Surface-Micromachining Process Flow

- Deposit sacrificial PSG:
  - Target = 2 μm
  - 1 hr. 40 min. LPCVD @450°C
- Densify the PSG
  - Anneal @950°C for 30 min.
- Lithography to define anchors using the ANCHOR(df) mask
  - Align to the poly1 layer
- Etch anchors
  - RIE using CHF₃/CF₄/He
    @350W, 2.8Torr
  - Remove PR in PRS2000
  - Quick wet dip in 10:1 HF to remove native oxide
- Deposit structural polySi
  - Target = 2 μm
  - In-situ Phosphorous-doped
  - 11 hrs. LPCVD @650°C

Silicon Substrate

Oxide Hard Mask

Silicon Substrate

Silicon Substrate

Polysilicon Surface-Micromachined Examples

* Below: All surface-micromachined in polysilicon using variants of the described process flow

Free-Free Beam Resonator

Folded-Beam Comb-Driven Resonator

Three-Resonator Micromechanical Filter
### Structural/Sacrificial Material Combinations

<table>
<thead>
<tr>
<th>Structural Material</th>
<th>Sacrificial Material</th>
<th>Etchant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poly-Si</td>
<td>SiO₂, PSG, LTO</td>
<td>HF, BHF</td>
</tr>
<tr>
<td>Al</td>
<td>Photoresist</td>
<td>O₂ plasma</td>
</tr>
<tr>
<td>SiO₂</td>
<td>Poly-Si</td>
<td>XeF₂</td>
</tr>
<tr>
<td>Al</td>
<td>Si</td>
<td>TMAH, XeF₂</td>
</tr>
<tr>
<td>Poly-SiGe</td>
<td>Poly-Ge</td>
<td>H₂O₂, hot H₂O</td>
</tr>
</tbody>
</table>

* Must consider other layers, too, as release etchants generally have a finite E.R. on any material
* Ex: concentrated HF (48.8 wt. %)
  - Polysilicon E.R. ~ 0
  - Silicon nitride E.R. ~ 1-14 nm/min
  - Wet thermal SiO₂ ~ 1.8-2.3 µm/min
  - Annealed PSG ~ 3.6 µm/min
  - Aluminum (Si rich) ~ 4 nm/min (much faster in other Al)

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### Film Etch Chemistries

* For some popular films:

<table>
<thead>
<tr>
<th>Material</th>
<th>Wet etchant</th>
<th>Etch rate [nm/min]</th>
<th>Dry etchant</th>
<th>Etch rate [nm/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polysilicon</td>
<td>HNO₂·H₂O; NH₄F</td>
<td>120-600</td>
<td>SF₆ + He</td>
<td>170-920</td>
</tr>
<tr>
<td>Silicon nitride</td>
<td>H₃PO₄</td>
<td>5</td>
<td>SF₆</td>
<td>150-250</td>
</tr>
<tr>
<td>Silicon dioxide</td>
<td>HF</td>
<td>20-2000</td>
<td>CHF₃ + O₂</td>
<td>50-150</td>
</tr>
<tr>
<td>Aluminum</td>
<td>H₃PO₄·HNO₃; CH₂COOH</td>
<td>660</td>
<td>Cl₂ + SiCl₄</td>
<td>100-150</td>
</tr>
<tr>
<td>Photoresist</td>
<td>Acetone</td>
<td>&gt;4000</td>
<td>O₂</td>
<td>35-3500</td>
</tr>
<tr>
<td>Gold</td>
<td>KI</td>
<td>40</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

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### Wet Etch Rates (f/ K. Williams)

- Silox (low strain)
  - DRY: 80°C, 300-1000nm/min
  - WET: 80°C, 70-150nm/min
- Al (high tensile)
  - DRY: 1200°C, 0.06-0.45nm/min
  - WET: 80°C, 10-100nm/min
- Al (lower strain)
  - DRY: 500°C, 0.1-0.2nm/min
  - WET: 80°C, 5-10nm/min

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### Issues in Surface Micromachining

* Stiction: sticking of released devices to the substrate or to other on-chip structures
  - Difficult to tell if a structure is stuck to substrate by just looking through a microscope
* Residual Stress in Thin Films
  - Causes bending or warping of microstructures
  - Limits the sizes (and sometimes geometries) of structures
* Topography
  - Stringers can limit the number of structural levels
Microstructure Stiction

- **Stiction**: the unintended sticking of MEMS surfaces
- **Release stiction**: Occurs during drying after a wet release etch
  - Capillary forces of droplets pull surfaces into contact
  - Very strong sticking forces, e.g., like two microscope slides w/ a droplet between
- **In-use stiction**: when device surfaces adhere during use due to:
  - Capillary condensation
  - Electrostatic forces
  - Hydrogen bonding
  - Van der Waals forces

Hydrophilic Versus Hydrophobic

- **Hydrophilic**: A surface that invites wetting by water
  - Get stiction
  - Occurs when the contact angle $\theta_{\text{water}} < 90^\circ$
- **Hydrophobic**: A surface that repels wetting by water
  - Avoids stiction
  - Occurs when the contact angle $\theta_{\text{water}} > 90^\circ$