Physical Deposition - Evaporation (I)

Cha evaporator

- Materials: power of the evaporator, source
- Thickness control: crystal microbalance
- Evaporation rate \( \propto \frac{\cos \theta \cos \phi}{\pi R^2} \)
  
  Tooling factor

  Density, \( Z \)

- Contamination
- Temperature increases on sample
- Deposition evenness

- Source materials, configurations

Crucible heater  crucible

Mo, Ta  
graphite

BN, Alumina

coil

basket

boat
Physical Deposition- Evaporation (I)

Edwards Auto 306

Atomic force microscopy

<table>
<thead>
<tr>
<th>holder</th>
<th>tooling</th>
<th>Edge/center thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>3”</td>
<td>1.53</td>
<td>0.94</td>
</tr>
<tr>
<td>4”</td>
<td>2.80</td>
<td>0.76</td>
</tr>
</tbody>
</table>
Physical Deposition- Evaporation (II)

E-beam evaporation:

• Reduce crucible contamination

• Charge has to be of pre-melted before use.

• Reduce component outgassing by water cooling

• Multiple pockets allow multi-layer coating of different materials without breaking vacuum.

Multicomponent film of certain stoichiometry is difficult due to different vapor pressure of materials.
Step Coverage and Shadowing

- Metal evaporation is highly directional.

- Aspect Ratio $= \frac{\text{height}}{\text{diameter}}$

- Cannot form a continuous film if AR>1
  
  Marginal if $1 > \text{AR} > 0.5$

**Improvement**

- Raise sample temperature - enhance diffusion

- Sample rotation

**Shadow evaporation**

- Create lines and gaps much smaller than lithography

- 14 nm Al/AlOx/Al tunnel junctions made

Physical Deposition - Sputtering

Breakdown voltage: Paschen law

\[ V = \frac{Pd}{\ln(Pd) + b} \]

\( P \): pressure, \( d \): electrode spacing

Threshold energy \( \sim 10-30 \text{ eV} \)

Ion flux \( J \propto \frac{V^{3/2}}{\sqrt{m_{ion}d^2}} \)

- Less directional coverage
- No melting point limit
- Inert gas pressure \( < 0.1\text{Torr} \)
- \( d \sim 10 \text{ cm} \)
- Maximum yield \( E \sim 1 \text{ keV} \)
- \( E > 10 \text{ keV} \rightarrow \) implantation

Angular dependence

Ref: Campbell: 10.6
CVD Metal Deposition

- Plug can reduce contact area
- Cold wall LPCVD

\[ WF_6 + 3H_2 \rightarrow W + 6HF \]
SiO₂ Etch

- \( \text{H}_2\text{O} : \text{HF} = 6 : 1 \) etches thermal oxide at 120 nm/min

\[ \text{SiO}_2 + 6\text{HF} \rightarrow \text{H}_2\text{SiF}_6 + 2\text{H}_2\text{O} \]

- Selectivity: etch rate of SiO₂/Si = 100

- Buffered HF: maintain HF and pH

\[ \text{NH}_4\text{F} \rightarrow \text{NH}_3 + \text{HF} \]
\[ \text{NH}_4\text{F} : \text{HF} = 6 : 1 \]

At room temperature, Water: BHF=20:1

etch rate: thermal SiO₂ : 300Å/min, Si₃N₄: 10Å/min

Aluminum Etch

\[ \text{CH}_3\text{COOH} : \text{H}_3\text{PO}_4 : \text{HNO}_3 = 20 : 77 : 3 \]

Acetic acid, phosphoric acid, nitric acid
Isotopic Silicon Etch

- HNO₃ oxidizes Si and HF etches the SiO₂ hereby formed

\[ Si + HNO₃ + 6HF \rightarrow H₂SiF₆ + HNO₂ + H₂ + H₂O \]

- HNO₃ (70%): HF (49%): CH₃COOH = 20: 60: 20 produces an etch rate of 165 µm/min

**Region 1: High HF concentrations**
- Reaction limited by HNO₃, follow constant HNO₃ % lines.
- Rate limited by oxidation, etched wafer surface have some oxide.

**Region 2: High HNO₃ concentrations**
- Reaction limited by HF, follow constant HF % lines.
- Rate limited by reduction, etched wafer surface have more oxide.

Ref: Campbell: 11.1
Anisotropic Silicon Etch

- Strong alkaline solutions (pH>12) such as KOH and TMAH (tetramethylammonium hydroxide N(CH₃)₄OH•5H₂O) etch Si via

  \[
  \text{KOH (6 M, or 25.4 wt\%)} \quad Si + 4OH^- \rightarrow Si(OH)_4 + 4e^-
  \]

- SiO₂ or Si₃N₄ are the preferred masking materials; Au can be a mask too.

  Etch rate: Si(100)=13 µm/h  SiO₂ will also be etched

  Etch rate ratios in different crystal orientations:

  \[
  \frac{\text{Si(100)}}{\text{Si(111)}}=300, \quad \frac{\text{Si(110)}}{\text{Si(111)}}=600
  \]
Anisotropic Si(100) Etch
Anisotropic Si(110) Etch

32°C, 60 min

32°C, 75 min

32°C, 90 min

32°C, 33 h, 145 μm

48°C, 4 h

53°C, 4 h, 131+24 μm
Reactive Ion Etch (RIE)

- Reduce wet chemical waste, enhance anisotropic etching

- Capacitively coupled plasmas (DC, RF: 50 kHz, 13.56 MHz), Inductively coupled plasmas (ICP), Electron cyclotron resonance (ECR: 2.45 GHz microwave)

Barrel reactor: uniformity issue, lack of temperature control

Gases: O$_2$, CF$_4$, CCl$_4$, CHF$_3$, CCl$_3$F, CCl$_2$F$_2$, SF$_6$

Volatile products removed from surface.
Reactive Ion Etch (RIE)

- DC bias generated: \( V_{DC} \sim \left( \frac{A_{ground}}{A_{power}} \right)^n \)

- RIE-1C
  
  13.56 MHz, 75-225 mTorr gas pressure
  
  Power: increase energy and density of electrons

- Etch and passivation: SF\(_6\)/O\(_2\) etch Si

  \[
  \begin{align*}
  SF_6 &+ e \rightarrow SF_5 + F \cdot + e \\
  SF_5 &+ e \rightarrow SF_4 + F \cdot + e \\
  O_2 &+ e \rightarrow O + e \\
  O + Si &\rightarrow SiO_x \\
  SiO_x + F &\rightarrow SiF_x + SiO_x F_y
  \end{align*}
  \]

- Polymer formation: can affect profile

- Selectivity

- Increase vertical wall profile needs long mean free path or low pressure but denser plasma: ICP operate a 0.1-1 mTorr
**SF$_6$/O$_2$ RIE**

SF$_6$:O$_2$=10:5 sccm  
0.16 Torr, 50W, 10 min

SF$_6$:O$_2$=20:5 sccm  
0.22 Torr, 50W, 7 min

SF$_6$:O$_2$=18:5 sccm  
0.18 Torr, 50W, 2 min

KOH: 32 min, 50 °C

SF$_6$:O$_2$=20:5 sccm  
0.22 Torr, 50W, 7 min

SF$_6$:O$_2$=10:10 sccm  
0.15 Torr, 50W, 1 min

Black Si formation

**Images:**
- PR9315-B5_02
- PR76I6_06
- PR76N6_40
- PR76P8_07
- PR93-02
- PR93-05