Overview of CVD Processes: Process types

Categories for classification:

- By pressure (APCVD, LPCVD, SACVD)
- By activation: thermal CVD, Plasma enhanced (PE)CVD
- By type of reactor: hot wall / cold wall reactor

Hot wall: reactor wall is at same temperature as the wafer; depositions at the chamber wall → reactor wall cleaning is required after a defined number of wafers processed
mostly hot wall reactors are batch reactor

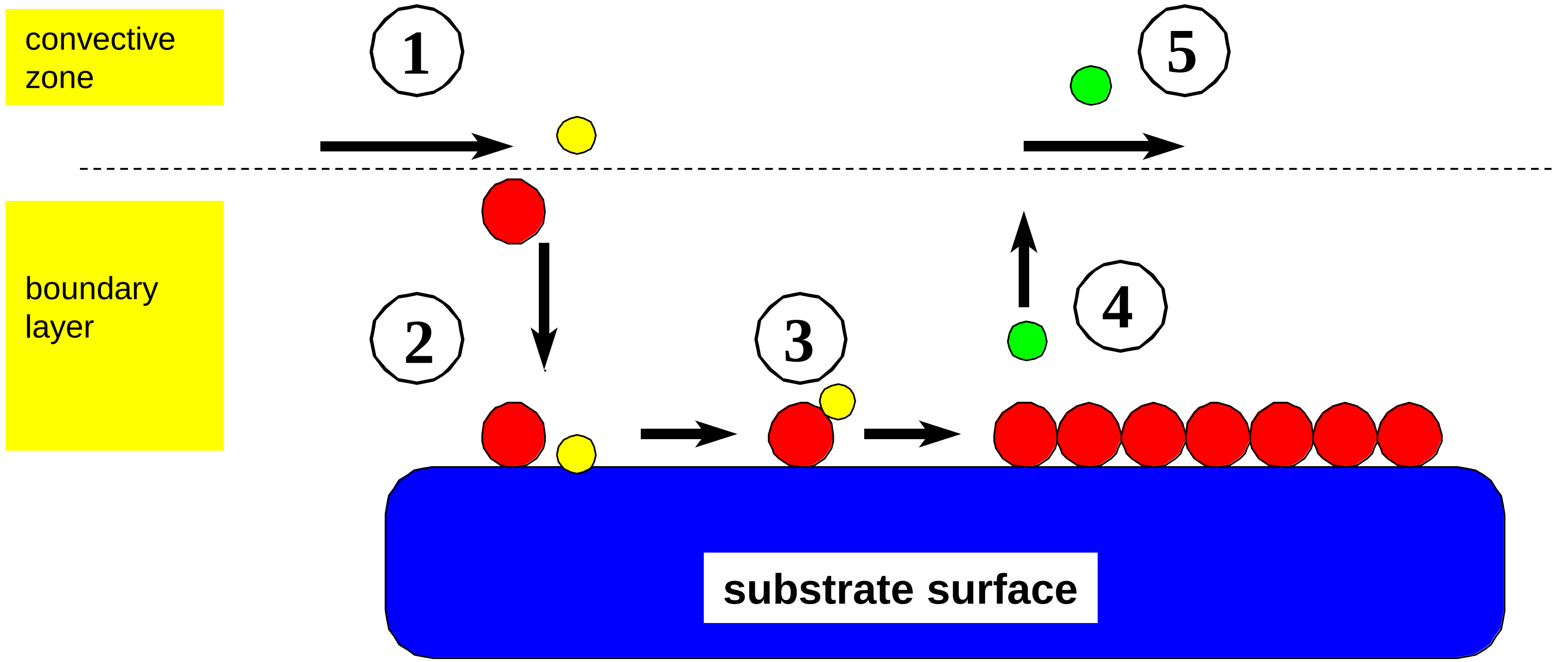
Cold wall: reactor wall is well below wafer temperature; depositions at chamber wall are very low or zero -> chamber cleaning is necessary only after high numbers of wafer processed (or if the process reuqires it more frequently)
often single wafer reactors (in situ (plasma) cleaning is often applied (mean time between wet cleans is minimized)

Overview of CVD Processes

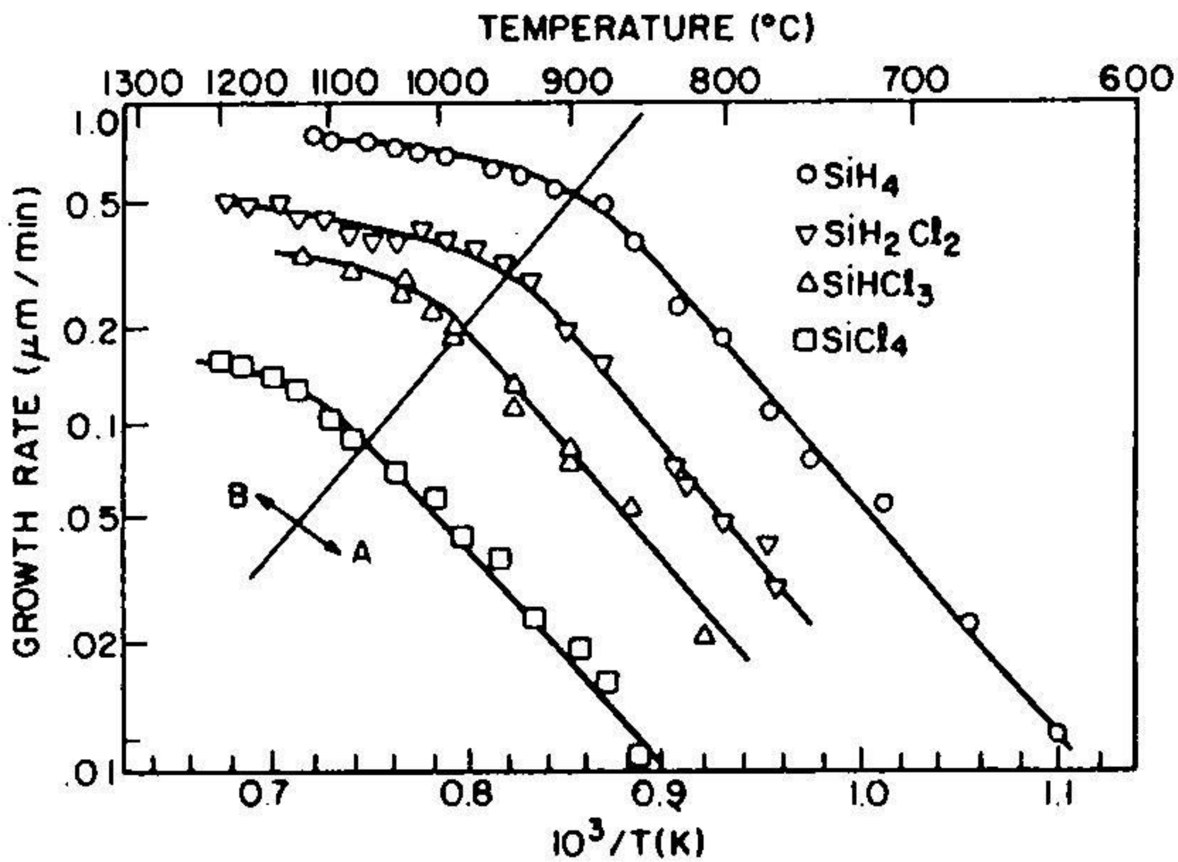
CVD

Process	Type of Reactor	Examples
APCVD (**A**tmospheric **P**ressure **CVD**)	Hot wall	Poly-Si, SiO_2...
	Cold wall	Si epitaxy, SiO_2...
SACVD (**S**ub-**A**tmospheric Pressure **CVD**)	Cold wall	SiO_2: gap fill (BEOL) Shallow trench isolation – STI
LPCVD (**L**ow **P**ressure **CVD**)	Hot wall	Poly-Si, SiO_2, Si_3N_4...
	Cold wall	Si epitaxy, W, Al, Cu...
PECVD (**P**lasma **E**nhanced **CVD**)	Hot wall	SiO_2, Si_3N_4...
	Cold wall	SiO_2, Si_3N_4...

Thin film deposition: CVD – basic processes



1 transport of reactands/precursors by gas flow/carrier gas stream (enforced convection)
2 Diffusion through the boundary layer (caused by the concentration gradient) and adsorption (**physisorption** or chemisorption in case of a direct reaction with the substrate)
3 Surface diffusion, surface reaction, layer growth
4 Reaction byproduct is desorbing from wafer surface, diffusion through the boundary layer (caused by the concentration gradient) to the convective zone
5 Removal of byproducts in the gas flow to the exhaust (enforced convection)



A - reaction limited growth → high step coverage

B - mass-transport limited growth
→ Reduction in the step coverage

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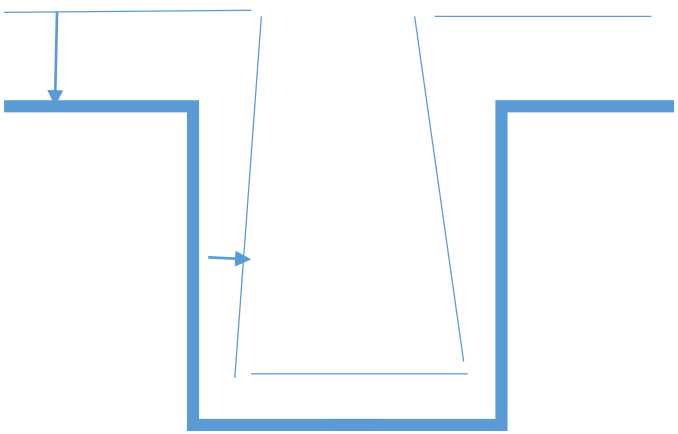
Step Coverage:



Step coverage = ratio of film thickness in the feature / at the sidewall to film thickness on top

If step coverage is 100%, we have a conformal film (deposition)

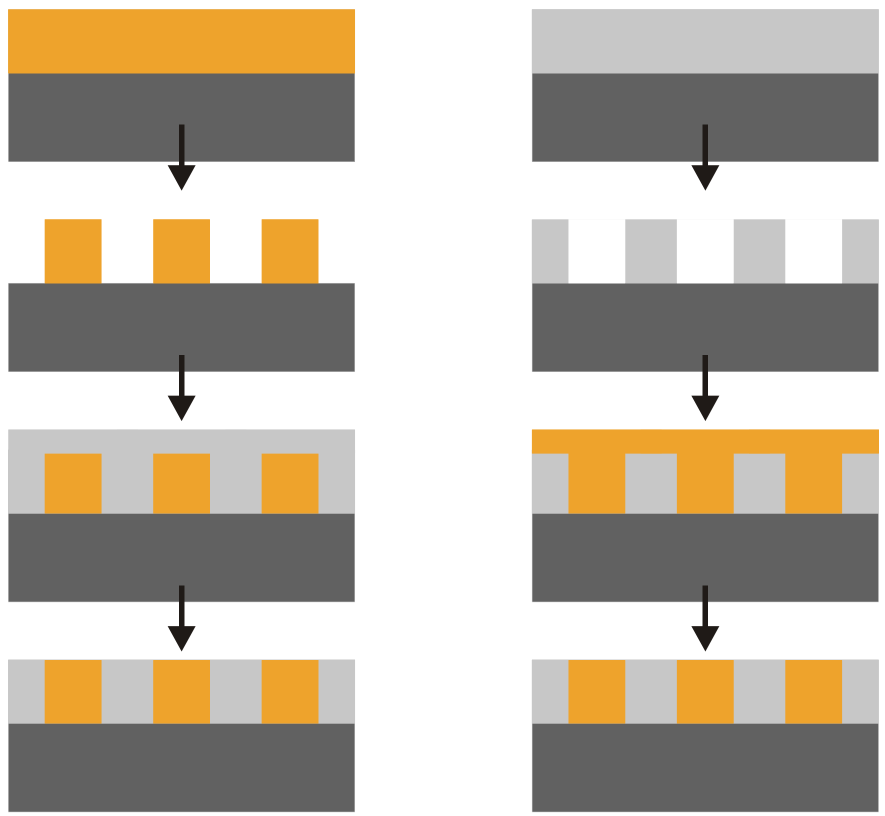
Metallization Approaches in the on-chip interconnection system

Architectures:
- Cu lines/vias: dual damascene (single damascene would also be possible)
- W contacts or vias: single damascene
- Al lines: subtractive approach (conventional)

Materials:
- Horizontal interconnect (lines): Al or Cu
- Vertical interconnects (contact (to S/D/G), vias): W, Cu

Metallization Approaches in the on-chip interconnection system

Conventional Technology (Subtractive)	Single Damascene Technology
Metal deposition	Isolator Deposition
Metal structuring	Isolator structuring
Isolator Deposition	Metal deposition
Isolator back etch and planarization	Metal back etch and planarization



Q1 Which types of chemical reactions involved Chemical Vapor Deposition processes do you know?

One reactand = precursor

1) (thermal decomposition/) pyrolysis (example: ($SiH_4 \rightarrow Si$)
2) Disproportionation (e.g. Cu precursor Cupraselect™)

Two reactands (two precursors or one precursor and one co-reactand) or more

1) Reduction (example: W-CVD: precursor WF_6, co-reactand: Hydrogen H_2)
2) Oxidation (formation of an oxide: two precursors)
3) Nitridation (example: TiN deposition using $TiCl_4 + NH_3$, two precursors)

Typical reaction types in CVD

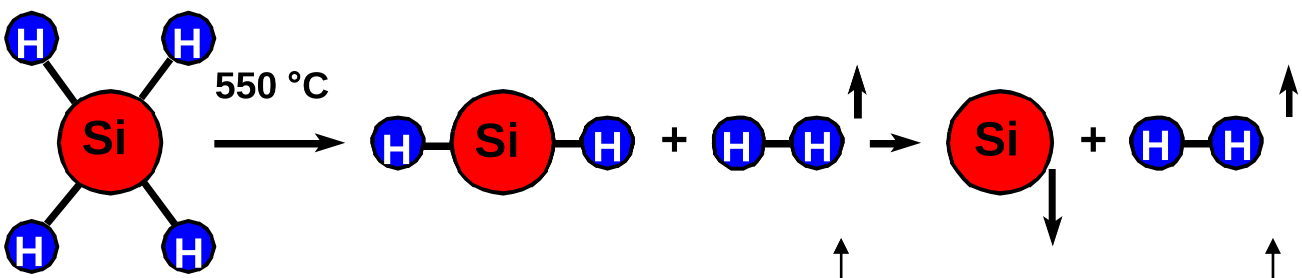
1. Dissociation reaction

$$(AB)_g \underset{}{\overset{T}{\rightleftarrows}} A_s + B_g \quad \text{(Pyrolytic dissociation)}$$

s = solid
g = gaseous

Pyrolysis: Thermal decomposition of gaseous species (hydrides, carbonyls, metal-organic compounds) on hot substrates

→ **Example:** ***LPCVD of polycrystalline or amorphous silicon films***



$$SiH_4 \longrightarrow SiH_2 + H_2\uparrow \longrightarrow Si\downarrow + H_2\uparrow$$

2. Reaction of two gaseous substances on the surface

$$(AB)_g + (CD)_g \rightleftharpoons (AC)_s + (BD)_g$$ = dominating reaction type

Oxidation: **CVD of SiO_2 *and glasses* by reaction of gaseous hydrides or halides of Si *and dopants* with oxygen or oxygen-containing compounds**

→ **Example: *LPCVD of PSG***

$$SiH_4 + O_2 \xrightarrow{450\ °C} SiO_2\downarrow + 2\ H_2\uparrow$$

$$4\ PH_3 + 5\ O_2 \xrightarrow{450\ °C} 2\ P_2O_5\downarrow + 6\ H_2\uparrow$$

Nitridation:

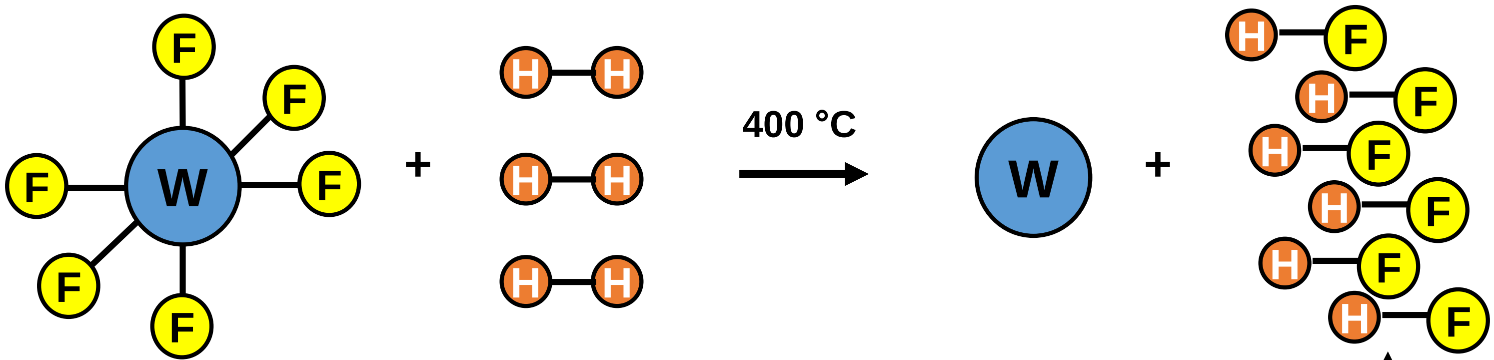
→ **Examples:** ***LPCVD of silicon nitride***

$$3\ SiH_4 + 4\ NH_3 \xrightarrow{800\ °C} Si_3N_4\downarrow + 12\ H_2\uparrow$$

$$3\ SiCl_2H_2 + 4\ NH_3 \xrightarrow{700\ °C} Si_3N_4\downarrow + 6\ H_2\uparrow + 6\ HCl\uparrow$$

<u>Reduction:</u> Reaction of halides or oxygen-containing compounds with hydrogen or hydrogen-containing compounds to generate solid deposits and gaseous byproducts

→ Examples: ***<u>LPCVD of Tungsten, blanket deposition</u>***



$$WF_6 \; + \; 3\ H_2 \longrightarrow W \; + \; 6\ HF\uparrow$$

Requirements for conducting CVD barriers (in copper interconnects)

- *Ultrathin, but nevertheless very stable*
  - *High density / no or stuffed diffusion paths*
  - *Low defect level*
  - *Thermodynamically stable*
- *Good adhesion to underground and Cu*
- *Low stress*
- *Low resistivity*
- *Conformal or at least uniform sidewall coverage*