Layout and Masking Layers

* At Left: Layout for a folded-beam capacitive comb-driven micromechanical resonator

* Masking Layers:
  - 1st Polysilicon: POLY1(cf)
  - Anchor Opening: ANCHOR(df)
  - 2nd Polysilicon: POLY2(cf)

Folded-beam support structure for stress relief

Surface-Micromachining Process Flow

Cross-sections through A-A'

- Deposit isolation LTO (or PSG):
  - Target = 2μm
  - 1 hr. 40 min. LPCVD @450°C
- Densify the LTO (or PSG)
  - Anneal @950°C for 30 min.
- Deposit nitride:
  - Target = 100nm
  - 22 min. LPCVD @800°C
- Deposit interconnect polysilicon:
  - Target = 300nm
  - In-situ Phosphorous-doped
  - 1 hr. 30 min. LPCVD @650°C

- Lithography to define poly1 interconnects using the POLY1(cf) mask
- RIE polysilicon interconnects:
  - CF₄/He/O₂ @300W, 280mTorr
- Remove photoresist in PRS2000
- Quick wet dip in 10:1 HF to remove native oxide

- Deposit structural polysilicon:
  - Target = 2μm
  - In-situ Phosphorous-doped
  - 11 hrs. LPCVD @650°C

Surface-Micromachining Process Flow

- Deposit sacrificial PSG:
  - Target = 2μm
  - 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 = 2μm
  - In-situ Phosphorous-doped
  - 11 hrs. LPCVD @650°C

Surface-Micromachining Process Flow

- Deposit oxide hard mask:
  - Target = 300nm
  - 25 min. LPCVD @450°C
- Stress Anneal:
  - 1 hr. @ 1050°C
  - Or RTA for 1 min. @ 1100°C in 50 sccm N₂
- Lithography to define poly2 structure (e.g., shuttle, springs, drive & sense electrodes) using the POLY2(cf) mask
  - Align to the anchor layer
  - Hard bake the PR longer to make it stronger
- Etch oxide mask first:
  - RIE using CHF₃/CF₄/He @350W, 2.8Torr
- Etch structural polysilicon:
  - RIE using CF₄/He/O₂ @300W, 280mTorr
  - Use 1 min. etch/1 min. rest increments to prevent excessive temperature

Copyright © 2016 Regents of the University of California
Surface-Micromachining Process Flow

- Remove PR (more difficult)
  - Ash in O\(_2\) plasma
  - Soak in PRS2000

- Release the structures
  - Wet etch in HF for a calculated time that insures complete undercutting
    - If 5:1 BHF, then ~ 30 min.
    - If 48.8 wt. % HF, ~ 1 min.
  - Keep structures submerged in DI water after the etch
  - Transfer structures to methanol

- Supercritical CO\(_2\) dry release

![Silicon Substrate](image)

Hydrofluoric Acid Release Etchant

Free-Standing Polysilicon Beam

![Polysilicon Surface-Micromachined Examples](image)

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

Free-Free Beam Resonator

Three-Resonator Micromechanical Filter

Wet Etch Rates (f/ K. Williams)

<table>
<thead>
<tr>
<th>Structural Material</th>
<th>Sacrificial Material</th>
<th>Etchant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poly-Si</td>
<td>SiO(_2), PSG, LTO</td>
<td>HF, BHF</td>
</tr>
<tr>
<td>Al</td>
<td>Photoresist</td>
<td>O(_2) plasma</td>
</tr>
<tr>
<td>SiO(_2)</td>
<td>Poly-Si</td>
<td>XeF(_2)</td>
</tr>
<tr>
<td>Al</td>
<td>Si</td>
<td>TMAH, XeF(_2)</td>
</tr>
<tr>
<td>Poly-SiGe</td>
<td>Poly-Ge</td>
<td>H(_2)O(_2), hot H(_2)O</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 SiO\(_2\) ~ 1.8-2.3 \(\mu\)m/min
  - Annealed PSG ~ 3.6 \(\mu\)m/min
  - Aluminum (Si rich) ~ 4 nm/min (much faster in other Al)
**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>

**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
  - Occurs when the contact angle \( \theta_{\text{water}} < 90^\circ \)
- **Hydrophobic**: A surface that repels wetting by water
  - Occurs when the contact angle \( \theta_{\text{water}} > 90^\circ \)

Lotus Surface [Univ. Maine]

Microstructure Stiction Modeling

- The pressure difference (i.e., force) is given by the Laplace equation:
  \[
  F = -\Delta p_{\text{meniscus}} A = \frac{2\sigma \cos \theta}{r}
  \]

- Force needed to keep the plunger apart
- \( (\Leftrightarrow) \) force means a \( + \) Laplace pressure

Avoiding Stiction

- Reduce droplet area via mechanical design approaches
- Avoid liquid-vapor meniscus formation
  - Use solvents that sublime
  - Use vapor-phase sacrificial layer etch
- Modify surfaces to change the meniscus shape from concave (small contact angle) to convex (large contact angle)
  - Use teflon-like films
  - Use hydrophobic self-assembled monolayers (SAMs)
**Supercritical CO₂ Drying**

- *A method for stictionless drying of released microstructures by immersing them in CO₂ at its supercritical point*
- *Basic Strategy: Eliminate surface tension-derived sticking by avoiding a liquid-vapor meniscus*
- *Procedure:*
  - Etch oxide in solution of HF
  - Rinse thoroughly in DI water, but do not dry
  - Transfer the wafer from water to methanol
  - Displace methanol with liquid CO₂
  - Apply heat & pressure to take the CO₂ past its critical pt.
  - Vent to lower pressure and allow the supercritical CO₂ to revert to gas → liquid-to-gas Xstiction in supercritical region means no capillary forces to cause stiction

---

**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 \( \theta_{\text{water}} > 90^\circ \)

---

**Tailoring Contact Angle Via SAM’s**

- *Can reduce stiction by tailoring surfaces so that they induce a water contact angle > 90°*
- **Self-Assembled Monolayers (SAM’s):**
  - Monolayers of “stringy” molecules covalently bonded to the surface that then raise the contact angle
- **Beneficial characteristics:**
  - Conformal, ultrathin
  - Low surface energy
  - Covalent bonding makes them wear resistant
  - Thermally stable (to a point)

---

**Dry Release**

- *Another way to avoid stiction is to use a dry sacrificial layer etch*
- **For an oxide sacrificial layer**
  - Use HF vapor phase etching
  - Additional advantage: gas can more easily get into tiny gaps
  - **Issue:** not always completely dry → moisture can still condense → stiction → soln: add alcohol
- **For a polymer sacrificial layer**
  - Use an O₂ plasma etch (isotropic, so it can undercut well)
  - **Issues:**
    - Cannot be used when structural material requires high temperature for deposition
    - If all the polymer is not removed, polymer under the suspended structure can still promote stiction

---

*Lotus Surface [Univ. Mainz]*

*Sealing Oxide*

*Encapsulation Si*

*Released via vapor phase HF [Kenny, et al., Stanford]*

*Electrode*

*Beams of Tuning Fork*

*[Kobayashi]*

---

*Figures are courtesy of MEMS Devices Lecture 5.*
Residual Stress in Thin Films

- After release, poorly designed microstructures might buckle, bend, or warp → often caused by residual film stress
- Origins of residual stress, $\sigma$
  - Growth processes
    - Non-equilibrium deposition
    - Grain morphology change
    - Gas entrapment
    - Doping
  - Thermal stresses
    - Thermal expansion
    - mismatch of materials → introduce stress during cool-down after deposition
    - Annealing

Need to Control Film Stress

- Resonance frequency expression for a lateral resonator:
  $$ f_0 \approx \frac{1}{2\pi} \sqrt{\frac{4E_yW^3}{ML^2}} + \frac{24\sigma_r/W}{5ML} $$

  Since $W \ll L$, the stress term will dominate if $\sigma_r \approx E_y$

Tensile Versus Compressive Stress

- Under tensile stress, a film wants to shrink w/r to its substrate
  - Caused, e.g., by differences in film vs. substrate thermal expansion coefficients
  - If suspended above a substrate and anchored to it at two points, the film will be "stretched" by the substrate

- Under compressive stress, a film wants to expand w/r to its substrate
  - If suspended above a substrate and anchored to it at two points, the film will buckle over the substrate
Vertical Stress Gradients

- Variation of residual stress in the direction of film growth
- Can warp released structures in z-direction

Stress in Polysilicon Films

- Stress depends on crystal structure, which in turn depends upon the deposition temperature
- Temperature \( \leq 600^\circ C \)
  - Films are initially amorphous, then crystallize
  - Get equiaxed crystals, largely isotropic
  - Crystals have higher density \( \rightarrow \) tensile stress
  - Small stress gradient
- Temperature \( \geq 600^\circ C \)
  - Columnar crystals grow during deposition
  - As crystals grow vertically and in-plane they push on neighbors \( \rightarrow \) compressive stress
  - Positive stress gradient

Annealing Out Polysilicon Stress

- Control polySi stress by annealing at high temperatures
  - Typical anneal temperatures: 900-1150°C
  - Grain boundaries move, relax
  - Can dope while annealing by sandwiching the polysilicon between similarly doped oxides (symmetric dopant drive-in), e.g. using 10-15 wt. % PSG
- Rapid thermal anneal (RTA) also effective (surprisingly)

Topography Issues

- Degradation of lithographic resolution
  - PR step coverage, streaking
- Stringers
  - Problematic when using anisotropic etching, e.g., RIE
Nickel Surface-Micromachining

**Process Flow**

1. **Deposit isolation LTO**:
   - Target: 2 μm
   - 1 hr, 40 min. LPCVD @450°C
2. **Densify the LTO**
   - Anneal @950°C for 30 min.
3. **Define metal interconnect via lift-off**
   - Spin photoresist and pattern lithographically to open areas where interconnect will stay
   - Evaporate a Ti/Au layer
     - Target: 30nm Ti
     - Target: 270nm Au
   - Remove photoresist in PRS2000 → Ti/Au atop the photoresist also removed

Nickel Metal Surface-Micromachining

1. **Evaporate Al to serve as a sacrificial layer**
   - Target: 1 μm
2. **Lithography to define anchor openings**
3. **Wet etch the aluminum to form anchor vias**
   - Use solution of $H_3PO_4/HNO_3/H_2O$
4. **Remove photoresist in PRS2000**
5. **Electroplate nickel to fill the anchor vias**
   - Use solution of nickel sulfamate @ 50°C
   - Time the electroplating to planarize the surface

**Electroplating: Metal MEMS**

- Use electroplating to obtain metal structures
- When thick: call it “LIGA”
- **Pros**: fast low temp deposition, very conductive
- **Cons**: drift, low mech. Q
  \[ \text{but may be solvable?} \]
Nickel Metal Surface-Micromachining

- Evaporate a thin film of nickel to serve as a seed layer for subsequent Ni electroplating
  - Target = 20nm
- Form a photoresist mold for subsequent electroplating
  - Spin 6 μm-thick AZ 9260 photoresist
  - Lithographically pattern the photoresist to delineate areas where nickel structures are to be formed
- Electroplate nickel structural material through the PR mold
  - Use a solution of nickel sulfamate @ 50°C
  - Cathode-to-anode current density ~ 2.5 mA/cm²
- Strip the PR in PRS2000
- Remove the Ni seed layer in Ni wet etchant
- Release the structures
  - Use a K₄Fe(CN)₆/NaOH etchant that attacks Al while leaving Ni and Au intact
  - Etch selectivity > 100:1 for Al:Ni and Al:Au

Nickel Surface-Micromachining Example

* Below: Surface-micromachined in nickel using the described process flow

3D “Pop-up” MEMS
**Pop-Up MEMS**

First MEMS hinge
[K. Pister, et al., 1992]

Corner Cube Reflector
[v. Hsu, 1999]

**3D Direct-Assembled Tunable L**

[Ming Wu, UCLA]

**Hinge Process Flow**

- Deposit first sacrificial
- Deposit and pattern first poly
- Pattern contacts
- Deposit and pattern second poly
- Etch sacrificial
- Assemble part
“Foundry” MEMS: The MUMPS Process

MUMPS: MultiUser MEMS Process

- Originally created by the Microelectronics Center of North Carolina (MCNC) → now owned by MEMSCAP in France
- Three-level polysilicon surface micromachining process for prototyping and “foundry” services
- Designed to service as many users as possible; basically an attempt to provide a universal MEMS process
- 8 photomasks
- $4,900 for 1 cm² dies

Micromotor fabricated via MUMPS

Masks in polyMUMPS

<table>
<thead>
<tr>
<th>Material Layer</th>
<th>Thickness (µm)</th>
<th>Lithography Level Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrile</td>
<td>0.5</td>
<td>POLY0 (HOLE0)</td>
</tr>
<tr>
<td>Poly 0</td>
<td>0.5</td>
<td>POLY1 (HOLE1)</td>
</tr>
<tr>
<td>First Oxide</td>
<td>2.0</td>
<td>POLY1, POLY2_VIA, ANCHOR2</td>
</tr>
<tr>
<td>Poly 1</td>
<td>2.0</td>
<td>POLY1 (HOLE1)</td>
</tr>
<tr>
<td>Second Oxide</td>
<td>0.75</td>
<td>POLY1, POLY2_VIA, ANCHOR2</td>
</tr>
<tr>
<td>Poly 2</td>
<td>1.5</td>
<td>POLY2 (HOLE2)</td>
</tr>
<tr>
<td>Metal</td>
<td>0.5</td>
<td>METAL (HOLEM)</td>
</tr>
</tbody>
</table>

Field type:
- Light (or clear) field (cf): in layout, boxes represent features that will stay through fabrication
- Dark field (df): in layout, boxes represent holes to be cut out
MUMPS Process Flow

- Deposit PSG on the starting n-type (100) wafers
- Anneal to heavily dope the wafers
- Remove the PSG
- LPCVD 600 nm of low stress nitride
- LPCVD 500 nm of polysilicon
- Lithography using the POLY0(cf) mask and RIE etching to pattern the poly0 ground plane layer
- LPCVD 2 µm of PSG as the 1st sacrificial layer
- Lithography using the DIMPLE(df) mask (align to poly0)
- RIE 750 nm deep to form dimple vias
- Lithography using the ANCHOR1 (df) mask (align to poly0)
- RIE anchor vias down to the nitride surface

MUMPS Process Flow (cont.)

- Recoat with photoresist and do lithography using the ANCHOR2(df) mask to define openings where poly2 contacts nitride or poly0 (align to poly0)
- RIE the PSG at ANCHOR2 openings
- LPCVD 1.5 µm undoped polysilicon
- LPCVD 200 nm PSG as a hard mask and doping source
- Anneal for 1 hr @ 1050°C to dope the polysilicon and reduce residual stress
- Lithography using the POLY2(cf) mask (align to anchor2)
- RIE PSG hard mask
- RIE poly2 film
- Remove PR and hard mask

Final Structure: Micromotor
MUMPS: MultiUser MEMS Process

- Originally created by the Microelectronics Center of North Carolina (MCNC) → now owned by MEMSCAP in France
- Three-level polysilicon surface micromachining process for prototyping and “foundry” services
- Designed to service as many users as possible; basically an attempt to provide a universal MEMS process
- 8 photomasks
- $4,900 for 1 cm² dies

Micromotor fabricated via MUMPS

polyMUMPS Minimum Feature Constraints

- Minimum feature size
  - Determined by MUMPS’ photolithographic resolution and alignment precision
  - Violations result in missing (unanchored), under/oversized, or fused features
  - Use minimum feature only when absolutely necessary

<table>
<thead>
<tr>
<th>Feature Type</th>
<th>Nominal [μm]</th>
<th>Min Feature [μm]</th>
<th>Min Spacing [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>POLY0, POLY1, POLY2</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>POLY1_POLY2_VIA</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>ANCHOR1, ANCHOR2</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>DIMPLE</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>METAL</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>HOLE1, HOLE2</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>HOLEM</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

MUMPS Design Rules (cont.)

<table>
<thead>
<tr>
<th>Rule</th>
<th>Rule Letter</th>
<th>Figure #</th>
<th>Min. Value [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>POLY0 space to ANCHOR1</td>
<td>A</td>
<td>2.5</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY0 enclose ANCHOR1</td>
<td>B</td>
<td>2.5</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY0 enclose POLY1</td>
<td>C</td>
<td>2.6</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY0 enclose POLY2</td>
<td>D</td>
<td>2.7</td>
<td>5.0</td>
</tr>
<tr>
<td>POLY0 enclose ANCHOR2</td>
<td>E</td>
<td>2.8</td>
<td>5.0</td>
</tr>
<tr>
<td>POLY0 space to ANCHOR2</td>
<td>F</td>
<td>2.8</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Oxide1

Poly0

Cross Sections

Mask Levels

Poly0 enclose ANCHOR1

Poly1 enclose DIMPLE

Poly1 enclose POLY1_POLY2_VIA

Poly1 enclose POLY0

Poly1 enclose to ANCHOR1

Lateral etch hole space in POLY1

Oxide1

POLY0

Cross Sections

Mask Levels

Poly1 enclose ANCHOR1
### MUMPS Design Rules (cont.)

<table>
<thead>
<tr>
<th>Rule</th>
<th>Rule Letter</th>
<th>Figure #</th>
<th>Min. Value (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POLY0 space to ANCHOR1</td>
<td>A</td>
<td>2.5</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY0 space to ANCHOR1</td>
<td>B</td>
<td>2.5</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY0 encode POLY1</td>
<td>C</td>
<td>2.8</td>
<td>5.0</td>
</tr>
<tr>
<td>POLY0 enclose POLY1</td>
<td>D</td>
<td>2.7</td>
<td>5.0</td>
</tr>
<tr>
<td>POLY0 space to ANCHOR2</td>
<td>E</td>
<td>2.8</td>
<td>5.0</td>
</tr>
<tr>
<td>POLY0 space to ANCHOR2</td>
<td>F</td>
<td>2.8</td>
<td>5.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rule</th>
<th>Rule Letter</th>
<th>Figure #</th>
<th>Min. Value (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POLY1 enclose ANCHOR1</td>
<td>G</td>
<td>2.6</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY1 enclose DIODE1</td>
<td>N</td>
<td>2.13</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY1 enclose POLY1_POLY2_VIA</td>
<td>H</td>
<td>2.9</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY1 enclose POLY2</td>
<td>O</td>
<td>2.14</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY1 space to ANCHOR2</td>
<td>K</td>
<td>2.11</td>
<td>3.0</td>
</tr>
<tr>
<td><em>Lateral etch holes space in POLY1</em></td>
<td>R</td>
<td>2.15</td>
<td>&lt;50 (max. value)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rule</th>
<th>Rule Letter</th>
<th>Figure #</th>
<th>Min. Value (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POLY2 enclose ANCHOR2</td>
<td>J</td>
<td>2.7, 2.10</td>
<td>5.0</td>
</tr>
<tr>
<td>POLY2 enclose POLY1_POLY2_VIA</td>
<td>L</td>
<td>2.9</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY2 cut-out POLY1</td>
<td>P</td>
<td>2.14</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY2 cut-out POLY1</td>
<td>Q</td>
<td>2.14</td>
<td>4.0</td>
</tr>
<tr>
<td>POLY2 enclose METAL</td>
<td>M</td>
<td>2.12</td>
<td>3.0</td>
</tr>
<tr>
<td>POLY2 space to POLY1</td>
<td>I</td>
<td>2.10</td>
<td>3.0</td>
</tr>
<tr>
<td>HOLE2 enclose HOLE1</td>
<td>T</td>
<td>2.16</td>
<td>2.0</td>
</tr>
<tr>
<td>HOLE2 enclose HOLE1</td>
<td>U</td>
<td>2.16</td>
<td>2.0</td>
</tr>
<tr>
<td><em>Lateral etch holes space in POLY2</em></td>
<td>S</td>
<td>2.15</td>
<td>&lt;50 (max. value)</td>
</tr>
</tbody>
</table>

### TABLE 2.7. PolyMUMPs design rule summary sheet. Table shows minimum dimensions (μm), rule name, and figure number, respectively.