Drawing with Nanostencils on Flexible Substrates

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Stencil lithography is a technique enabling nanopatterning without using a chemical, mechanical, or thermal load on the substrate.[1] Flexible substrates benefit most from these advantages, as many of them cannot withstand standard processing conditions. The process is also parallel and cost-efficient, as material is evaporated through re-usable nanoapertures fabricated in membranes spread across a full wafer (stencil).In the dynamic mode, the stencil is moving during the evaporation, the pattern being the convolution of the trajectory with the aperture design (Fig. 1a).[2, 3] This work demonstrates two-dimensional (2D) patterning on flexible substrates using dynamic nanostencils at full-wafer scale.

The full 100 mm wafer stencils had 100-500 nm thick low-stress SiN membranes, whose apertures were patterned by optical and electron-beam lithography. Some of the substrates used were Si for bench-marking, parylene C, and polyimide (PI). On one hand, the relative motion between the substrate and the stencil requires the existence of a gap between the two. On the other hand, a large gap induces a lack of pattern resolution due to blurring.[4] Thus, for all experiments, we chose the minimum gap for which the two wafers were moving independently (usually 100 μm). The material was Al evaporated at 0.5-2 A/s while the stencil was moved with speeds between 40-120 nm/s.

A stencil with holes having diameters between 0.2-2 μm was used for the parylene-C and Si substrates. On Si the 2D actuation of the stencil resulted in continuous patterns corresponding to apertures as small as 200 nm in diameter (Fig 1b,c). On parylene patterns corresponding to below 1 μm diameter apertures were detected by AFM, with their thickness depending on the deposition rate (Fig.2b,c). On PI, square openings created variable-thickness structures, a convolution of the motion and the square's dimensions (Fig 2c). The height of the structures is modulated by their lateral size, decreasing with a smaller aperture as the zone under the opening sees only a fraction of the source (Fig 3).

Thus, the first nanopatterns were created by dynamic stencil lithography at full 100 mm wafer scale. Further research is currently focusing on parameter optimization for various materials and substrates and device integration.

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[2] V. Savu *et al.*, J. of Vacuum Science & Technology B **26**, 2054 (2008).
[3] J. L. Wasserman *et al.*, Rev. Sci. Instrum. **79**, 4 (2008).
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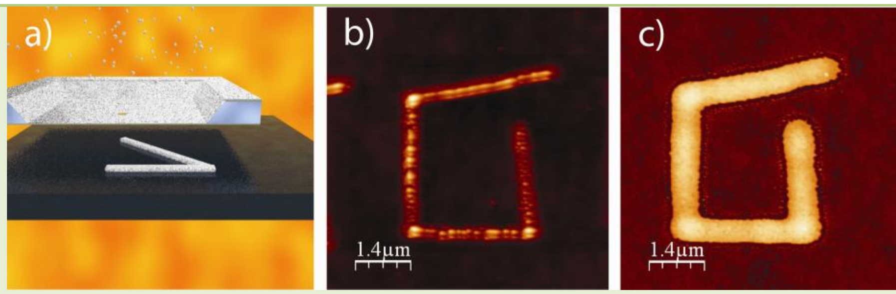

Figure 1: **a) Schematic of dynamic stencil lithography - the stencil moves relative to the substrate during material evaporation; AFM scans of Al deposited on Si through a b) 200 nm, and c) 600 nm diameter moving hole**

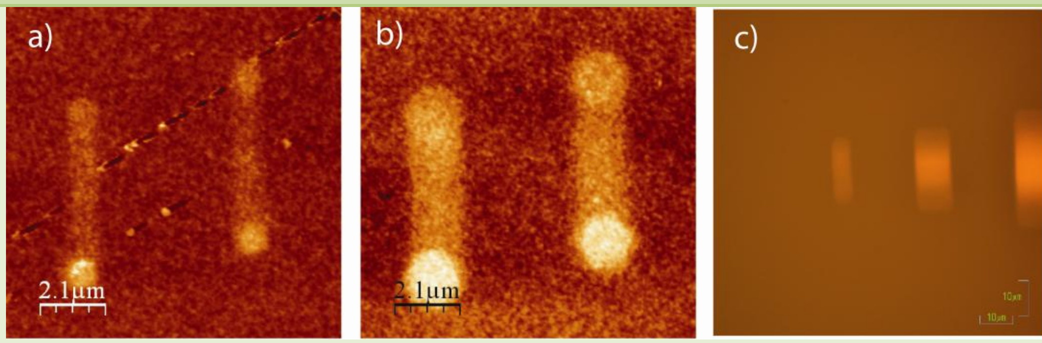

Figure 2: **Patterns obtained on a) parylene through a 1.0 μm hole, and b) parylene through a 1.8 μm hole (AFM scans) and b) polyimide through a 5 μm square (optical image)**

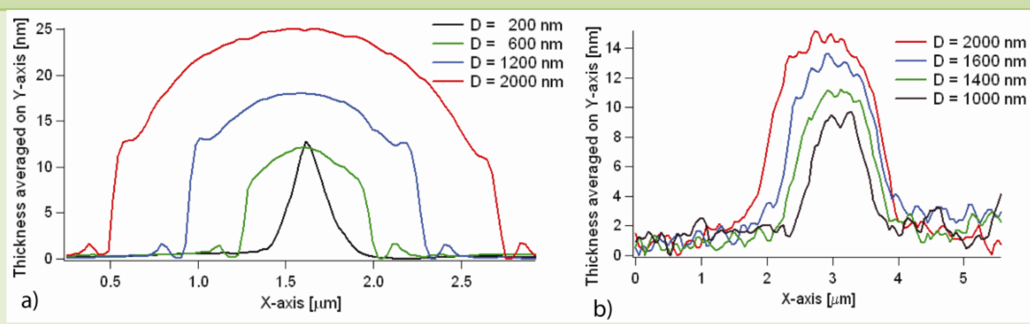

Figure 3: **Thickness modulation by aperture's lateral size for patterns a) on Si from Fig. 1 and b) on parylene from Fig. 2; the narrower the opening, the thinner the deposited structure**