

Atmospheric Pressure Reactor (APCVD)

- Once used for silicon dioxide passivation in integrated circuits
- Substrates fed continuously
- Large diameter wafers
- Need high gas flow rates
- Mass transport-limited regime (high pressure, so tougher for gas to get to the wafer surface)

Problems/Issues:

- ⊗ Wafers lay flat, and thus, incorporate foreign particles
- ⊗ Poor step coverage

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Low Pressure Reactor (LPCVD)

- Many films available: polysilicon, SiGe, Si₃N₄, SiO₂, phosphosilicate glass (PSG), BPSG, W
- Temp.: 300 → 1150°C
- Press.: 30 → 250 Pa (200mTorr → 2Torr)
- Reaction rate limited; reduced pressure gives gas molecular high diffusivity; can supply reactants very fast!
- Can handle several hundred wafers at a time
- Excellent uniformity

Problems:

- ⊗ Low dep. rate (compared to atm.)
- ⊗ Higher T (than atmospheric)
- ⊗ In hot wall reactors, get deposition on tube walls (must clean)

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Plasma-Enhanced CVD Reactor (PECVD)

- RF-induced glow discharge + thermal energy to drive reactions → allows lower temperature deposition with decent conformability
- Still low pressure

Problems:

- ⊗ Pin-holes
- ⊗ Non-stoichiometric films
- ⊗ Incorporation of H₂, N₂, O₂ contaminants in film; can lead to outgassing or bubbling in later steps

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Polysilicon CVD

Polysilicon Deposition:

(Handwritten red squiggle)

600°C → Fairly high temperature → conformal

$$\text{SiH}_4 \rightarrow \text{Si} + 2\text{H}_2 \text{ (thermal decomposition of silane)}$$

(conformal → high T)

LPCVD (25 to 150 Pa) → 100-200Å/min

- **In situ doping of polysilicon:**
 - ⊗ n-type: add PH₃ (phosphine) or Arsine gases (but greatly reduces dep. rate)
 - ⊗ p-type: add diborane gas (greatly increases dep. Rate)

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Silicon Oxide CVD

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Silicon Dioxide Deposition:

- **After metallization** (e.g., over aluminum)
 - ↪ Temperature cannot exceed the Si-Al eutectic pt.: 577°C
 - ↪ Actually, need lower than this (<500°C) to prevent hillocks from growing on Al surfaces
 - ↪ Similar issues for copper (Cu) metallization
- **Low temperature reactions:**
 - LPCVD
 - $\text{SiH}_4 + \text{O}_2 \xrightarrow{300-500^\circ\text{C}} \text{SiO}_2 + 2\text{H}_2 \rightarrow \text{LTO}$ (silane)
 - LTO
 - $4\text{PH}_3 + 5\text{O}_2 \xrightarrow{300-500^\circ\text{C}} 2\text{P}_2\text{O}_5 + 6\text{H}_2 \rightarrow \text{PSG}$ (phosphine)

Phosphosilicate glass (PSG)

Handwritten notes: hillocks, >577°C, eutectic reaction, contact p-type substrate, leakage!

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Silicon Oxide CVD (cont.)

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- **Phosphosilicate glass can be reflow**
 - ↪ 6-8 wt. % allows reflow @ 1000-1100°C
 - ↪ Very useful to achieve smoother topography
 - ↪ Lower concentration → won't reflow
 - ↪ Higher concentration → corrodes Al if moisture is present
 - ↪ 5-15% P can be used as a diffusion source to dope Si
- **Before metallization:**
 - ↪ Can use higher temperature → better uniformity and step coverage

HTO

$\text{SiCl}_2\text{H}_2 + 2\text{N}_2\text{O} \xrightarrow{\sim 900^\circ\text{C}} \text{SiO}_2 + 2\text{N}_2 + 2\text{HCl}$

(dichlorosilane) (Nitrous oxide) (nice conformal step coverage)

or ...

Handwritten notes: T↑, P↑, ox, Ti, TiO₂, H₂

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Silicon Oxide CVD (cont.)

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$\text{Si}(\text{OC}_2\text{H}_5)_4 \xrightarrow{650-750^\circ\text{C}} \text{SiO}_2 + \text{by-products}$

(Tetraethylorthosilicate) (TEOS)

(excellent uniformity & conformal step coverage)

Handwritten note: P↑, T↑

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Silicon Nitride CVD

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Silicon Nitride Deposition:

- First, note that thermal growth is possible:
 - ↪ Si in NH₃ @ 1000-1100°C
 - ↪ But very slow growth rate, thus, impractical
- **LPCVD reactions:**
 - Silane reaction:** $3\text{SiH}_4 + 4\text{NH}_3 \xrightarrow[(\text{Atm. Press.})]{700-900^\circ\text{C}} \text{Si}_3\text{N}_4 + 12\text{H}_2$
 - Dichlorosilane reaction:** $3\text{SiCl}_2\text{H}_2 + 4\text{NH}_3 \xrightarrow[(\text{LPCVD})]{700-800^\circ\text{C}} \text{Si}_3\text{N}_4 + 6\text{HCl} + 6\text{H}_2$

Handwritten notes: limited to 350 nm thick if thicker → peels, 2µm w/ very little stress

↪ Increase and T = 835°C → Si rich nitride → low stress

Problem: Clobbers your pumps! Expensive to maintain!

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Silicon Nitride CVD (cont.)

Comments on LPCVD nitride films:

- Hydrogen rich: ~8% H₂
- High internal tensile stresses: films >1000Å crack and peel due to excessive stress
- Can get 2µm films with Si-rich nitride
- LPCVD gives high resistivity (10¹⁶ Ω-cm) and dielectric strength (10 MV/cm)

PECVD Nitride:

$$\text{SiH}_4 + \text{N}_2 \xrightarrow{\text{Nitrogen discharge}} 2\text{SiNH} + 3\text{H}_2$$

or

$$\text{SiH}_4 + \text{NH}_3 \xrightarrow{\text{Ar plasma}} \text{SiNH} + 3\text{H}_3$$

PECVD films:

- Non-stoichiometric nitride (Si_xN_y)
- 20-25% H₂ content
- Can control stress
- (10⁶ Ω-cm) resistivity

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Metal CVD

CVD Metal Deposition:

Tungsten (W) - deposited by thermal, plasma or optically-assisted decomposition

$$\text{WF}_6 \rightarrow \text{W} + 3\text{F}_2$$

or via reaction with H₂:

$$\text{WF}_6 + 3\text{H}_2 \rightarrow \text{W} + 6\text{HF}$$

Other Metals - Molybdenum (Mo), Tantalum (Ta), and Titanium (Ti)

$$2\text{MCl}_5 + 5\text{H}_2 \rightarrow 2\text{M} + 10\text{HCl}$$

where M = Mo, Ta, or Ti

(Even Al can be CVD'ed with tri-isobutyl Al ... but other methods are better.)
(Cu is normally electroplated)

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Epitaxy

Epitaxy:

- Use CVD to deposit Si on the surface of a Si wafer
- Si wafer acts as a seed crystal
- Can grow a single-crystal Si film (as opposed to poly-Si)

Modeling - similar to CVD → in fact, the model discussed so far for CVD is more relevant to epitaxy than CVD!

get similar curve:

Reactions - can use SiCl₄, SiH₄, SiH₂Cl₂ for vapor phase epitaxy.

SiCl₄: Silicon tetrachloride
SiH₄: silane
SiH₂Cl₂: dichlorosilane

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Epitaxy (cont.)

Most popular: SiCl₄ (gas) + 2H₂ (gas) $\xrightarrow{1200^\circ\text{C}}$ Si (solid) + 4HCl (gas)

(Note that this is reversible!) ⇒ Reverse reaction (i.e., etching) if have excessive HCl → sometimes used before deposition to clean the Si wafer surface.

Also get a competing reaction.

$$\text{SiCl}_4 (\text{gas}) + \text{Si} (\text{solid}) \leftrightarrow 2\text{SiCl}_2 (\text{gas})$$

- Too much SiCl₄ → etching rather than growth takes place!
- Growth rate too fast → get polysilicon instead of Si. (> 2µm/min.)

See Figure 4.2

Important that the right conc. of SiCl₄ is used!

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