# Flexible Membranes Improve Resolution in Stencil Lithography

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Stencil lithography (SL) is a shadow mask technique, in which a solid mask with apertures is used to locally pattern a surface. This method can, for example, be applied with thin-film deposition, plasma etching or ion implantation through the apertures in the mask. The use of SL avoids resist coating, baking of the wafers and exposure to chemicals which makes it suitable to pattern fragile substrates. In addition, SL has demonstrated to be a valid technique for patterning nanometric structures [1-3] and useful for various applications [4, 5].

A remaining challenge in SL is the so-called blurring, i.e. the enlargement of the transferred structures on the substrate compared to the apertures in the stencil (Figure 1a). It is documented that the blurring depends on the gap between the stencil and the substrate [6]. Due to the non-planarity of stencil and substrate, the gap is unavoidable with a mechanical clamping configuration. We propose a solution to this issue based on a stencil with protruding membranes which are mechanically uncoupled from the Si frame of the stencil wafer (Figure 1b) [7]. We now present new results with further improved resolution including a detailed system study.

The fabrication of these stencils starts with a 100 mm Si wafer coated with 200 nm SiN. Squares of SiN were left on the wafer after photolithography and subsequent dry etching. The wafer was exposed to KOH to define 40 µm high mesa structures (Figure 2a). The SiN mask was removed by HF etching and a 500 nm thick low stress SiN film was deposited by LPCVD (Figure 2b). Backside openings for the final etching in KOH were then defined (Figure 2c). The front-side was patterned using a 14 µm thick resist layer followed by dry etching. The membrane supporting cantilevers on the KOH defined slope and the membrane apertures on top of the mesa structures were patterned (Figure 2d). Finally, a backside etching in KOH released the membranes from the bulk Si (Figure 2e). After releasing, nanoapertures were defined on several membranes by focused ion beam milling (FIB) (Figure 2f, 3a).

A 50 nm thick aluminum film was deposited by e-beam evaporation through the stencil mechanically clamped to a flat Si wafer. SEM inspection revealed that the approach to the substrate deflects the decoupled membranes (Figure 3b) but not the coupled ones, in-plane with the Si frame. This proves that the flexible membranes were protruding enough to overcome the stencil-substrate inherent gap. Subsequently, the stencil was removed leaving the pattern on the Si wafer.

The aluminum structures on the substrate present a central thick part corresponding to the membrane apertures plus a lateral thinner part which can be divided into geometric factor (geometric blurring GB) and a very thin halo (H) around it. Careful inspection showed that both blurring contributions were minimized by the use of compliant membranes as compared to standard membranes (Figure 4).

Our results prove a compliant stencil reduces the blurring as it conforms the stencil membrane to the surface and it minimizes the gap between stencil and substrate. Thus by using a compliant stencil, sub-micrometer SL becomes a reliable patterning technique on full-wafer scale.

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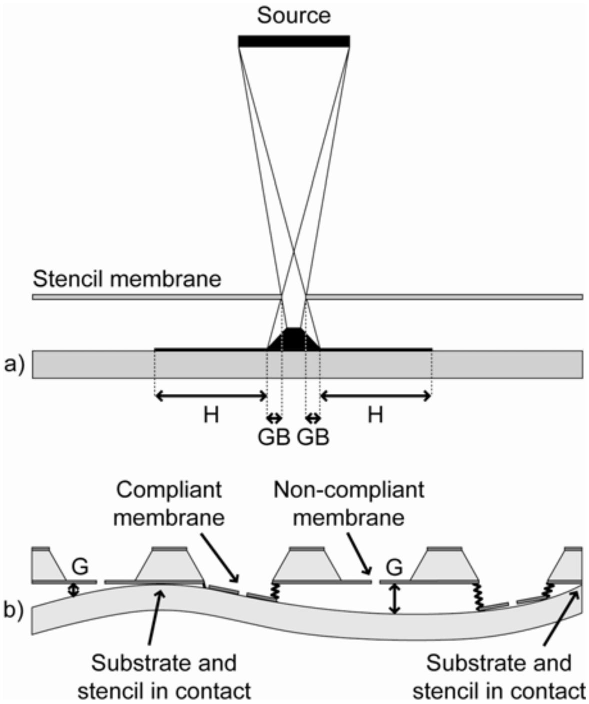


Figure 1 a) Structures patterned by stencil lithography are, compared to the stencil membrane aperture, enlarged due to a geometrical blurring GB and a thin halo H. b) The blurring is determined by the stencil and substrate curvature which results in a gap G of several µm to tens of µm. In a compliant stencil configuration, the gap and therefore the blurring are minimized due to mechanically uncoupled membranes. Not drawn to scale.

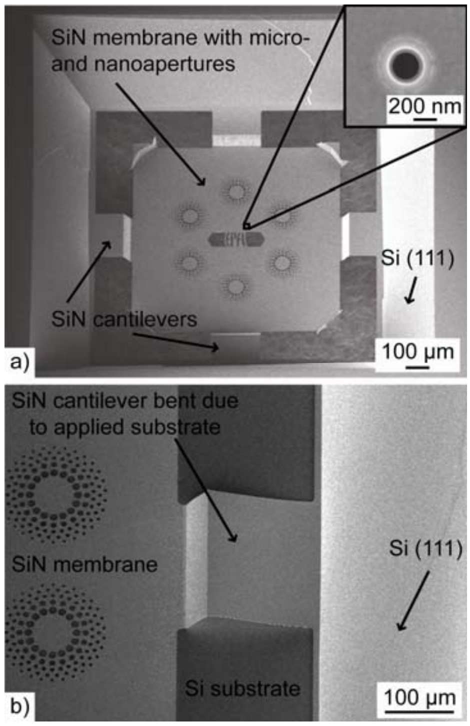


Figure 3 a) SEM micrograph of a compliant stencil shows the backside of a membrane with micro- and nanoapertures. The freestanding SiN membrane is decoupled from a rigid Si frame by four SiN cantilevers. Inset: SEM micrograph of a nanoaperture in a low stress SiN membrane. The nanoaperture was defined using FIB. b) SEM micrograph of a deflected beam of a compliant stencil membrane in contact with a Si wafer.

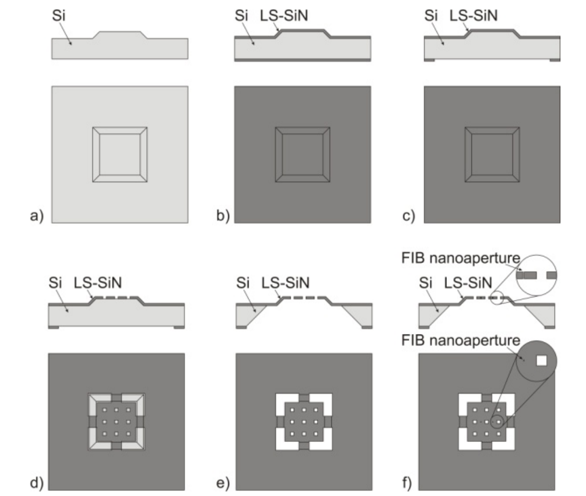


Figure 2 Schematic side and top view of the process flow for a compliant stencil. The process starts with a 10 mm Si wafer on which non-planar SiN beams and microapertures are defined by UV lithography. After the release of the membranes by KOH, nanoapertures were defined by FIB.

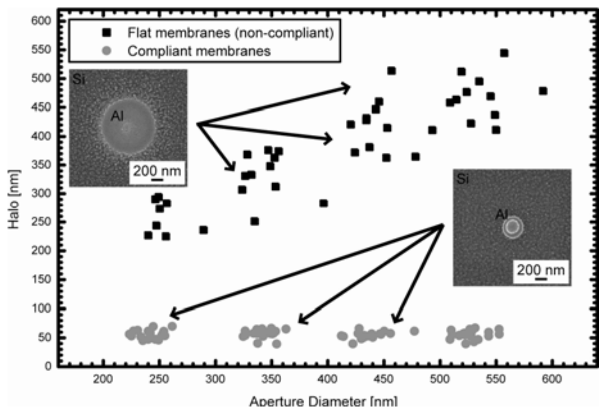


Figure 4 Graph comparing the halo due to surface diffusion obtained from standard membranes and from compliant membranes. A reduction in size can be observed in all the cases. Insets show SEM micrographs of 50 nm thick aluminum structures deposited through standard and compliant membranes.