Lecture 4-1 Surface Micromachining

- **Definition:** A technique for fabricating three-dimensional micromechanical structures from multilayer stacked and patterned thin film.

Layer stacking and sacrificial etching:

![Diagram of Surface Micromachining]

**Figure 4.1** Surface micromachining: (a) patterned sacrificial layer; (b) patterned structural layer; (c) suspended beam after sacrificial etching.
Sealing:

Figure 4.2 Sealing: (a) cavity after sacrificial etching; (b) reactive sealing; (c) sealing by deposition.

Figure 4.2 continued.
- Materials: polysilicon, silicon nitride, silicon dioxide, polyimide, tungsten, molybdenum, amorphous silicon carbide, TiNi alloy, nickel-iron permalloy, Aluminum, or composite films, such as polysilicon-ZnO, polysilicon-silicon nitride-polysilicon.

- Comparison to bulk micromachining:
  1. Produce smaller sensors or actuators, scale ~1-hundreds of μm
  2. Share with many current IC processes
  3. Better feature definition, thickness can be controlled in submicron, however, it can be a problem to get thickness more than 10 μm
  4. Selection from many materials...

- Sacrificial layers:

<table>
<thead>
<tr>
<th>Table 4.2</th>
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</thead>
<tbody>
<tr>
<td>Combination of Structural and Sacrificial Layers in Surface Micromachining</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structural Layer Material</th>
<th>Typical Thickness (μm)</th>
<th>Sacrificial Layer Material</th>
<th>Typical Thickness (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polysilicon</td>
<td>1–4</td>
<td>PSG, SiO₂</td>
<td>1–7</td>
</tr>
<tr>
<td>Si₃N₄</td>
<td>0.2–2</td>
<td>PSG, SiO₂</td>
<td>2</td>
</tr>
<tr>
<td>SiO₂</td>
<td>1–3</td>
<td>Polysilicon</td>
<td>1–3</td>
</tr>
<tr>
<td>Polyimide</td>
<td>10</td>
<td>Al</td>
<td>1.5–3</td>
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<tr>
<td>W</td>
<td>2.5–4</td>
<td>SiO₂</td>
<td>8</td>
</tr>
<tr>
<td>Mo</td>
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<td>Al</td>
<td>0.7</td>
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<tr>
<td>SiC</td>
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<td>SiO₂</td>
<td>1.5</td>
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<tr>
<td>TiNi</td>
<td>8</td>
<td>Polyimide or</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Au</td>
<td>2</td>
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<tr>
<td>NiFe</td>
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<td>Al or</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cu</td>
<td>7</td>
</tr>
<tr>
<td>PolySi-ZnO</td>
<td>2–0.95</td>
<td>PSG</td>
<td>0.6</td>
</tr>
<tr>
<td>PolySi-Si₃N₄-PolySi</td>
<td>1–0.2–1</td>
<td>PSG</td>
<td>2</td>
</tr>
</tbody>
</table>
Properties of polysilicon:

1. Deposited by LPCVD, PECVD, APCVD system at temperature from 530°C-700°C. Transition temperature at 560-600°C from amorphous to polycrystalline silicon.
2. Grain size decrease from 530-630°C and increase from 630-700 °C, highest stress and resistivity also show up at 630°C.
3. Film stress:
   fully amorphous and fully polycrystalline LPCVD poly silicon: compressive stress, -300~-500 MPa
   transition polysilicon: film stress ranges from tensile to compressive. (+500~-500 Mpa)
Stress gradient: bent upward

Figure 4.6 SEM micrograph of 2.0-μm thick polysilicon film deposited at 630°C and 290 mtorr total pressure.
4. Annealing of undoped polysilicon films
   Long time annealing at temp from 650-1050 °C can reduce compressive stress. However, the film grain size does not change much during the annealing process.

5. Doping: (mostly Phosphorus)
   Reduce film resistivity up to 0.04, promotion of crystallization,
   a. In situ: reduce total process steps, offer a flat concentration profile over the thickness of film, precision dopant concentration control. tensile stress from 500-100 MPa.
   b. Ex-situ: doping from PSG or predeposition. Moderate temperature causes film bend down-increase compressive stress.

- Sacrificial etching:
  PSG (phosphosilicate glass) from LPCVD etching rate in 1.25% HF: 0.55-1 μm/min
  Reaction limit: ~t
  Diffusion limit: ~t^n, n<1.

![Figure 4.13 Schematic representation of PSG sacrificial etching mechanism.](image-url)
Step coverage
Stiction:

Caused from water capillary force, which draw microstructures toward the substrate, then other forces develop between the contact surfaces.

Solution:
1. low surface tension solution, such as methanol, IPA
2. Heat up when drying
3. supercritical sublimation
4. surface treatment-hydrophobic: SAM (self assembly monolayer)
5. Structure modification: bump, temporary supporting materials
6. Gas type releasing: N₂ HF vapor releasing, XeF₂
Testing structure

Figure 4.17 Surface-micromachined bridge array for the evaluation of residual compressive strains in thin films: (a) optical interference micrograph of an array of polysilicon bridges; (b) theoretical buckling strains for the bridges in this array.

Figure 4.18 Schematic drawing of a ring-and-beam micromechanical test structure for the measurement of residual tensile stress in thin films (after [47]).
SEM micrograph of a polysilicon Archimedian spiral structure used for the characterization of internal stress gradients.
Figure 4.21 Mechanical characterization of thin films using the Nanoindenter technique: (a) schematic drawing of the measurement technique (after [92]); (b) load-deflection data for a surface-micromachined polysilicon cantilever beam.

Figure 4.22 Mechanical characterization of thin films using resonant frequency measurements: (a) schematic drawing of the experimental setup; (b) typical frequency response of an SiO₂ cantilever beam; (c) resonant frequency versus beam length for an array of SiO₂ beams.

Figure 4.23 Mechanical characterization of thin films with the membrane-deflection technique: (a) schematic drawing of the test structure; (b) pressure-deflection data for polyimide membranes.
Example: micro motor process

Reference: