ECE 418/518
Semiconductor Device Processing

Etching
Subtractive Process

1. Blanket deposit film
   Sputter, Oxidize, CVD, Evaporate, etc.
2. Photolithography (or E-beam lithography)
3. Etch
Wet Etch v.s. Dry Etch

- Inexpensive
- High selectivity
- Anisotropic etch for crystalline materials
- Can’t make features smaller than film thickness

- Better process control
- Better uniformity
- Less undercut of mask
- Smaller linewidths
- Less waste products
- Fewer particles/defects
Isotropic vs. Anisotropic Etch

- Etch rate same in all directions
- Mask is undercut

- Etch rate different in different directions

Diagram:

Mask

“Bias”
Etch Selectivity

- Want to etch film but not mask
- Typically, layer below should be etch stop

- Selectivity = \( \frac{\text{Etch rate of desired material}}{\text{Etch rate of other material}} \)
Wet Chemical Etching

- Etch rate depends on
  - Chemistry
  - Concentration
  - Temperature
  - Agitation

- Edge of wafer may etch faster than middle
  - Agitation will help
- Large openings will etch faster than small
  - Agitation can help
- Etch rate may slow as etchant is depleted
  - Buffer may help
## Wet Etch Examples

<table>
<thead>
<tr>
<th>Material</th>
<th>Etchant</th>
<th>Etching Rate</th>
<th>Mask</th>
<th>Selectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si (a-Si)</td>
<td>1) KOH</td>
<td>~ 6 – 600 nm/min (anisotropic)</td>
<td>Resist</td>
<td>&gt; 50:1</td>
</tr>
<tr>
<td></td>
<td>2) HNO3 + H2O + HF</td>
<td>~ 100 nm/min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO2</td>
<td>1) HF</td>
<td>~ 10 – 1000 nm/min</td>
<td>Resist</td>
<td>&gt; 50:1</td>
</tr>
<tr>
<td></td>
<td>2) BHF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si3N4</td>
<td>1) HF</td>
<td>~ 100 nm/min</td>
<td>Resist</td>
<td>&gt; 50:1</td>
</tr>
<tr>
<td></td>
<td>2) BHF</td>
<td>~ 100 nm/min</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3) H3PO4</td>
<td>~ 10 nm/min</td>
<td>SiO2</td>
<td></td>
</tr>
<tr>
<td>GaAs</td>
<td>1) H2SO4 + H2O2 + H2O</td>
<td>~ 10 um/min</td>
<td>Resist</td>
<td>&gt; 50:1</td>
</tr>
<tr>
<td></td>
<td>2) Br + CH3OH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Au</td>
<td>1) HCl + HNO3</td>
<td>~ 40 nm/min</td>
<td>Resist</td>
<td>&gt; 50:1</td>
</tr>
<tr>
<td></td>
<td>2) KI + I2 +H2O</td>
<td>~ 1 um/min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>1) HCl + H2O</td>
<td>~ 500 nm/min</td>
<td>Resist</td>
<td>&gt; 50:1</td>
</tr>
<tr>
<td></td>
<td>2) NaOH</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ion Milling

Argon ions

Etches pretty much anything!
Very anisotropic
Poor (no) selectivity
Re-deposition of etched material
Reactive Ion Etching (RIE)

- Combination of ion milling and chemical etching
- Volatile etch products pumped out of system
- Very anisotropic
- "Good" selectivity
## Typical RIE Gasses

<table>
<thead>
<tr>
<th>Material</th>
<th>Gas</th>
<th>Etching Rate (A/min)</th>
<th>Mask</th>
<th>Selectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si (a-Si)</td>
<td>1) CF4</td>
<td>~ 500</td>
<td>Resist Metal (Cr, Ni, Al)</td>
<td>~ 20:1 ~ 40:1</td>
</tr>
<tr>
<td></td>
<td>2) SF6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3) BCl2 + Cl2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>1) CHF3 + O₂</td>
<td>~ 200</td>
<td>Resist Metal (Cr, Ni, Al)</td>
<td>~ 10:1 ~ 30:1</td>
</tr>
<tr>
<td></td>
<td>2) CF4 + H₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si₃N₄</td>
<td>1) CF₄ + O₂ (H₂)</td>
<td>~ 100</td>
<td>Resist Metal (Cr, Ni, Al)</td>
<td>~ 10:1 ~ 20:1</td>
</tr>
<tr>
<td></td>
<td>2) CHF₃</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GaAs</td>
<td>1) Cl₂</td>
<td>~ 200</td>
<td>Si₃N₄ Metal (Cr, Ni)</td>
<td>~ 10:1 ~ 20:1</td>
</tr>
<tr>
<td></td>
<td>2) Cl₂ + BCl₃</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InP</td>
<td>1) CH₄/H₂</td>
<td>~ 200</td>
<td>Si₃N₄ Metal (Cr, Ni)</td>
<td>~ 40:1</td>
</tr>
<tr>
<td>Al</td>
<td>1) Cl₂</td>
<td>~ 300</td>
<td>Resist Si₃N₄</td>
<td>~ 10:1</td>
</tr>
<tr>
<td></td>
<td>2) BCl₃ + Cl₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resist / Polymer</td>
<td>1) O₂</td>
<td>~ 500</td>
<td>Si₃N₄ Metal (Cr, Ni)</td>
<td>~ 50:1</td>
</tr>
</tbody>
</table>
Endpoint Detection

Laser endpoint detection
Laser interferometer measures film thickness or reflectivity

Optical endpoint detection
Emission spectrum of plasma reveals species being etched

Residual gas analyzer
Monitor gas coming out of chamber
Anisotropic Etch in Si

KOH wet etch is highly anisotropic in crystalline silicon. <111> planes are etched 200 times slower than <100> planes.
Deep RIE (Bosch process)

1. Si
2. SF$_6$
3. C$_4$F$_4$
4. SF$_6$
5. Si
6. Teflon

Images show the process steps: (a) Si substrate, (b) Teflon mask, and intermediate stages with SF$_6$ and C$_4$F$_4$ gas treatments.