3D Fabrication by Stacking Pre-patterned, Rigidly-held Membranes

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The fabrication of complex three-dimensional (3D) structures at sub-100nm resolution presents a new and difficult challenge. 3-D photonic crystals that contain waveguides, resonant cavities, filters or other devices, and require deep-sub 100 nm dimensional control, are a particular example of this challenge. Complex 3D structures can be fabricated by repeated application of planar techniques, as is done, for example, in modern IC chips and has already been done for 3D photonic crystals[1]. Aside from the time-consuming and sometimes tedious nature of this layer-by-layer approach, an accidental defect in an upper layer implies discarding the entire composite and starting over. That is, yield goes down as the number of layers increases.

An alternative approach is to form multilayer 3D structures by stacking thin membranes that have been patterned in advance, as illustrated in Figure 1. The pre-patterned membranes can be inspected for defects prior to assembly, thereby enhancing yield. Moreover, the full panoply of 2D planar-fabrication techniques can be optimally brought to bear. The challenge then is how to reliably clean, align, bond and detach the membranes. In the approach described here, membranes are attached to a rigid frame by means of tethers that are strong enough to permit normal handling but can be cleaved after bonding. The tether shape was designed using finite-element analysis to enable clean cleavage at a specific location so that fragments that would interfere with the bonding of subsequent layers are avoided. Figure 2 shows the tether design and the stress-concentration location.

We used 10 x10 mm SiNx membranes, 350 nm thick, patterned with a square array of holes at 600 nm pitch, typical of a photonic-crystal pattern. Figure 3 (left) shows a membrane patterned in this way, with a boundary consisting of tethers. Figure 3 (right) shows the bonding to a substrate (presumably by Van der Waals forces) of a patterned membrane after cleaving the tethers and removing the frame to form a two-layer patterned structure. No particles that would interfere with the bonding of subsequent layers were generated by the cleavage. The practicality of this approach to fabricating 3D nanostructures will be compared to the conventional layer-by-layer approach.

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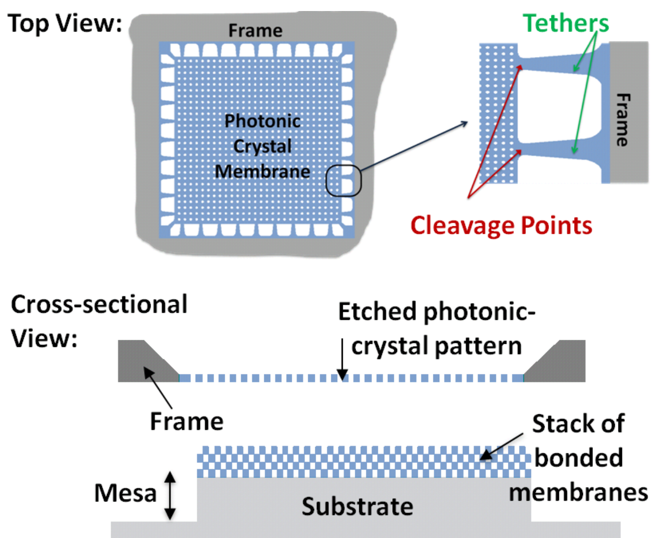
[1] M. Qi *et al.*, Nature*,* **429**, 538-542, 2004.



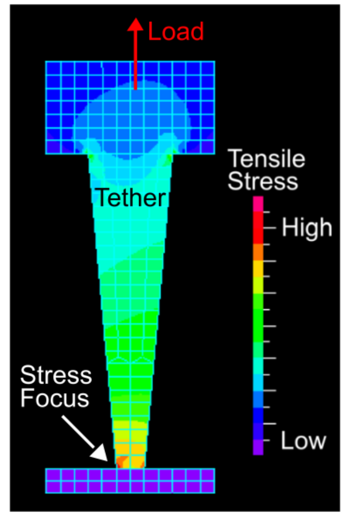


Figure 1- Schematic of a pre-patterned membrane attached to a rigid frame via tethers. The tethers are designed to have high stress concentration at a specific location so they will cleave cleanly without leaving residual fragments. After aligning and stacking the membrane, pushing downward further stresses the tethers, causing controlled cleavage and separation from the frame.

Figure 2 – Tether designs were simulated with finite-element analysis with a tensile load applied. Stress concentration is controlled by tether shape, width, spacing and radius of curvature at corners.

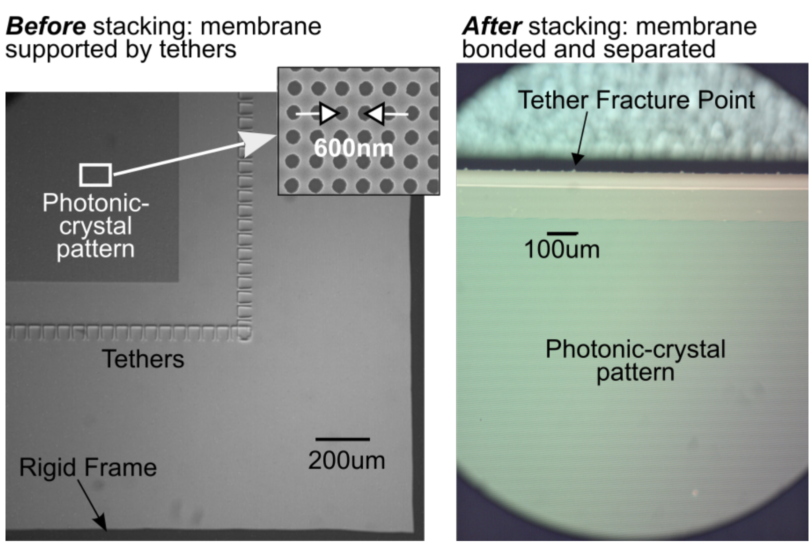


Figure 3: (Left) Membrane with photonic-crystal pattern and tether features at the boundary. (Right) Micrograph showing the result of bonding a 10mm x 10mm patterned membrane to a substrate to form a 2-layer photonic-crystal stack, and then cleaving the tethers to separate the membrane from its frame. No partic'-- were generated by the cleaving process.