

# Dynamic Simulation of Electrochemical Etching of Silicon with COMSOL

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## Abstract

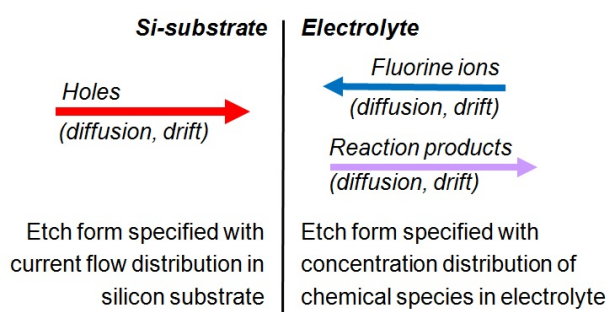
Introduction: Electrochemical etching of silicon (so-called anodization) is a process that can be used for etching of 3D-forms of nearly arbitrary shapes into the bulk silicon. However, as electrochemical etching depends on many parameters influencing the process, such as electrolyte concentration and temperature, silicon substrate doping and type [1], this process has not been transferred to mass production yet. COMSOL as a FEM simulation tool is very suitable for the modeling of this complicated multiphysics process. In the presented work the typical etch form development observed in the anodization process is modeled. The chemical reaction of the process requires supply of positive charges from silicon substrate (holes) and fluorine ions from electrolyte to the reaction site [1]. By altering supply of these reaction components, etch rate can be influenced and structures of various forms can be etched [2]. In the presented work a simple case of a frontside insulating masking layer of silicon nitride with a single, isolated opening in it is considered. As our experiments show, such masking layer will produce the edge effect in the beginning of the etching process, resulting in a convex shape (Figure 1a). During further etching, the etch form might transform into concave (Figure 1b) [2]. There are two mechanisms which can explain this shape conversion in the anodization process. First, the specific current density distribution in silicon provides the formation of convex shape at the beginning of the process, because current flow at structural edges (to masking layer) is considerably larger than flow in the center of the opening (Figure 2a, left). When structures get deeper (the distance to the backside of the wafer reduces), in case of electrolyte with the same conductivity as the substrate, the flow of current from beneath the structure increases because of the lower path resistance and leads to a more concave shape formation (Figure 2a, right). The second mechanism is based on consideration of transport of chemical species in the electrolyte in case of diffusion-controlled etching process: the resulting concentration of etching ions is then critically depending on geometry (mask thickness, opening dimensions) and thus will change during etching, which will transform the etch shape from convex to concave (isotropic) as known for wet chemical etching [3] (Figure 2b). Use of COMSOL Multiphysics: In order to demonstrate both mechanisms, they were simulated in COMSOL in 2D models with axial symmetry. Movement of etch front was implemented with the Moving Mesh (ALE) interface. The Transport of Diluted Species and Electric Currents physics interfaces has been used for the simulation of diffusion in electrolyte and current flow respectively. The models presented in the paper are further development of the previously presented models [4]. Results: The resulting etch forms are shown in Figures 3 and 4. Conclusion: The simulations have shown the transformation of etch form from convex to concave shape both with electrical and diffusion mechanisms. Influence of electrolyte conductivity and radius of the opening in the masking layer

will be discussed in the paper.

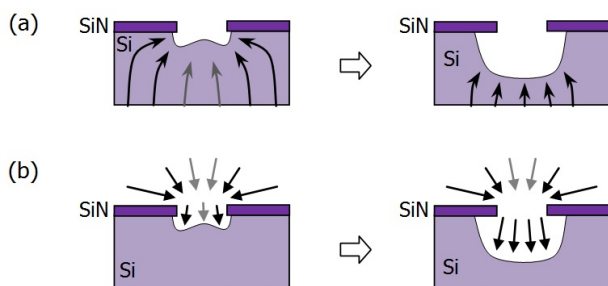
## Reference

- [1] V. Lehmann, *Electrochemistry of Silicon* (Wiley-VCH, Weinheim, 2002).  
 [2] Ivanov, A., Kovacs, A. and Mescheder, U. (2011), High quality 3D shapes by silicon anodization. *physica status solidi (a)*, 208: 1383–1388. doi: 10.1002/pssa.201000163.  
 [3] P. Rath, J. C. Chai, H. Zheng, Y. C. Lam, and V. M. Murukeshan, *Int. J. Heat Mass Transfer* 49, 1480–1488(2006).  
 [4] A. Ivanov, *Simulation of Electrochemical Etching of Silicon with COMSOL*, Proceedings, COMSOL Conference 2011, Ludwigsburg (Stuttgart), 26th-28th October 2011.

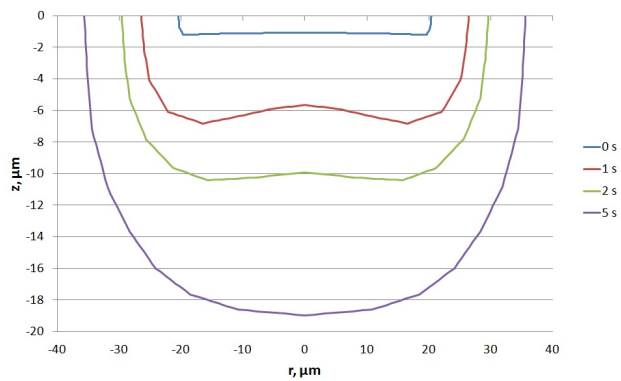
## Figures used in the abstract



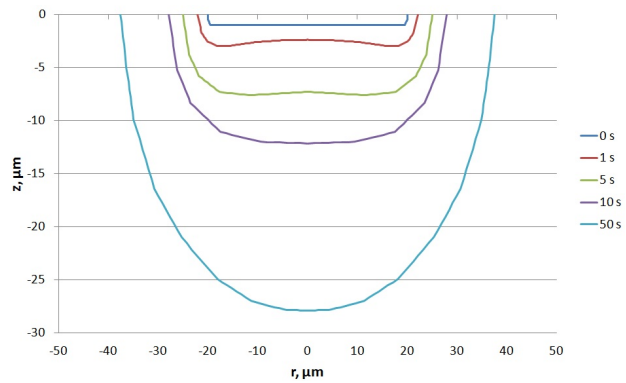
**Figure 1:** Flow of chemical species from electrolyte and positive charges in silicon substrate at the interface silicon–electrolyte during anodization process.



**Figure 2:** Simplified mechanism of shape conversion convex-concave: (a) effect of current distribution (arrows represent current flow); (b) effect of diffusion-controlled etching process (arrows represent flow of F-ions to the reaction site). Left: at the beginning of the process, right: after etching deep into silicon substrate; darker arrows mean stronger flow.



**Figure 3:** Etch form development observed in the electrical model for a circular opening of radius 20  $\mu\text{m}$  in silicon nitride masking, assuming electrolyte conductivity equal to the conductivity of the silicon substrate.



**Figure 4:** Etch form development observed in the diffusion model for a circular opening of radius 20  $\mu\text{m}$  in silicon nitride masking.