3D nanostructures by stacking pre-patterned, fluid-supported single-crystal Si membranes

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The fabrication of complex three-dimensional (3D) structures at sub-100 nm resolution presents a new and difficult challenge. 3D 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. 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, stack and bond the membranes.

Membranes containing patterns that are not perfectly regular will exhibit in-plane distortion unless their intrinsic stress is zero. Zero-stress is difficult to achieve in patterned membranes rigidly held on a frame. In the approach described here, thin single-crystal Si on an oxide substrate is first patterned and then removed by etching the oxide in hydrofluoric acid (HF). The freed Si membrane readily floats on the liquid surface, aided by the hydrophobic nature of H-terminated Si. Presumably, floating freely eliminates, or greatly reduces, the problem of distortion. Figure 1 shows a stack of two pre-patterned membranes after HF etching and free floating on water. We have captured free-floating membranes on a rigid substrate with an intervening liquid layer, as illustrated in Figure 2. We believe this to be a near-zero-stress configuration. Alternatively, a controlled bubble could be used to bring a free-floating membrane into bonded contact, as illustrated in Figure 3. The relative merits of various stacking approaches will be compared, and means of achieving nanometer-level alignment described.

This work was supported by the Air Force Office of Scientific Research under Grant Number: FA9550-08-1-0379

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

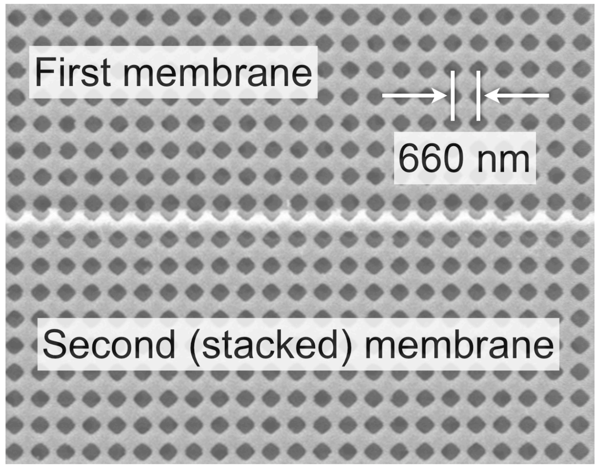

Figure 1. Micrograph of a stack of two pre-patterned Si membranes; each has a 660 nm-pitch grid and is 350 nm thick. The two membranes were released from oxide using HF, transferred to water and stacked after freely floating on the liquid surface.

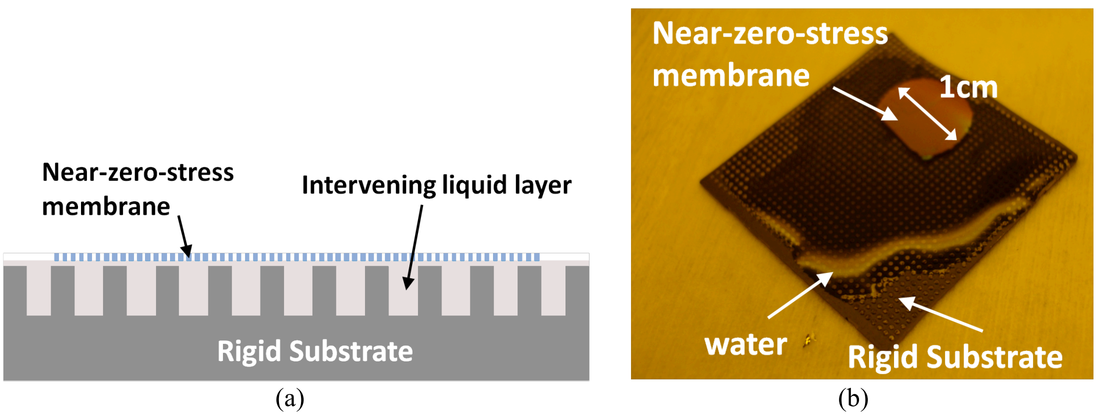

Figure 2. Schematic (a) and micrograph (b) of a patterned membrane captured on an intervening liquid layer on top of a rigid substrate. The membrane was patterned with a 660 nm-pitch grid, similar to that shown in Fig. 1. The rigid substrate is patterned with a grid of rods, 30 µm tall, 500 µm diameter, with a 1 mm pitch.

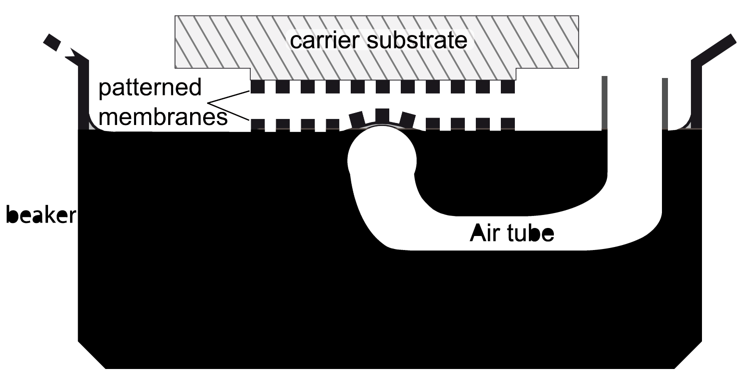

Figure 3. Schematic of membrane stacking using a controlled-bubble technique. The bubble, generated beneath the floating membrane, causes it to bow upward to facilitate bonding to a previously bonded membrane.