**Latest advances in nanostenciling**

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Three-dimensional (3D) and organic electronics, plasmonic sensors, and some niche applications have recently demonstrated that stencil lithography (SL) is a reliable contender for parallel, resist-free, low-temperature nanopatterning. The sub-100 nm minimum stencil aperture size can be translated into high-resolution patterns across full 100 mm wafers. Organic and non-organic materials can be evaporated through the stencil on a variety of substrates. Stencils can be used as masks not only for deposition, but also for etching through or ion implantation.

Enhancing the reliability and performance of SL at sub 100 nm scale is actively pursued. The main bottleneck for improving uniformity across large patterned areas with a standard stencil is the gap between stencil and substrate. For example, a gap varying between 5-30 μm across a 100 mm wafer, which is the average value for mechanically clamped stencil and substrate, can result in a loss of pattern resolution varying between 50 to 300 nm. Recent research demonstrated that by using membranes that comply with the wafer curvature/topography, the pattern distortion decreases by up to 95%.[1]

In standard SL, the deposited pattern aspect ratio is limited to about 1:1. The material is deposited both on the substrate and on the stencil apertures sidewalls, leading to a gradual stencil clogging. A novel approach uses an integrated local heater which prevents the material accumulation around the apertures during the evaporation. In dynamic SL, where the stencil moves relative to the substrate during the patterning process, the heated stencil can now be continuously used in-situ for longer periods of time, opening avenues to new applications.[2]

Efficient nanopatterning on 3D substrates is still a challenge. E-beam lithography, e.g., is limited by the possibility to spin a uniform thin film of resist across the sample. SL was successfully used to evaporate catalysts through nanoapertures on top of a 100 mm wafer of semi-released cantilevers.[3] The catalysts were used to grow silicon nanowires or carbon nanotubes at the apex of the cantilevers, providing thus ideal scanning probes for atomic force microscopy of high aspect ratio structures at the sub-micrometer scale.

Label-free biosensing of molecules using localized plasmon resonance in metallic nanostructures has high sensitivity and is stable. In order to be cost-efficient, high through-put and versatile nanopatterning techniques are investigated. Here too, SL proved its potential as a resist-free technique with patterning capabilities down to 50 nm.[4]

Stencil lithography at the sub-micrometer scale is proving thus a leading emerging technology for new applications in sensing, metrology, and electronics.

[1] K. Sidler *et al.*, Nanoscale **4** (2012).
[2] V. Savu, S. Xie, and J. Brugger, Nanoscale **3**, 2739 (2011).
[3] D. S. Engstrom *et al.*, Nano Lett. **11**, 1568 (2011).
[4] O. Vazquez-Mena *et al.*, ACS Nano **5**, 844 (2010).

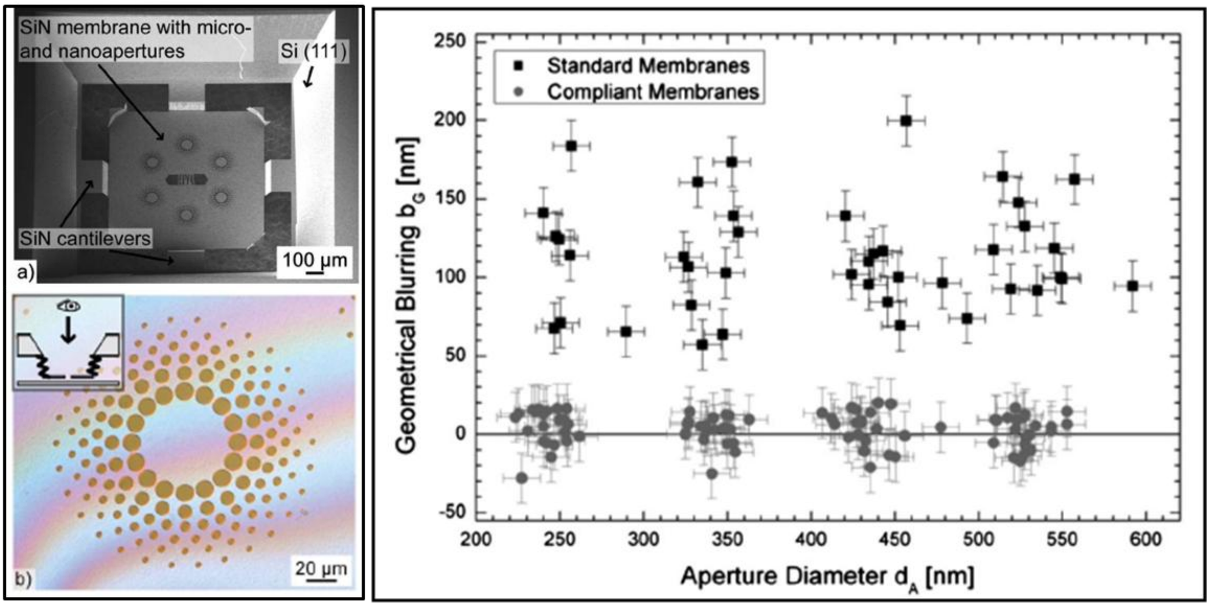


*Figure 1: Compliant membranes improve resolution in stencil lithography:* left) images of compliant membranes that reduce the stencil-substrate gap, and right) pattern distortion eliminated by the use of compliant membranes on flat Si substrates [1].

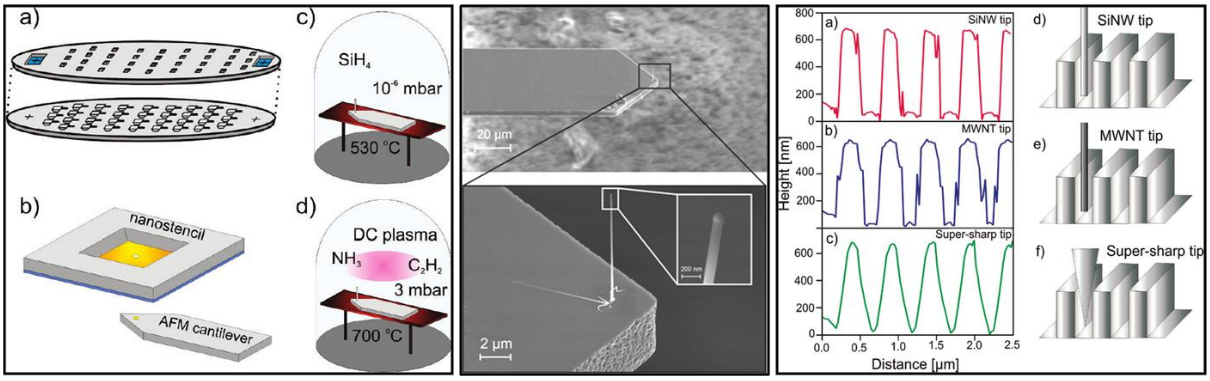


*Figure 2: Silicon nanowire (Si NW) and carbon nanotube scanning probes grown from catalysts deposited through nanostencil on semi-released cantilevers:* left) fabrication schematic, center) Si NW probes, and right) comparison of AFM scans [3].

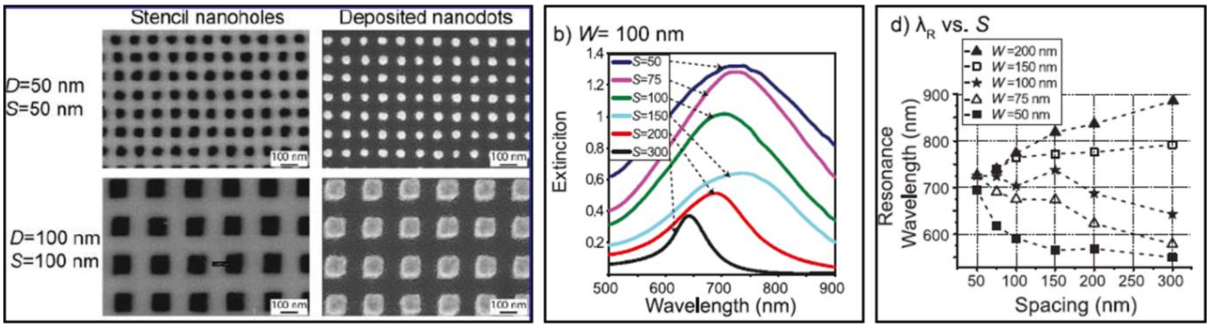


*Figure 3: Plasmonic arrays fabricated with nanostencil:* left) SEM images of stencils and resulting structures on Si substrate, center) extinction spectra of 100 nm size nanodots as a function of spacing, and right) resonance wavelength behavior with nanodot spacing [4].