

# Fabrication of hierarchical nanostructures using free-standing tri-layer membrane

Ke Du, Yuyang Liu, Ishan Wathuthanthri, Chang-Hwan Choi  
*Department of Mechanical Engineering, Stevens Institute of Technology,  
Hoboken, NJ, 07030, USA  
cchoi@stevens.edu*

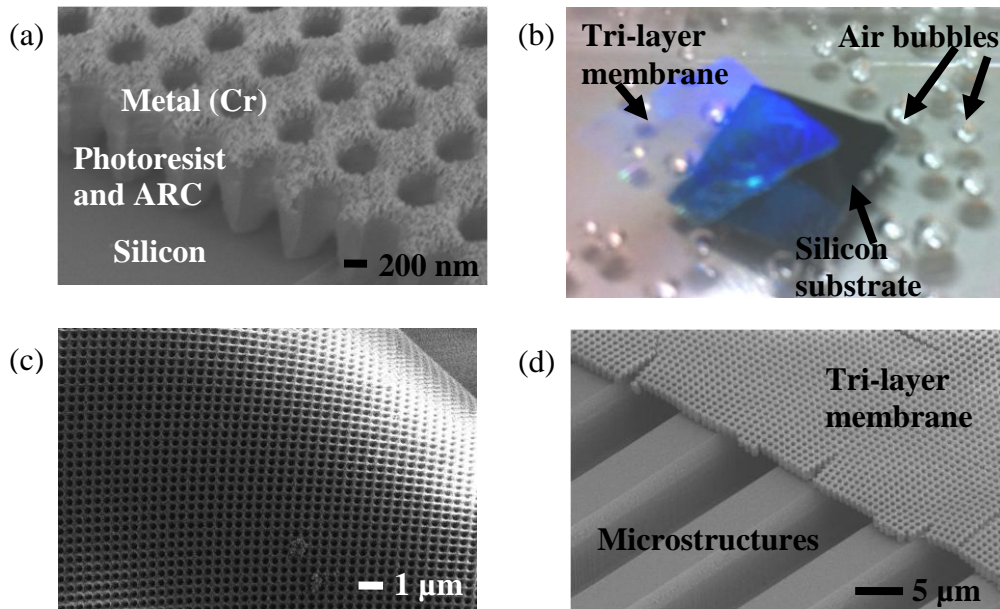
Traditionally, hierarchical nanostructures were fabricated by spinning resist and patterning on pre-patterned micro- or nano-structures [1]. However, such methods result in poor coverage when patterning on high-aspect-ratio micro- or nano-structures. In this work, we report a new fabrication method which can make hierarchical nanostructures even on high-aspect-ratio pre-patterns, using a free-standing tri-layer membrane comprised of metal and resist films as a versatile mask and stencil for robust and uniform pattern transfer including etching and deposition processes.

First, the nano-porous tri-layer membrane of composite films consisting of metal/resist/anti-reflective coating (ARC) is created on a polished silicon wafer by using laser interference lithography, reactive ion etching (RIE) etching, and e-beam deposition (Figure 1a) [2]. Then, a customized solution of mixture of  $\text{NH}_3$ ,  $\text{H}_2\text{O}_2$  and  $\text{H}_2\text{O}$  is used to release the membrane from the silicon substrate (Figure 1b) [3]. The free-standing membrane (Figure 1c) is then transferred on pre-patterned silicon microstructures (Figure 1d), showing no major defects on the membrane surface. The flexible and soft tri-layer membrane allows uniform and good contact to the top surface of pre-patterns. Thus, it can further be utilized as a robust etch mask in etching process. Figures 2a-b show the hierarchical nano-hole structures fabricated on the micro-grating pattern by using the tri-layer membrane as an etch mask in deep reactive ion etching (DRIE) of silicon. Since the membrane covers the top surfaces of microstructures seamlessly, no “blur” phenomenon is observed during the etching process. The membrane can also be used as a stencil for deposition process. For example, metal can be deposited through the nano-porous membrane and the membrane can be removed by lift-off process. Then, the retained metal nano-dot patterns can further be used as etch mask in DRIE process to achieve high-aspect-ratio hierarchical nano-pillar structures on the pre-patterned microstructures of silicon (Figures 2c-d).

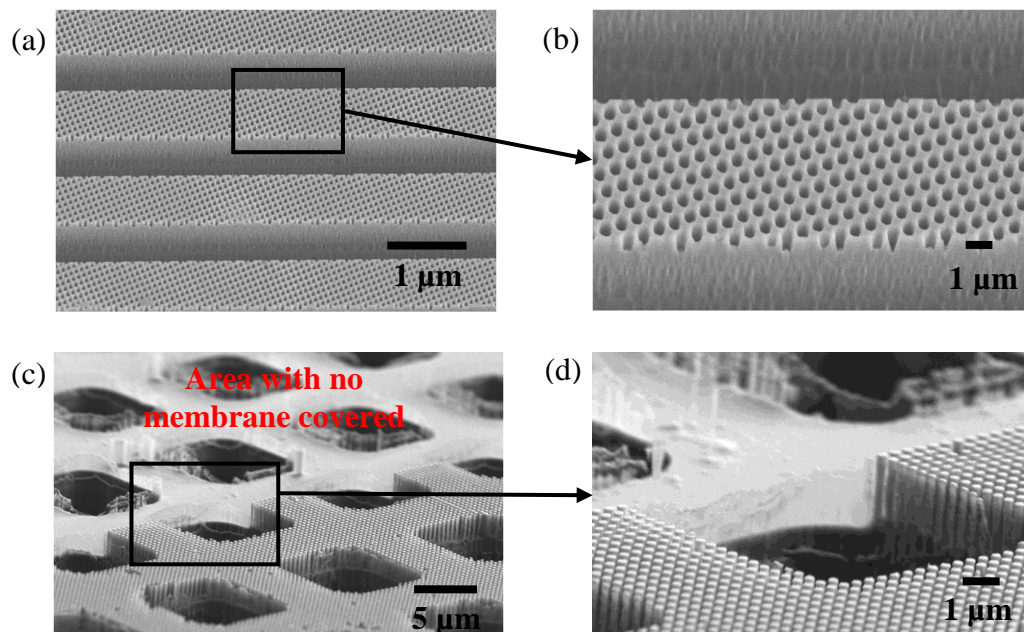
Compared to conventional methods to fabricate hierarchical nanostructure, the introduced new approach is more reliable to realize large-area hierarchical nanostructures with a good uniformity. The hierarchical nanostructures made by this technique will advance many scientific and engineering applications including micro/nano-fluidics, dry adhesion mechanisms, self-assembly of nano-materials, and anti-reflective surfaces.

## References

- [1] Y. Yang *et al.*, *Appl. Surf. Sci.*, 256, 3683, 2010.
- [2] K. Du *et al.*, *Nanotechnol.*, 22, 285306, 2011.
- [3] K. Du *et al.*, *J. Vac. Sci. Technol. B*, 30, 06FF04, 2012.



*Figure 1:* (a) Scanning electron microscope (SEM) image of the tri-layer membrane (Cr/photoresist/anti-reflective coating) fabricated on a silicon substrate. (b) Optical micrograph of the tri-layer membrane released off from the silicon substrate in a mixture solution of  $\text{NH}_3/\text{H}_2\text{O}_2/\text{H}_2\text{O}$ . (c) SEM image of the free-standing tri-layer membrane. (d) SEM image of the tri-layer membrane transferred onto the microstructures of silicon.



*Figure 2:* (a-b) SEM images of hierarchical nano-hole structures fabricated on the pre-patterned micro-grating structures of silicon. (c-d) SEM images of hierarchical nano-pillar structures fabricated on the pre-patterned micro-hole structures of silicon.