Section 5: Thin Film Deposition
Part 2: Chemical Methods

Jaeger Chapter 6
Chemical Vapor Deposition (CVD)

source ->

chemical reaction

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film

substrate

More conformal deposition vs. PVD

Shown here is 100% conformal deposition
LPCVD Examples

(a) $SiO_2 \xrightarrow{gas \rightarrow solid} SiH_4 + O_2 \rightarrow SiO_2 + 2H_2 \uparrow$

$\xrightarrow{gas \ 350^\circ C-500^\circ C}$

(b) PSG: phospho silicate glass. $[P_2O_5 + SiO_2]$

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

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

$350^\circ C-500^\circ C$

(c) TEOS: tetraethyl orthosilicate.

$Si(OC_2H_5)_4 \rightarrow SiO_2 + C_XH_YO_Z \uparrow$
**LPCVD Examples**

(d) $Si_3N_4$

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

(e) Poly $\rightarrow$ Si

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

(f) W

$$WF_6 + 3 H_2 \rightarrow W + 6 HF$$
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

\[ \text{H}_2 + \text{SiH}_2\text{Cl}_2 \rightarrow \]

\[ \text{Stagnant layer} \]

\[ \text{Wafer} \]
CVD Deposition Rate [Grove Model]

\[ \frac{D}{\delta} = h_G \]

\[ k_s = k_o e^{-\Delta E/kt} \]

\[ F_1 = \frac{D}{\delta} \left[ C_G - C_S \right] / \delta \]

\[ F_3 = k_s C_S \]

\[ F_1 = F_3 \]

\( \delta = \text{thickness of stagnant layer} \)
Grove model of CVD (cont’d)

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

Film growth rate = \( F_3 / N \)

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

[log scale] Rate

$\text{gas transport limited}$ \quad R \propto T^{\frac{3}{2}}$

$\text{surface-reaction limited}$

high $T$ \quad low $T$
Growth Rate Dependence on Flow Velocity

mass transport limited

surface reaction limited

(Gas Flow Rate, U)^{1/2}
(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

Furnace tube

(2) Mass depletion problem

in

more

less

out
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>Deposition</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LPCVD</td>
<td>PECVD</td>
</tr>
<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