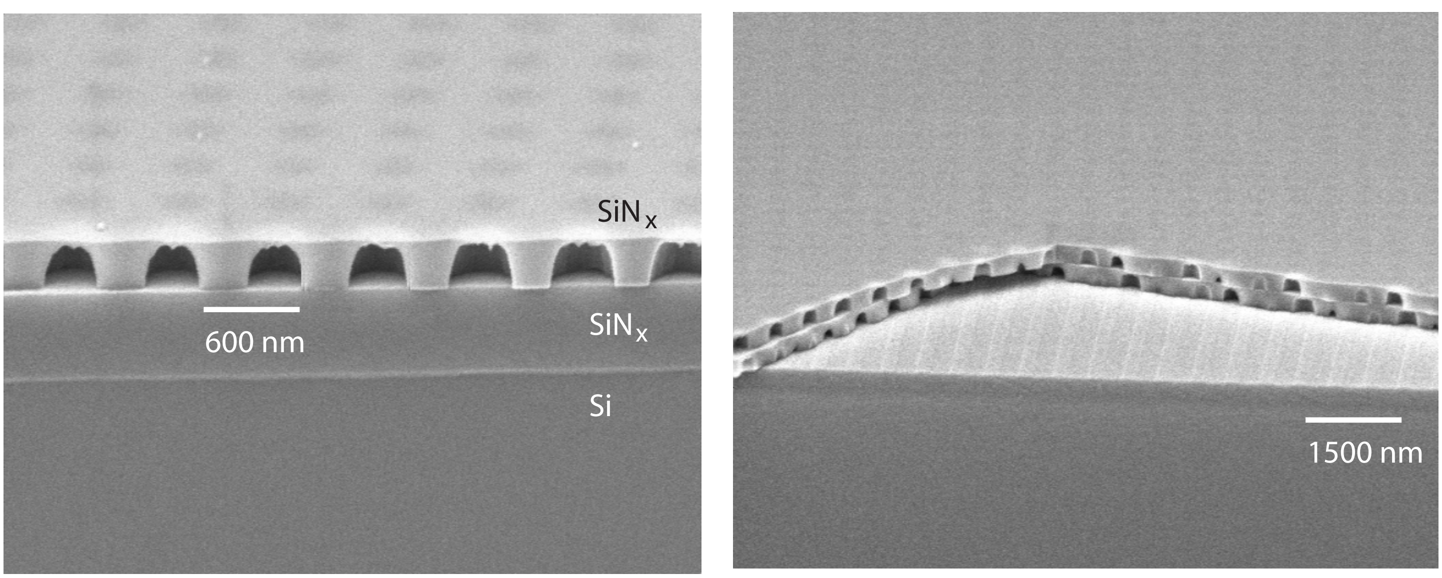


Figure 3: Initial stacking experiments. (Left) Patterned SiNx membrane is brought into contact with SiNx substrate. (Right) Two patterned SiNx membranes stacked onto a substrate patterned with shallow gratings.