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Diffusion-limited release-etch rate modeling for complex surface micromachined structures

W.P. Eaton*, J.H. Smith, and R.L. Jarecki

Sandia National Laboratories
P.O Box 5800, MS 1080
Albuquerque, NM 87185-1080
E-mail:eaton@chtm.eece.unm.edu

Abstract

Knowledge of release-etch kinetics is essential for designing manufacturing processes for large surface micromachined structures such as sealed cavities and flow channels. For large, closed structures, the use of numerous etch access holes is not feasible, although alternative release-etch approaches may be possible [1]. Because the etching of large structures from their edges rapidly becomes diffusion limited, long etch times are required to release these structures. Furthermore, for mechanical/sacrificial layer systems with non-ideal etch selectivities, degradation of the mechanical layer is a concern. For these reasons, understanding the etch rate behavior for a given geometry can be crucial to the successful fabrication of a micromachined part. Although simple geometries can be modeled analytically, modeling the etching of complex geometries can be difficult. However, by joining the solutions of release-etch kinetics of simple parts, the etching of complex structures can be modeled with less effort.

For oxide-based sacrificial layers and aqueous HF release-etch chemistries, the etch kinetics have been determined for the simple geometry of the rectangular etch port (Figure 1a) [2,3,4]. Other useful basic geometries can be identified, such as concentric circles and bubbles (Figure 1b and 1c). The solutions for the etch kinetics of these geometries can be joined to model more complex geometries (Figures 1d, 1e, and 6).

Fick's First and Second Laws, along with boundary conditions and proportionality constants can be used to determine solutions for release etch kinetics. It has been demonstrated that the etch rate is a non-first order function of concentration [1,2]. However, first order kinetics often yield analytical solutions, and behave similarly to non-first order kinetics. Etch distance as a function of etch time is plotted in Figure 2 for first order and second order kinetics of the concentric circles solutions. The first order solution is analytical; whereas, the second order solution is numerical. For both cases, the model predicts that the etch rate starts out high, decreases due to diffusion limitations, and then increases at the end of the etch.

Like many thin film properties, etch constants of the sacrificial layers are expected to be dependent on deposition parameters, deposition equipment, and processing details. Hence, these constants should be determined for any specific fabrication process. Once the etch constants are found for a specific geometry, they can be applied to other geometries.

Joined solutions for differently sized ports are plotted in Figure 3. The solution for a port-to-bubble geometry is plotted in Figure 4.

A surface micromachined pressure sensor diaphragm [5] is shown in Figure 5. The release-etch can be modeled by a port-to-bubble-to-wedge solution, as shown schematically in Figure 6 and plotted in Figure 7. Non-linear regression fits for a diaphragm bubble-to-wedge solution are plotted in Figure 8.

Detailed mathematical treatments for all of the geometries in Figures 1 and 6 will be presented. Limitations of the models will be discussed. Finally, experimental data for a variety of geometrical structures, built with both doped and undoped sacrificial oxide films, will be presented.

References

[1] M.W. Judy and R.T. Howe, "Polysilicon Hollow Beam Lateral Resonators", *Proceedings of IEEE Micro Electro Mechanical Systems*, Ft. Lauderdale FL, pp. 265-271 (February 1993).

[2] Y.-C. Tai and C.-M. Ho, "Silicon Micromachining and Its Applications", *Proceedings of the SPIE, Smart Structures and Materials 1995: Smart Electronics*, SPIE, **Vol 2448**, pp. 141-151 (March 1995).

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[3] D.J. Monk, "Controlled Structure Release for Silicon Surface Micromachining", *Ph.D. Dissertation, University of California at Berkeley*, Department of Chemical Engineering (1993).

[4] D.J. Monk, D.S. Soan, and R.T. Howe, "A diffusion/chemical reaction model for HF etching of LPCVD phosphosilicate glass sacrificial layers", *Technical Digest: IEEE Solid State Sensor and Actuator Workshop, Hilton Head '92*, pp. 46-49 (1992).

[5] W.P. Eaton, "Characterization of a Surface Micromachined Pressure Sensor Array", *Proceedings of the SPIE, Micromachining and Microfabrication Symposium*, SPIE, **Vol 2642** (October 23-24, 1995).

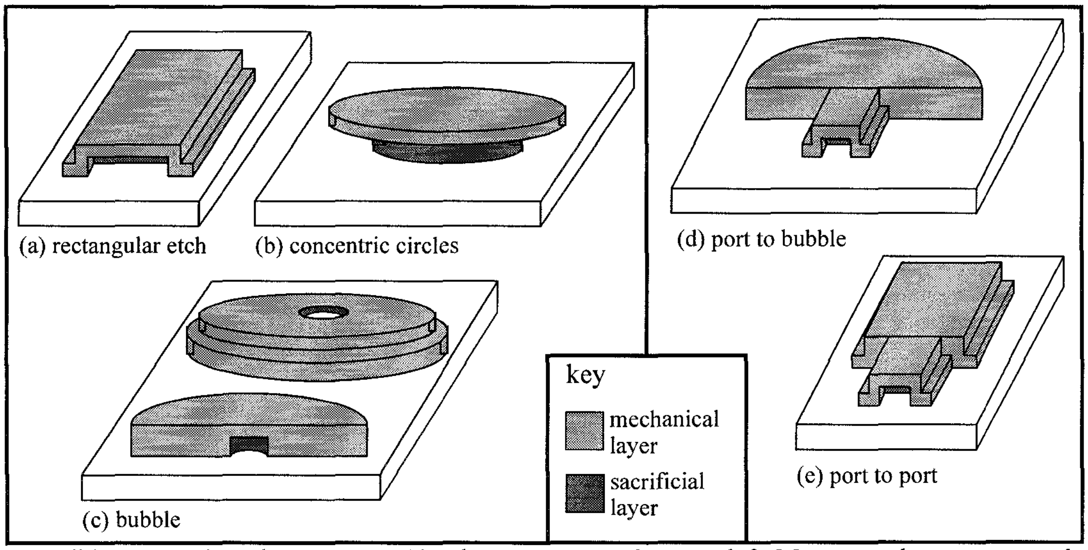

Figure 1. Possible geometric etch structures. Simple structure are shown at left. More complex structures, shown at right, are formed by combining simple structures.

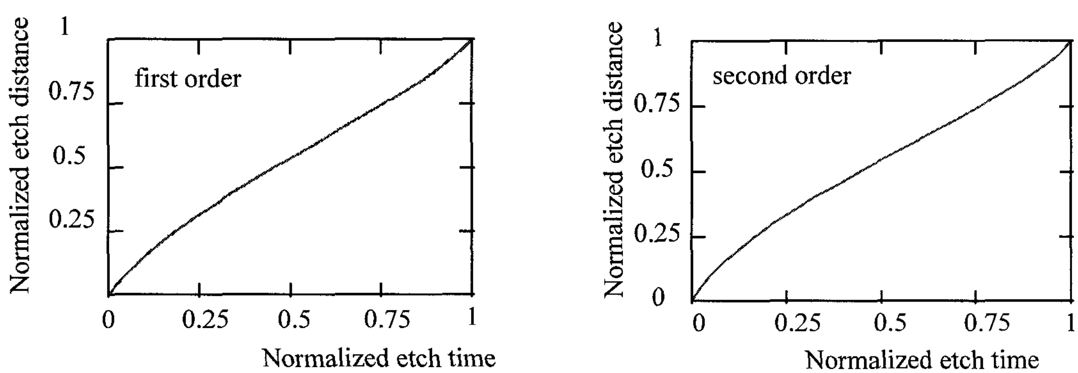

Figure 2. Normalized etch front position vs. Normalized etch time for first order (left) and second order (right) concentric circles solution. radius=500 μm. Physical constants from Tai *et. al* [2] were used.

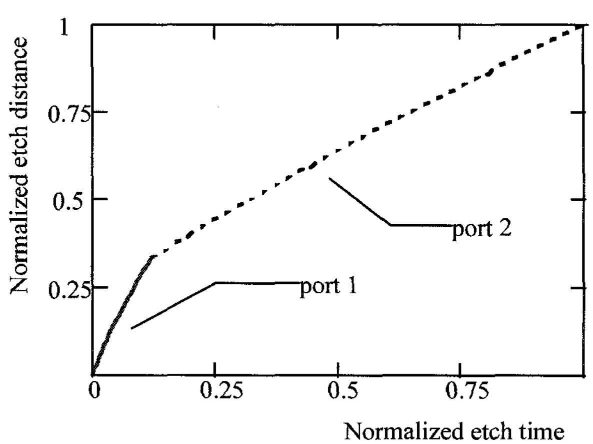

Figure 3. Normalized concentration at etch front vs normalized etch distance for second order port to port solution. port 1: length=50 μm, width=5 μm; port 2: length=100 μm, width=50 μm. Heights for both ports were 1μm. Physical constants from Tai *et. al* [2] were used.

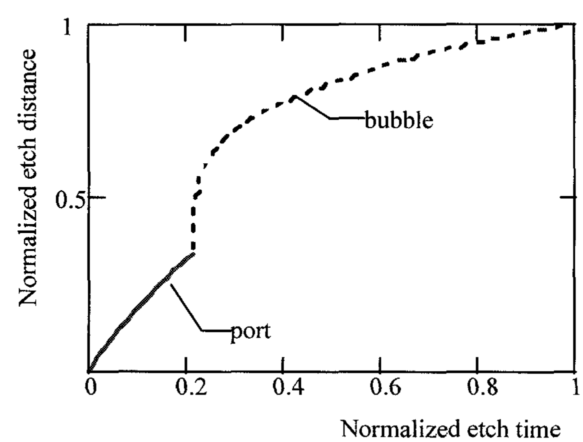

Figure 4. Normalized concentration at etch front vs normalized etch distance for second order port to bubble solution. port length=50 [μm]; final bubble radius=100 μm. Physical constants from Tai *et. al* [2] were used.

Figure 5. Scanning electron micrograph of surface micromachined pressure sensor diaphragm with 8 etch ports.

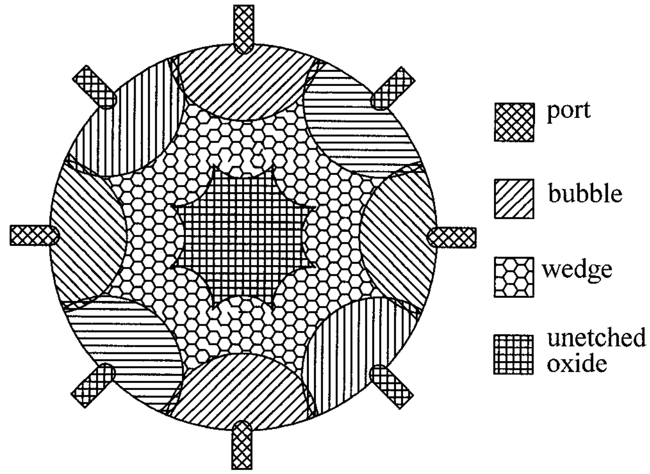

Figure 6. Schematic progression of release etch for port to bubble to wedge system (top view) of Figure 5. The wedge solution begins after all of the bubbles from their respective etch ports are joined.

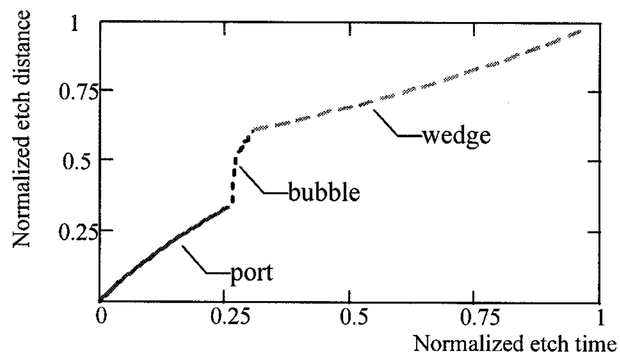

Figure 7. Normalized etch distance vs normalized etch time for second order port to bubble to wedge solution of Figure 6. port length=50 µm, port width=5 µm, circular radius=100 µm. Physical constants from Tai *et. al* [2] were used.

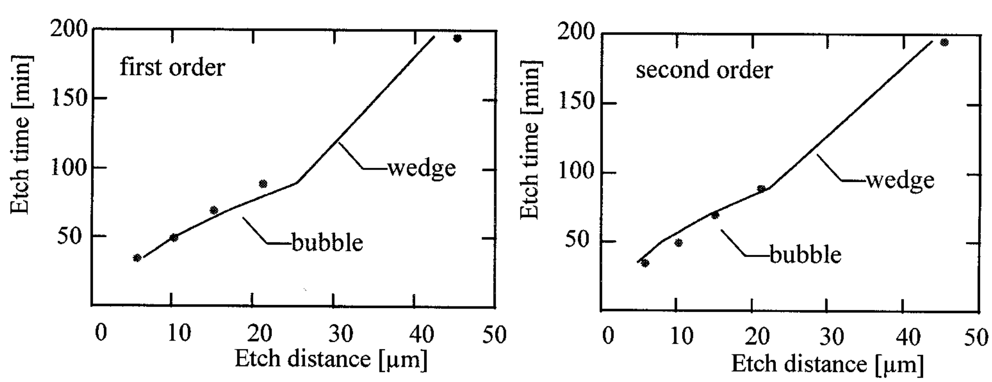

Figure 8. Etch time/distance curve fits for an 8 port circular surface micromachined pressure sensor diaphragm. (left) first order solution. (right) order solution. The radius of the diaphragm was 250 µm. Only bubble and wedge regimes were fit. A constant port etch time of 2 min was used and an effective port length of 49 µm was used for diffusion resistance.