Transfer Processes of Silicon Nanomembranes for Three Dimensional Integration of Photonics and Electronics

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Three dimensional integration (3DI) of electronics remains one of the most attractive ways to aggressively scale modern devices beyond Moore's Law. On-chip photonics applications will like-wise benefit greatly from the development of techniques for 3DI. The ability to integrate both electronic and photonic devices monolithically in controlled stacks provides a way forward to many new technology platforms in communications, sensing, and computing. Proper 3DI of CMOS circuitry would be enabled by the successive stacking of high quality single crystal silicon nanomembranes. For silicon photonic lightwave circuits, a similar requirement is held because of the losses which can be associated with grain boundaries in polycrystalline material and the losses associated with surface roughness.

An optical phased array was previously demonstrated within a silicon nanomembrane [1]. For interferometric lightwave circuits such as these, loss due to transmission can significantly degrade optical performance. We suggest a process flow (Figure 1) to allow the fabrication of several optical phased arrays with precision vertical as well as horizontal alignment for a 3DI photonic system. The process requires a "starter material" of a thin (230nm) Si nanomembrane on a thick SiO_2 film to provide otpical isolation from the handle wafer or neighboring lightwave circuits.

There are many ways to achieve this starter source and still utilize the same basic integration process. We undertook as study of the optical properties of the transferred nanomembranes fabricated via different techniques to determine the sufficient material properties to deliver the desired system performance. Table 1 shows the work various fabrication technologies undertaken and briefly notes the relative success for each. Deposited Si nanomembranes, whether amorphous or polycrystalline, were too lossy to provide sufficient guiding (Figure 2a). Layers transferred by ion-cut were again too lossy unless additional polishing was provided (Figure 2b). Specifically, the best starter material was determined to be commercially purchased ion-cut material because of the low surface roughness on the transfer layer (Figure 3).

This work is continuing with the assembly and testing of a multi-layer system from the best starter materials. Additionally, further quantification of the link between material properties of the starter material and the device performance of the photonic system is ongoing as well.

TABLE 1: Performance of Various Starter Materials

Technique	**Notes**
Deposited amorphous Si	Lossy and poor coupling
Deposited poly-Si by LPCVD	High transmission loss, large surface roughness
Deposited poly-Si by epitaxial deposition	Extremely high transmission loss, very large surface roughness
Anodically bonded ion-cut single crystal silicon	Lossy transmission
Fusion bonded single crystal silicon with CMP	Moderate loss, low yield of device due to bonding
Commercially purchased SOI	Lowest loss in coupling and transmission

References:

[1] D. Kwong, A. Hosseini, Y. Zhang, R.T. Chen, *1x12 Unequally spaced waveguide array for actively tuned optical phased array on a silicon nanomembrange*, Applied Physics Letters **99**, 051104 (2011).

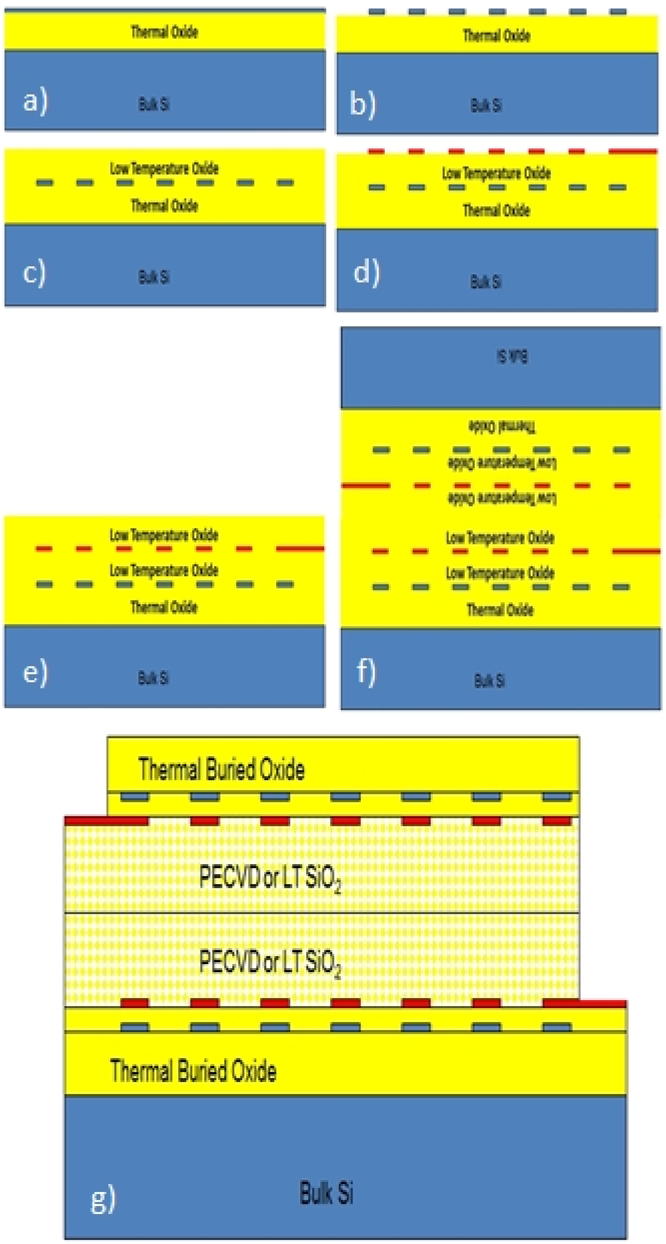

Figure 1: Process flow for fabricating a multi-layered photonic lightwave circuit. From (a) the initial starting material is patterned (b) to define the waveguides. Then (c) these waveguides are isolated optically by thick SiO_2 deposition. Next (d) metallic heater electrodes are patterned and (e) thermally isolated by thick SiO_2. Two system (f) are bonded together and then (g) one of backing wafers is removed by etching.

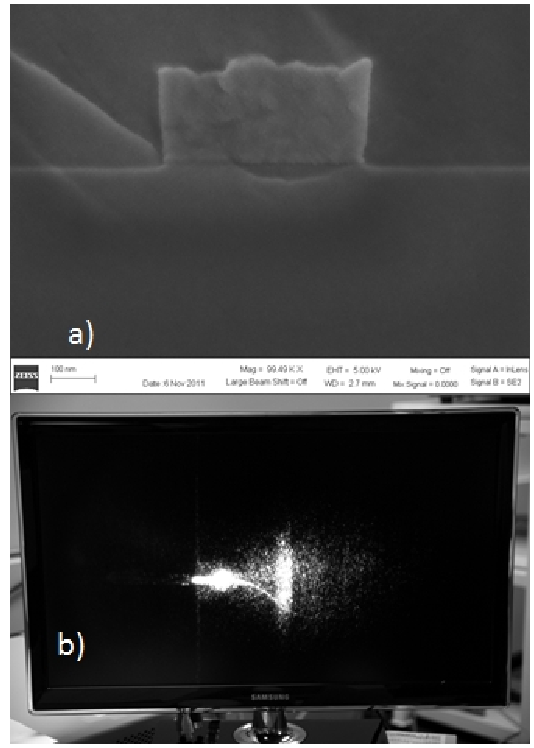

Figure 2: a) SEM of epitaxial deposited silicon nanomembrane and b) test lightwave circuit showing large transmission loss.

Figure 3: a) SEM of fusion bonded silicon nanomembrane and b) test lightwave circuit showing significant output and low loss.