Three-Dimensional Sacrificial Etching

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Abstract

In MEMS fabrication micro-mechanical components have to be partially released from a substrate. Selectively etching away sacrificial layers, such that a free standing structure remains, is a widely used technique for this purpose. Free standing structures allow MEMS devices to induce or to sense mechanical movements or vibrations.
During sacrificial etching lower etch rates than the blanket ones are observed. This reduction can be explained by additional factors like the transport of the etch medium and its etch reactants via the relatively narrow (in relation to the etch depth) already etched channel under the free standing structure.
Sacrificial etching is mainly controlled by process parameters like the etch agent concentration, chamber temperature, and pressure. Furthermore, local geometrical features and the nature of chemical reactions are responsible for different etch speeds at material boundaries and, therefore, they influence the propagation of the etch front. In order to analyze these effects we have developed a three-dimensional topography simulation tool and the required models for the etch rates.

1 Modeling

During etching the surface of the etched material forms an interface to the chemical solution, where the reactions take place [1]. Depending on involved materials and acid concentrations, locally varying etch rates determine the evolution of the etch front. These etch rates are interpreted as the speed function F of a three-dimensional level-set calculation [2]:

$$F\,|\nabla\Phi(\vec{x},t)| = -\frac{\partial\Phi(\vec{x},t)}{\partial t}, \tag{1}$$

where $\Phi(\vec{x},t)$ represents the level-set function. This differential equation delivers the evolving boundary, which is the etch front, for all points $\vec{x}$ that satisfy $\Phi(\vec{x},t) = 0$ at time t [3].

2 Material Transport

In the most simple case, the transport of the etch agent can be described by a diffusion process governed by the etchant concentration in the reactor. With the assumption that the system reacts in a quasi-static way, the transient processes $\partial/\partial t$ can be neglected, which results in the Laplace equation:

$$\triangle c(\vec{x}) = 0 \qquad \text{for } \vec{x} \text{ inside the etchant domain,} \tag{2}$$

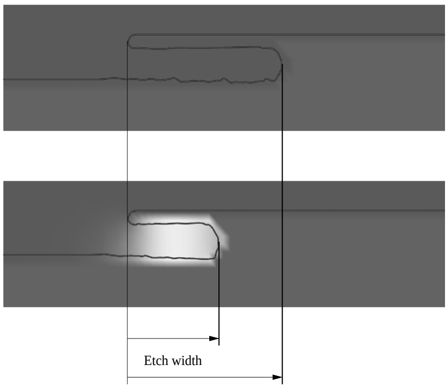

Figure 1: Lateral cut, with and without inclusion of the etchant transport.

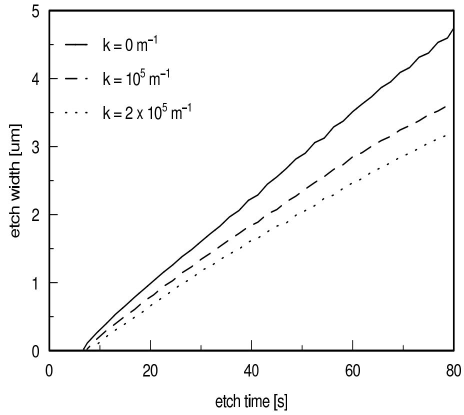

Figure 2: The etch width in dependence of the etch time for different surface factors k.

where $c(\vec{x})$ describes the concentration of the etch agent. The boundaries to the etched materials represent the boundaries of the diffusion process. Accordingly, this boundary condition can be written as an out-flux J_{HF} of the etchant

$$\frac{\partial c(\vec{x})}{\partial \vec{n}} = \nabla c(\vec{x}) \cdot \vec{n} = \nabla c(\vec{x}) \cdot \frac{\nabla \Phi(\vec{x})}{|\nabla \Phi(\vec{x})|} = -J_{\mathrm{HF}}(c(\vec{x})), \tag{3}$$

which depends on the etchant concentration. Different bases for the out-flux $J_{\mathrm{HF}}(c)$ can be found in [4, 5], for instance. The out-flux $J_{\mathrm{HF}}(c)$ is proportional to the etch speed F, given by

$$F = -\frac{\Delta\delta}{\Delta t} = -6\,J_{\mathrm{HF}}\,\frac{1}{\rho_{\mathrm{SiO_2}}} \tag{4}$$

for etching SiO_2. The consumption of etchant on this boundary dilutes the acid concentration itself, resulting in a locally lowered etch speed.
Fig. 1 shows a lateral cut through a simulated structure. During etching the front has moved forward under a resistant layer. The upper and lower simulation results show the etch front with and without accounting for the diffusive transport at some snapshot. In Fig. 2 a comparison of the etch depth over time is shown with a base of $J_{\mathrm{HF}}(c) = k\,c$ for three different parameters k.

3 Simulation Example

A typical situation before sacrificial etching is illustrated in Fig. 3. The oxide has to be removed to release the polysilicon cantilever from the substrate. Additionally, the oxide layer is surrounded by a PECVD layer which has approximately $1/100$ the etch speed of the oxide.
Fig. 4 shows the etch front after some time. The oxide layer has been attacked from the top and a slight lateral underetch of the cantilever can be seen. The PECVD layer is almost untouched.

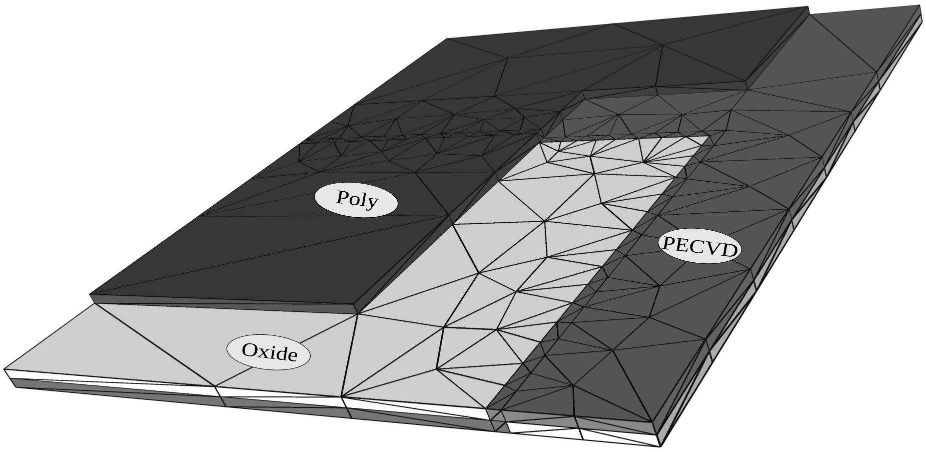

Figure 3: Initial material configuration of a cantilever structure for sacrificial etching. The materials Oxide and PECVD are etched away. Oxide is etched 100 times faster than PECVD.

At the end of the simulation, as shown in Fig. 5, the oxide layer has been completely removed and the exposed region of the PECVD layer has been etched away, too.
Finally, Fig. 6 shows the resulting structure converted back to a volume mesh. In the regions under the polysilicon layer an underetch of the PECVD layer can be observed. Two additional layers, a tungsten and a LPCVD layer, are bared.

4 Outlook

We have shown the simulation of sacrificial etching on a quite complex structure. The inclusion of effects caused by adhesive attraction of the etchant atoms to the underlying materials are particular model improvements. This attraction reduces the transport of the etch medium and, therefore, lowers the etch speed.

References

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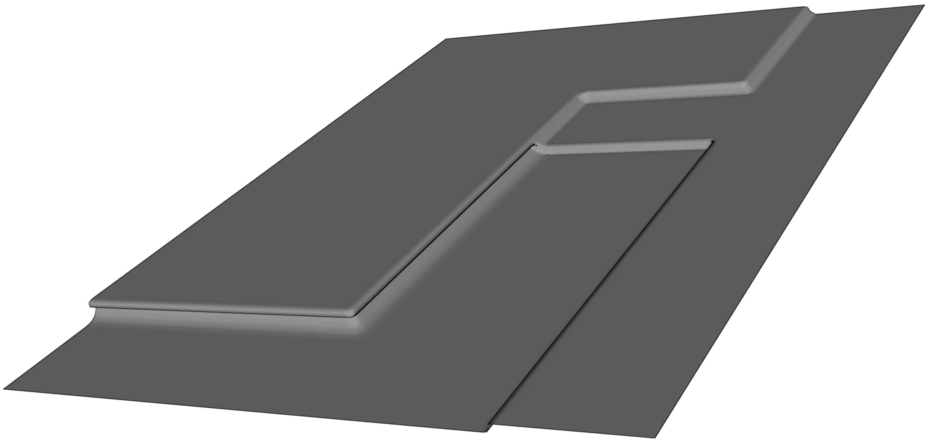

Figure 4: Oxide is already etched to the bottom layer and a smart underetch can be identified.

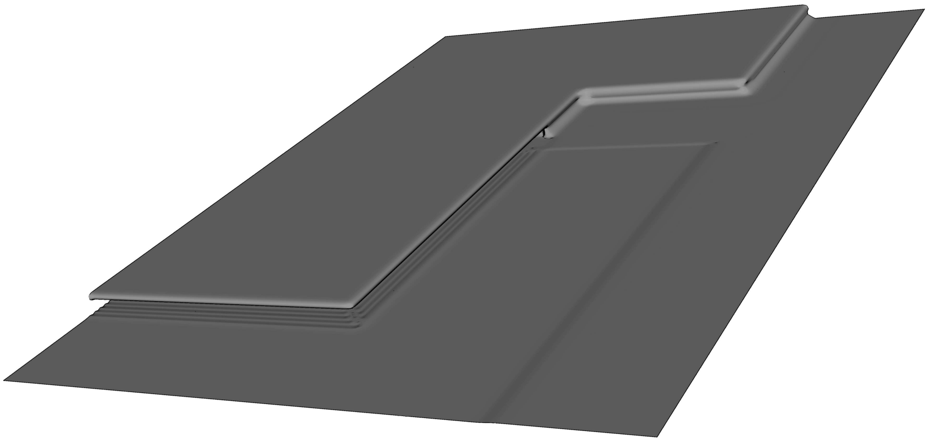

Figure 5: Reaching the final simulation time, Oxide and the exposed PECVD part are totally removed.

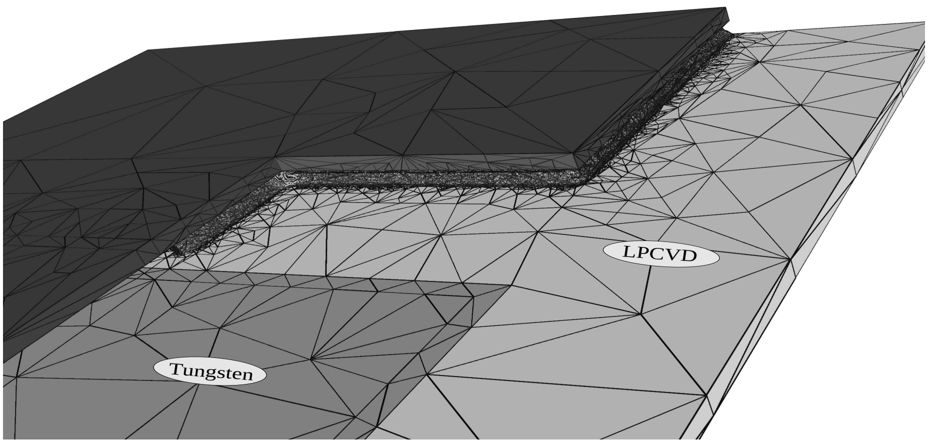

Figure 6: Finally, a volume mesh representation is reconstructed. The underetch of the LPCVD layer can be observed.