## Silicon Trench Etch (Bosch) - Process Trends / Parameter Adjustments

<table>
<thead>
<tr>
<th>Process Parameter</th>
<th>Direction</th>
<th>Etch Rate</th>
<th>General Effect On: Wall Profile</th>
<th>Selectivity</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIE (13.56) Power</td>
<td>increase</td>
<td>increase</td>
<td>toward re-entrance (-)</td>
<td>decrease</td>
<td>Most sensitive adjustment - 1 watt can make a big change in results! Too low can cause grass formation.</td>
</tr>
<tr>
<td></td>
<td>decrease</td>
<td>decrease</td>
<td>toward positive (+)</td>
<td>increase</td>
<td></td>
</tr>
<tr>
<td>Etch Time</td>
<td>increase</td>
<td>increase</td>
<td>toward re-entrance (-)</td>
<td>decrease</td>
<td>Wall roughness will increase with increased time. Effect on selectivity not as dramatic as RIE power</td>
</tr>
<tr>
<td></td>
<td>decrease</td>
<td>decrease</td>
<td>toward positive (+)</td>
<td>increase</td>
<td>If time is too short, grass may form.</td>
</tr>
<tr>
<td>Dep Pressure</td>
<td>increase</td>
<td>increase</td>
<td>toward re-entrance (-)</td>
<td>----</td>
<td>Dep pressure affects deposition efficiency - higher pressure results in less deposition</td>
</tr>
<tr>
<td>(see data plots)</td>
<td>decrease</td>
<td>decrease</td>
<td>toward positive (+)</td>
<td>----</td>
<td>Effect on results are much less dramatic Vs etch step parameters</td>
</tr>
<tr>
<td>Fluorocarbon Flow</td>
<td>increase</td>
<td>see attached data plots</td>
<td></td>
<td></td>
<td>Deposition parameters can be used as a refinement tool to gently adjust the etch.</td>
</tr>
<tr>
<td></td>
<td>decrease</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF6 Flow</td>
<td>increase</td>
<td></td>
<td>Behaves as a standard RIE type process. Less flow (lower conc. free fluorine) will reduce etch rate with a slight effect on profile (less SF6 =&gt; slightly toward positive (+) profile)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>decrease</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Profile Definition:

- Vertical (90°)
- Positive Taper (< 90°)
- Re-entrant (> 90°)
Bosch Process
Variation of Etch Depth with Time

- **Graph:**
  - Y-axis: Etch Depth (µm)
  - X-axis: Time (min)
  - Lines represent different Feature Widths (micron):
    - 3 µm
    - 5 µm
    - 10 µm
    - 20 µm
    - 50 µm

Bosch Process
Profile Variation with Aspect Ratio

- **Graph:**
  - Y-axis: Wall Angle (degrees)
  - X-axis: Trench Aspect Ratio
  - Lines indicate different processes:
    - Process Optimized for Small Features
    - Process Optimized for Large Features
Etch Rate / Wall Profile Vs Deposition Pressure

CMX test pattern - 11μm space
Etch Rate / Selectivity Vs Deposition Pressure

CMX test pattern - 11μm space
Etch Rate / Wall Profile Vs Fluorocarbon Flow Rate

- Etch Rate (μm/min.)
- Wall Profile (degrees)

CMX test pattern - 11 μm space
Etch Rate / Selectivity Vs Fluorocarbon Flow Rate

<table>
<thead>
<tr>
<th>Etch Rate (μm/min.)</th>
<th>Selectivity (Si:PR)</th>
</tr>
</thead>
</table>

Fluorocarbon Flow (secm)
This process is designed primarily to etch deep features into single crystal silicon. The etch rate for silicon is in the range of 1 - 3 \( \mu \text{m/min} \) and the selectivity to mask materials ranges from 50-100 : 1 for photo-resist and from 150-200: 1 for an oxide mask. These characteristics of the process permit silicon to be etched very deeply (including through wafer) and high aspect ratio features to be defined.

Although the process has extremely good etch properties, there are certain characteristics of the process which should be understood, particularly when very deep features are required. These process issues fall into two areas - the variation of etch rate with etch depth, and the variation of wall profile with feature width. Studies of both of these responses indicate that the important parameter is actually the aspect ratio (ratio of depth/width) of the feature, and specifically the aspect ratio of the trench which is etched into the silicon. Thus in defining a narrow, free-standing beam into silicon, the quality of the etch is determined not so much by the actual dimensions of the beam, but rather by the dimensions of the adjacent open area (trench), of which the beam constitutes one wall.

**Etch Rate Variation**

As etch depth increases, so the aspect ratio of a given feature will increase, and the silicon etch rate is seen to decrease. The effect is small for aspect ratios < 2, but can be significant in deep, narrow features. The effect is believed due to diffusion phenomena limiting the rate of arrival of etching species and the rate of removal of etch by-products from the bottom of such features. The variation of etch rate with aspect ratio has been characterized over a wide range of feature sizes and depths, and the response is shown in Fig 1. The practical consequences of this are shown in Fig 2, where the etch depth vs time is shown for a number of trench widths. For shallow etches, the etch depth is similar for all feature sizes, but as the depth increases then the etch depth of the smaller features will be smaller than that of the larger features. It should be noted that because the mask etch rate is *not* feature size dependent, this will remain constant throughout the etch. Consequently the selectivity to the mask will decrease as the silicon etch rate decreases, and the additional loss of mask material should be factored in for deep etches.

**Profile variation**

Ideally the profile of the trench sidewall produced by the etch process would be perfectly vertical (90\(^\circ\)). In practice it is found to deviate from this by a small amount, the magnitude of the deviation again being determined by the aspect ratio of the etched trench. In general high aspect ratio trenches (small trench widths) will exhibit a tapered (<90\(^\circ\)) profile, while low aspect ratio trenches (large trench widths) will have a negative, or re-entrant profile (>90\(^\circ\)). The extent of these variations is small, of the order of 1\(^\circ\), but the effect can be important at large etch depths. It is possible to produce a vertical etch
for a particular feature size by optimizing the process for that feature, though the magnitude of the profile range for different features will remain the same, simply shifted. This is shown in Fig 3 where three different processes are shown, optimized for small, medium and large feature sizes respectively. As noted above, when isolated features, rather than trenches are the main structures of interest, it is important to optimize the process for the large open areas.