Section 5: Thin Film Deposition
Part 2: Chemical Methods

Jaeger Chapter 6

Chemical Vapor Deposition (CVD)

Source → Chemical reaction → Film → Substrate

More conformal deposition vs. PVD

Shown here is 100% conformal deposition
**LPCVD Examples**

(a) $SiO_2_{\text{gas}} \xrightarrow{350^\circ\text{C}-500^\circ\text{C}} SiO_2_{\text{solid}} + 2H_2 \uparrow$

(b) $PSG : \text{phospho silicate glass} \left[ P_2O_5 + SiO_2 \right]$

$4PH_3 + 5O_2 \rightarrow 2P_2O_5 + 6H_2$

$SiH_4 + O_2 \rightarrow SiO_2 + 2H_2 \uparrow$

(c) $TEOS : \text{tetraethylene orthosilicate}$.

$Si(OC_2H_5)_4 \rightarrow SiO_2 + C_xH_yO_z \uparrow$

**LPCVD Examples**

(d) $Si_3N_4$

$3SiH_4 + NH_3 \rightarrow Si_3N_4 + 12H_2$

(e) Poly - Si

$SiH_4 \xrightarrow{600^\circ\text{C}} Si + 2H_2$

(f) W

$WF_6 + 3H_2 \rightarrow W + 6HF \uparrow$
**CVD Mechanisms**

1. Diffusion of reactant to surface
2. Absorption of reactant to surface
3. Chemical reaction
4. Desorption of gas by-products
5. Outdiffusion of by-product gas

**Example Poly-Si Deposition**

The process involves the reaction of hydrogen and silicon tetrachloride to form silicon and hydrogen chloride. The diagram illustrates the steps of the reaction:

1. Reaction of $H_2$ with $SiH_2Cl_2$
2. Absorption of reactants
3. Chemical reaction
4. Desorption of by-products
5. Outdiffusion of by-products
6. Deposition on the wafer
\[ F_1 = \frac{D}{\delta} = h_G \]
\[ k_s = k_o e^{-\Delta E/kt} \]

\[ \delta = \text{thickness of stagnant layer} \]

\[ F_3 = \frac{k_s C_S}{\delta} \]

\[ F_1 = F_3 \]

\[ F_3 = \frac{1}{1 + \frac{1}{h_G} + \frac{1}{k_s}} \cdot C_G \]

Film growth rate = \( \frac{F_3}{N} \)

\[ \frac{dx}{dt} = \frac{F_3}{N} = \text{constant with time} \]

Note: This result is exactly the same as the Deal-Grove model or thermal oxidation with oxide thickness = 0
**Deposition Rate versus Temp**

![Graph showing deposition rate versus temperature with a log scale. The rate is given by \( R \propto T^{3/2} \). There are two regions indicated: gas transport limited at higher temperatures and surface-reaction limited at lower temperatures.]

**Growth Rate Dependence on Flow Velocity**

![Graph showing growth rate dependence on flow velocity. The growth rate is limited by mass transport up to a certain point and then limited by surface reaction. The flow velocity is given by \( U^{1/2} \).]
**LPCVD Features**

(1) More conformal deposition, if T is uniform

(2) Inter-wafer and intra-wafer thickness uniformity less sensitive to gas flow patterns. (i.e. wafer placement).

**Comments about LPCVD**

(1) Sensitivity to gas flow pattern

(2) Mass depletion problem
Plasma Enhanced CVD

- Ionized chemical species allows a lower process temperature to be used.
- Film properties (e.g. mechanical stress) can be tailored by controllable ion bombardment with substrate bias voltage.

**DIELECTRIC DEPOSITION PROCESSES**

<table>
<thead>
<tr>
<th>Reaction</th>
<th>LPCVD</th>
<th>PECVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiH₄ + NH₃ → Si₃N₄</td>
<td>850°C</td>
<td>200-400°C</td>
</tr>
<tr>
<td>SiH₄ + N₂O → SiO₂</td>
<td>800°C</td>
<td>200-400°C</td>
</tr>
<tr>
<td>TEOS + O₂ → SiO₂</td>
<td>720°C</td>
<td>350°C</td>
</tr>
<tr>
<td>SiH₄ + O₂ → SiO₂</td>
<td>400°C</td>
<td></td>
</tr>
</tbody>
</table>

Atomic Layer Deposition

- The process involves two self-limiting half reactions that are repeated in cycles.
- Unlike CVD, in ALD pulses of precursors are introduced in each cycle.
- ALD is highly conformal and enables excellent thickness uniformity and control down to nm-scale.