Building Three-dimensional Nanostructures via Membrane Folding

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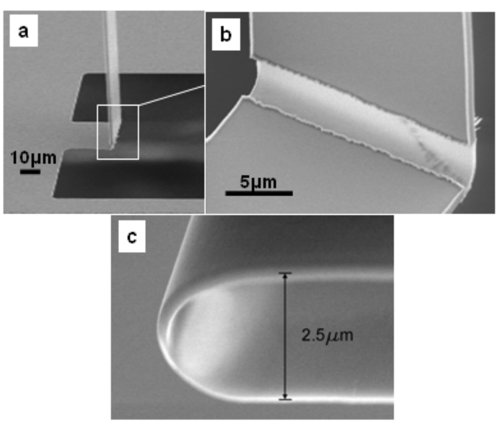
Nanostructured Origami [1] describes a method of fabricating three-dimensional (3D) nanostructures. Nanometer-scale structures are best fabricated with various two-dimensional (2D) lithography techniques. This project investigates the idea of patterning thin membranes in 2D and then folding them up into a 3D configuration. We have developed methods of both folding and aligning patterned silicon-nitride membranes.

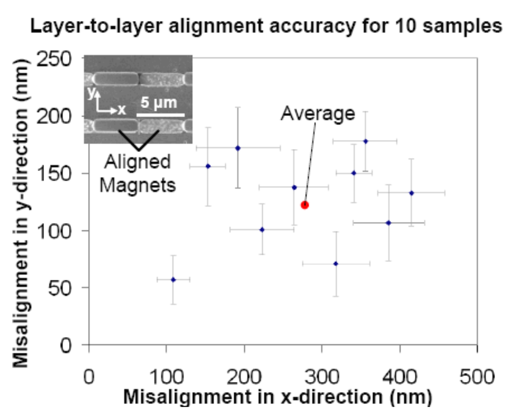
Ion implantation can be used to fold membranes. Membranes are implanted locally with a high dose to create a large stress. By varying the implanted ion energy, the implantation depth can be controlled and hence where the stress is generated. This depth control enables one to fold membranes either up or down. In our experiments, helium ions are used because they do almost no sputtering, do not damage the membrane and can be implanted to depths of 20 to 200 nm with low voltages (2-20 kV). Results are shown in Figure 1.

Magnetic forces can be used to both fold and align nanopatterned membranes [2]. Silicon nitride membranes of 1μm thickness and 100 μm×100 μm area were patterned with arrays of 75 nm thick cobalt nanomagnets. The membrane segments were then patterned and released from the substrate, making them free to rotate about compliant torsional hinges. Before folding, a 0.2 tesla external field magnetized the nanomagnets along their long axis. The field was then rotated 180º to create a magnetic torque to fold the membranes. This procedure resulted in the membranes completely folding over into a coarse layer-to-layer alignment of 2 μm.

After coarse alignment is achieved via folding, the nanomagnet arrays on the folded segments interact resulting in a very precise self-aligning force between arrays. Figure 2 shows the alignment results for folding ten samples. As shown in the plot, the magnet array interaction resulted in alignment error of roughly 200 nm. Therefore, the coarse alignment was reduced by a factor of ten. We modeled the dynamics and found that the alignment accuracy can actually be much better than the lithographic patterning accuracy. Therefore, this method may be useful for 3D nano-systems that need feature placement accuracy better than 20 nm, such as 3D nanophotonics, 3D integrated circuits, and 3D memory.



▲ Figure 1: a) A 600-nm SiN_x membrane folded to 90º. b) Magnified view of folded region, which was thinned to 150 nm by CF_4 RIE. The ion implantation was done at 16kV with a dose of 10^{18} ions/cm^2. c) View of a 180º fold illustrating typical fold radius of about 1μm.



▲ Figure 2: The layer-to-layer alignment error for 100μm ×100μm ×1 μm SiN_x membranes that were folded and aligned using arrays of nanomagnets and an external magnetic field.

REFERENCES

[1] H.J. In, W.J. Arora, T. Buchner, S.M. Jurga, H.I. Smith, and G. Barbastathis, “The nanostructured Origami/sup TM/3D fabrication and assembly process for nanomanufacturing,” in *Proc. 4th IEEE Conference on Nanotechnology,* Aug. 2004, pp. 358-60.

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