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# Corrugated membranes for improved pattern definition with micro/nanostencil lithography

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**Abstract**

We present a MEMS process for the fabrication of arbitrary (adaptable to specific aperture geometries) stabilization of silicon nitride membranes to be used as miniature shadow masks or (nano) stencils. Stabilization was realized by the fabrication of silicon nitride corrugated support structures integrated into large-area thin-film solid-state membranes. These corrugated support structures are aimed to reduce the membrane deformation due to the deposition-induced stress and thus to improve the dimensional control over the surface patterns created by stencil lithography. We have performed physical vapor deposition (PVD) of chromium on unstabilized (standard) stencil membranes and on stabilized (corrugated) stencil membranes to test the proposed stabilization geometry. Both the membrane deformation and the surface structures were analyzed, showing reduced deformation and improved pattern definition for the stabilized stencil membranes. The structures have been modeled using a commercial finite element method (FEM) software tool. The simulation and experimental results confirm that introducing stabilization structures in the membrane can significantly (up to 94%) reduce out-of-plane deformations of the membrane. The results of this study can be applied as a guideline for the design and fabrication of mechanically stable, complex stencil membranes for direct deposition.


*Keywords:* Shadow mask; Nanostencil; Stress-induced deformation; Mechanical stabilization; Local deposition; FEM modeling

## 1. Introduction

An increased demand for micro- and nanometer scale patterning on “unconventional” surfaces and/or non-IC applications has given rise to new and alternative patterning technologies. These new methods include: indentation of polymers by nanoimprint lithography (NIL) [1,2], local deposition of molecules via a stamp by microcontact printing (μCP) or soft-lithography [3,4], or via dip-pen nanolithography (DPN) [5], nanoscale fluidic dispensing (NADIS) [6] and localized material deposition through ultra-miniature shadow masks (nanostencils) [7–10]. The stencil method has the advantage of being a direct vacuum patterning technology, i.e. a controlled amount of material is directly deposited through the stencil apertures without the need for cyclic processing steps used in, for example, resist-based photolithography. An additional advantage of stenciling over other patterning methods is its possible non-contact application avoiding cross-contamination or surface damage in case of fragile surfaces, whereas, for example, NIL relies on a hard contact and μCP on a soft contact to transfer the patterns successfully. Recently, we have introduced a process for the fabrication of micro/nanostencils (containing 1 mm × 1 mm membranes) on a full wafer scale (100 mm) using a combination of a DUV exposure tool and standard MEMS processing [11]. This type of stencil allows for direct, resistless patterning of mesoscopic surface structures (200 nm up to several 100 μm) at a full wafer scale.

The deposition through stencils suffers, however, from drawbacks such as clogging of apertures and membrane deformation due to the deposition-induced stresses. Clogging occurs when the evaporated material accumulates on top and inside the membrane apertures. This phenomenon changes the shape of the aperture during the deposition process and leads to a distortion of the deposited pattern, eventually resulting in the complete clo-

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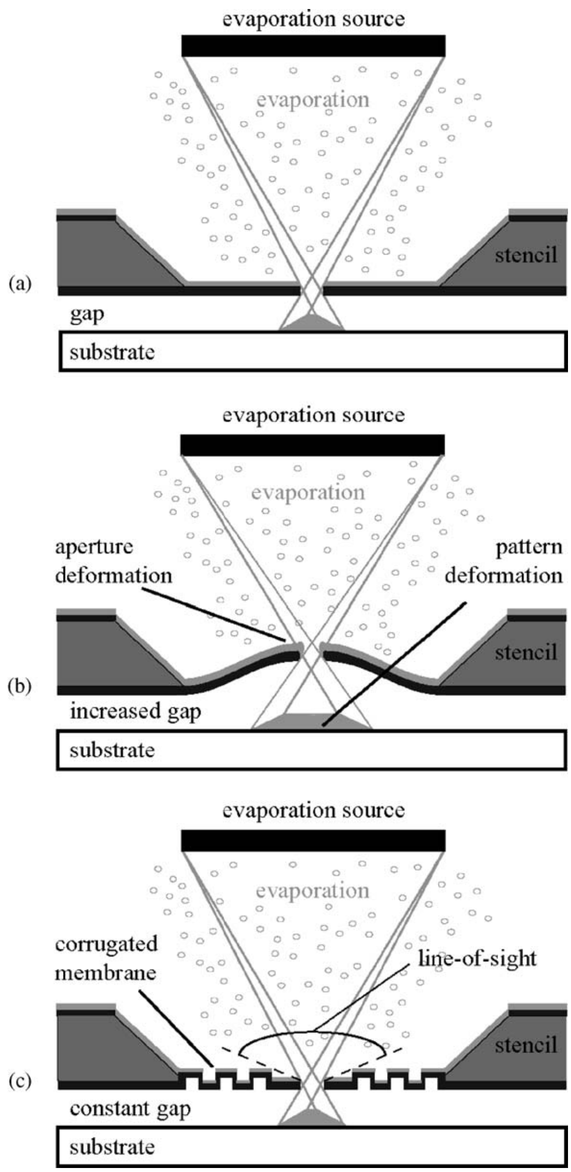



Fig. 1. Schematic representation of a stencil membrane in close proximity of a substrate during evaporation. (a) Ideal stencil deposition. The membrane remains "static" and does not add to pattern deformation. (b) Realistic situation during stencil deposition. The deformed membrane has both an increased gap and aperture deformation resulting in pattern deformation. (c) Deposition through a corrugated stencil. The membrane is locally supported; thus, the membrane deformation and pattern blurring are reduced.

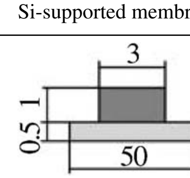
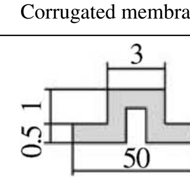
sure of the aperture. Membrane deformation results from high levels of in-plane residual stresses caused by the accumulation of the deposited material on the stencil membrane. Since these stencil membranes can contain arbitrary apertures specified by the need for specific surface patterns, the membrane deformation can locally be more severe, resulting in aperture distortion and an increased gap between the substrate and the stencil. This leads to pattern deformation and blurring, i.e. reduced sharpness of edges and limited spatial detail (Fig. 1b).

Residual stresses in MEMS structures arise typically from thin film deposition. These stresses can be of a various nature. When a film on a substrate is subjected to a temperature change during the evaporation, differences in thermal expansion coefficients of the two materials (in this case: film and membrane) result in a thermal stress $\sigma_{\text{th}}$ [12]. All other stresses developed during thin-film deposition fall in the category of intrinsic stress $\sigma_{\text{int}}$. Various physical factors responsible for the intrinsic stress of thin films have been studied [13,14]. The difference in thermal expansion coefficients and the lattice spacing mismatch are thought to be the dominant sources of deposition-induced stress causing a substantial deformation of micromachined bi-layered structures.

## 2. Design and fabrication of corrugated stencil membranes

To overcome or minimize the effects of membrane deformation, we have developed a concept in which we mechanically reinforce and thus stabilize the membrane, exploiting an earlier idea presented by Hammer [15]. The improved micro/nanostencils incorporate in situ, local stabilization structures increasing their moment of inertia, *I*, which is the structural property directly related to stiffness or deformability. The stabilization is realized by using a corrugated membrane instead of a planar membrane. Table 1 summarizes cross-sections of three different designs of thin cantilevers (unstabilized, silicon supported and corrugated) with there corresponding *I* values. It is noteworthy that a single 1-μm stabilization rim/corrugation results in a four-fold increase of *I* with respect to that of the unstabilized (planar) membrane. This increase of *I* can be achieved with only one additional fabrication step with respect to the stencil fabrication process of planar membranes. The fabrication of Si-supported membranes, however, requires more elaborate processing [16] in order to obtain a similar increase in *I*.

Table 1
Cantilever cross-sections and their corresponding moment of inertia

| | Unstabilized membrane | Si-supported membrane | Corrugated membrane |
|---|---|---|---|
| Cross-section [μm] |   |   |   |
| Moment of inertia [$\mu m^4$] | 0.52 | 1 rim: 2.88<br>2 rims: 4.73<br>3 rims: 6.25<br>4 rims: 7.53 | 1 rim: 2.05<br>2 rims: 3.36<br>3 rims: 4.47<br>4 rims: 5.41 |