Principles of Micro- and Nanofabrication for Electronic and Photonic Devices

Film Deposition
Part IV: CVD

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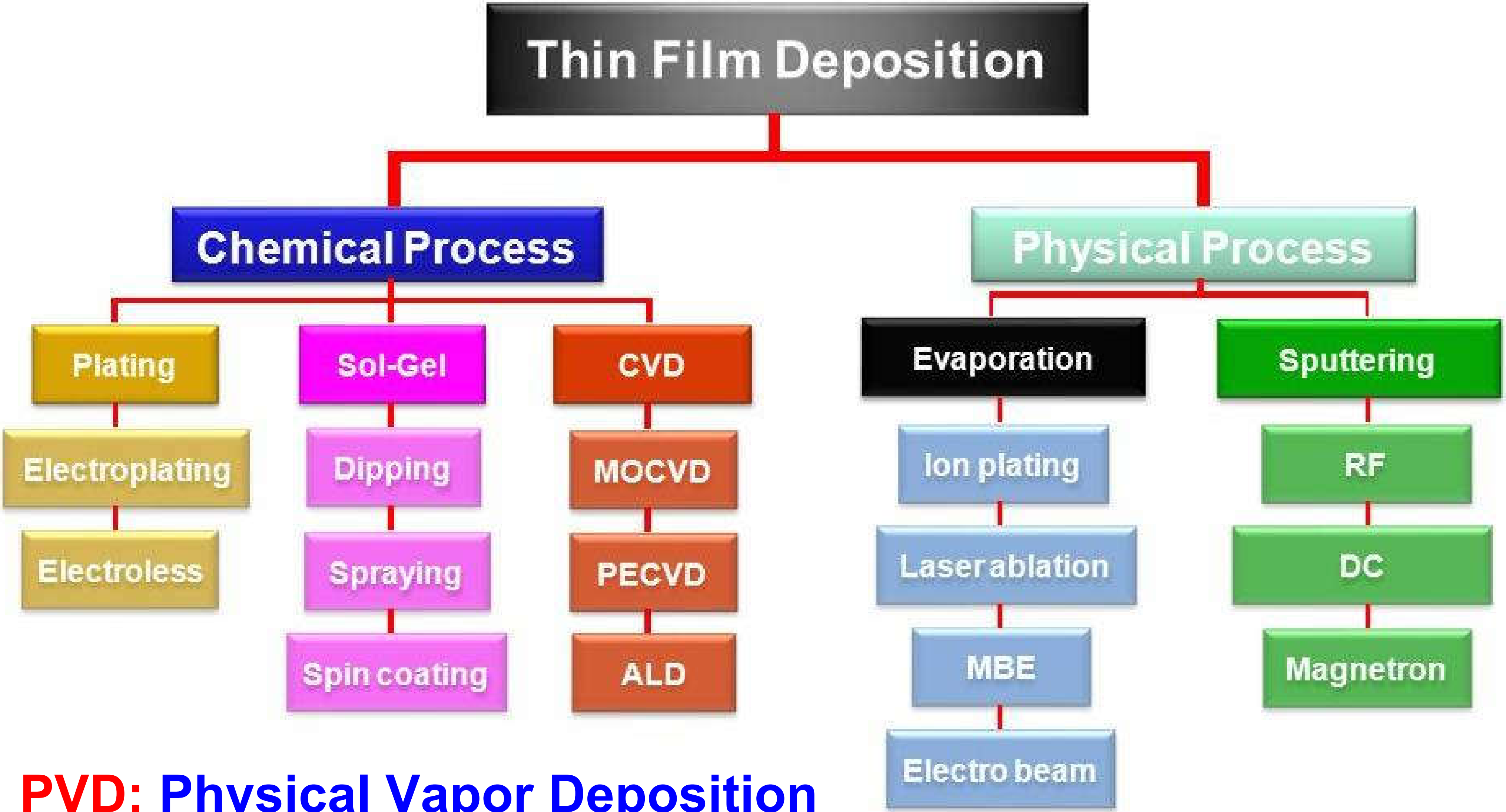
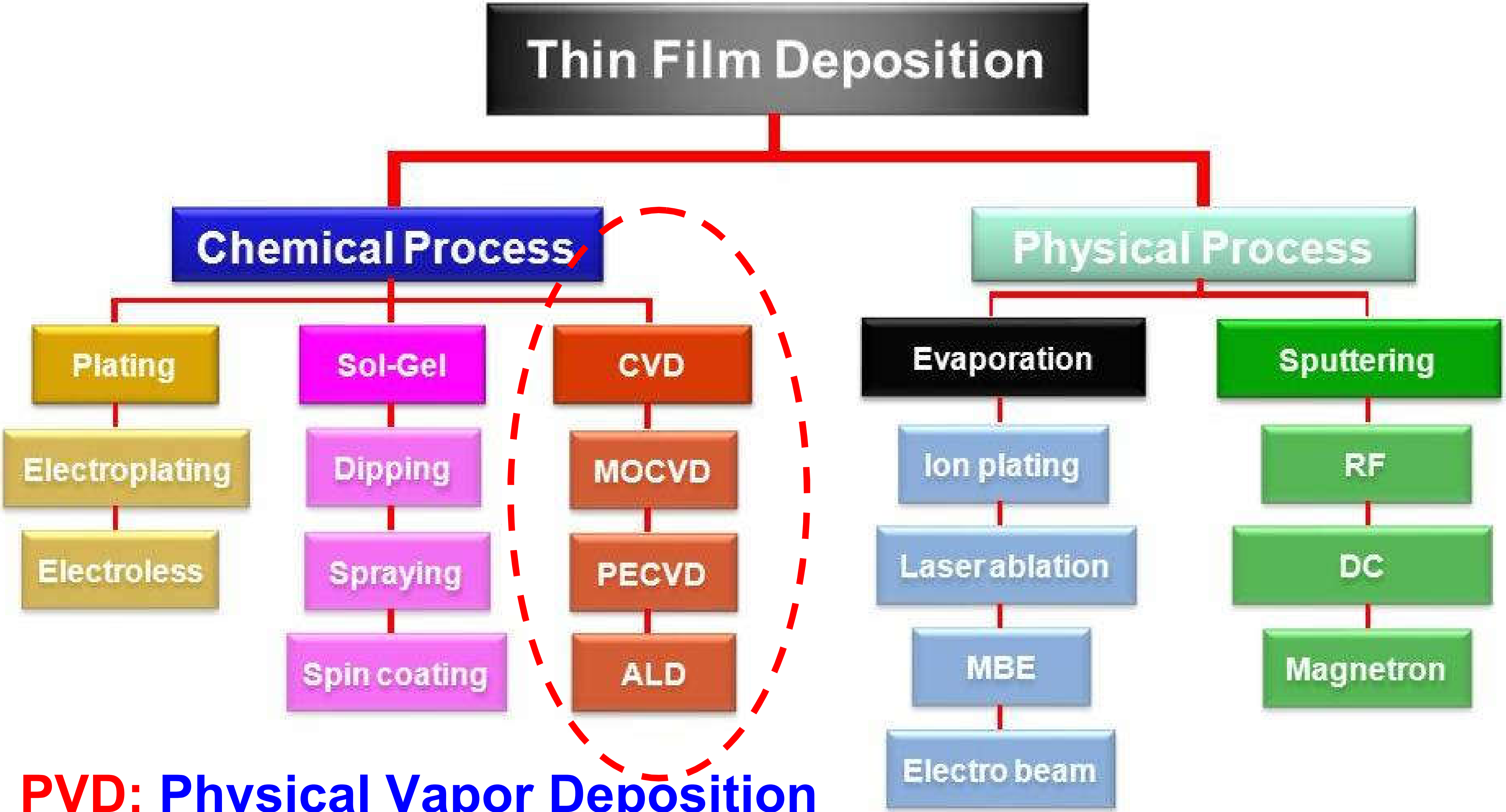
Film Deposition



PVD: Physical Vapor Deposition

CVD: Chemical Vapor Deposition

Film Deposition

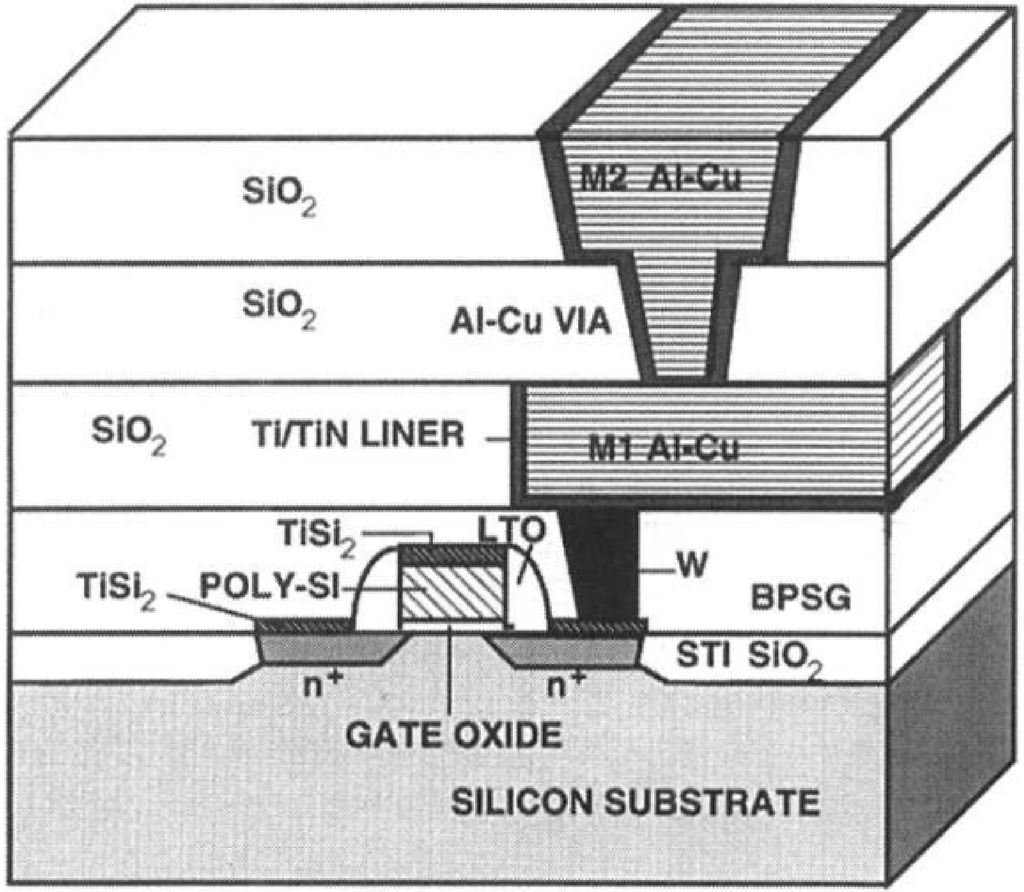


PVD: Physical Vapor Deposition

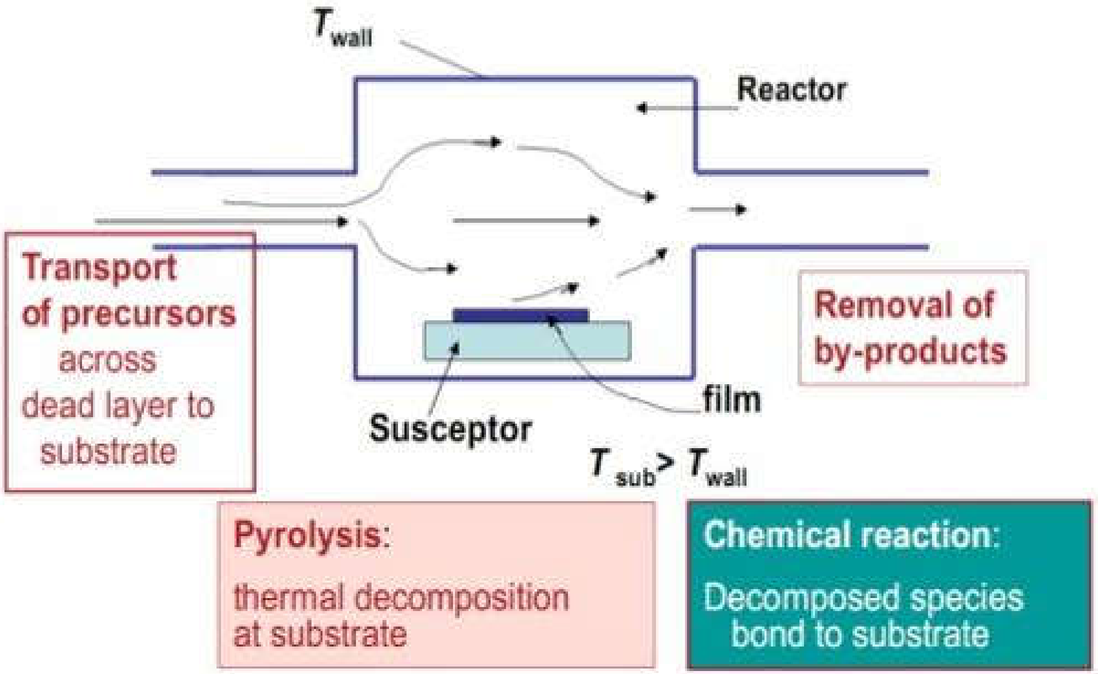
CVD: Chemical Vapor Deposition

Thin Film in CMOS

- **CVD**
  - Si
  - poly-Si
  - W, SiO_2, ...
- **PVD**
  - Al, Ti
  - ...
- **Electrodeposition**
  - Cu

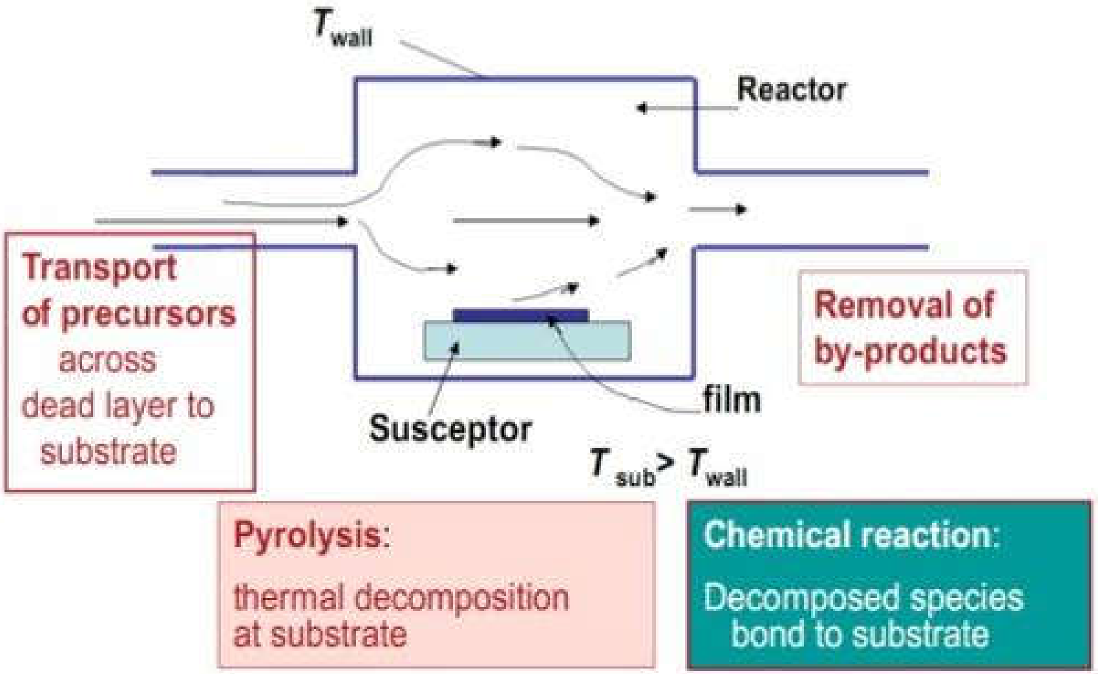


CVD: Chemical Vapor Deposition



- **APCVD** — **Atmosphere Pressure CVD**
- **LPCVD** — **Low Pressure CVD**
- **UHVCVD** — **Ultrahigh Vacuum CVD**
- **MOCVD** — **Metal Organic CVD**
- **PECVD** — **Plasma Enhanced CVD**
- **ALD** — **Atomic Layer Deposition**
- **...**

CVD: Chemical Vapor Deposition



- **Example:**

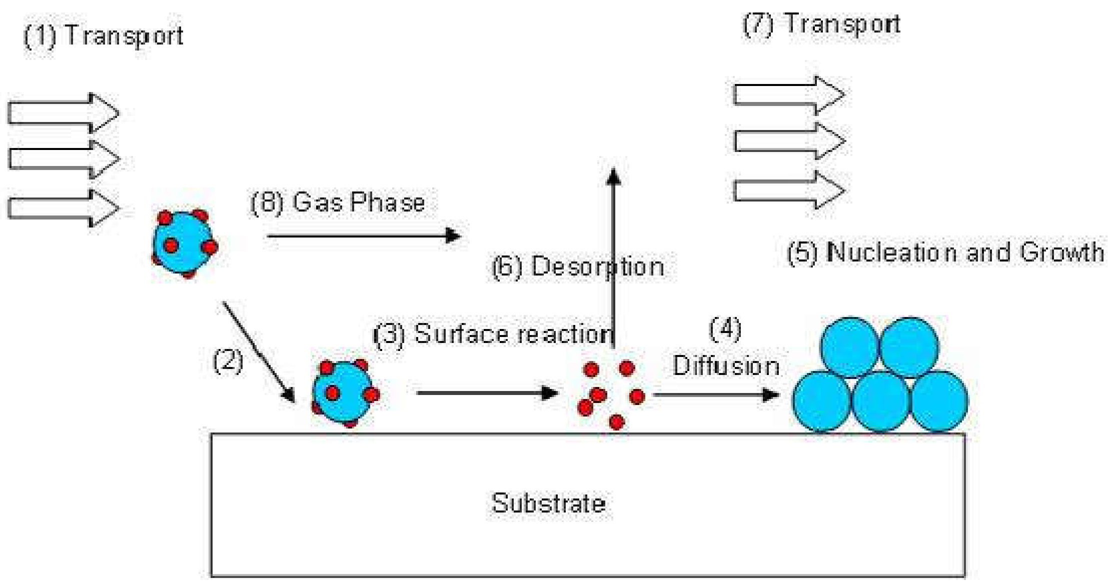
$$SiH_4\ (g) = Si\ (s) + 2H_2\ (g)$$

$$SiH_4\ (g) + O_2\ (g) = SiO_2\ (s) + 2H_2\ (g)$$

CVD

- Process Parameters
  - Time
  - Temperature
  - Gas type
  - Gas pressure
  - Flow rate
  - ...

- gas transport
- surface reaction



- Control Parameters
  - Film thickness
  - Crystallinity
  - Film quality (defects, dielectric strength, ...)

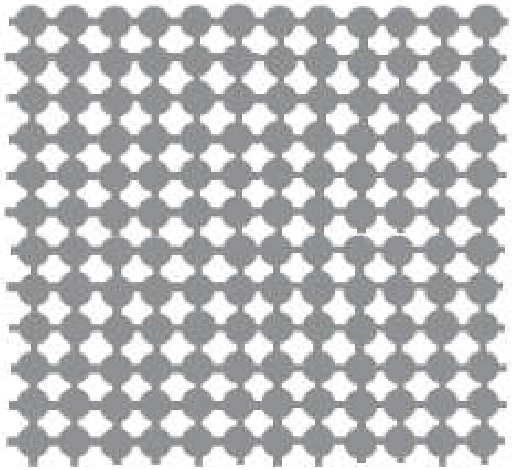
Q: differences between CVD and oxidation?

Crystallinity

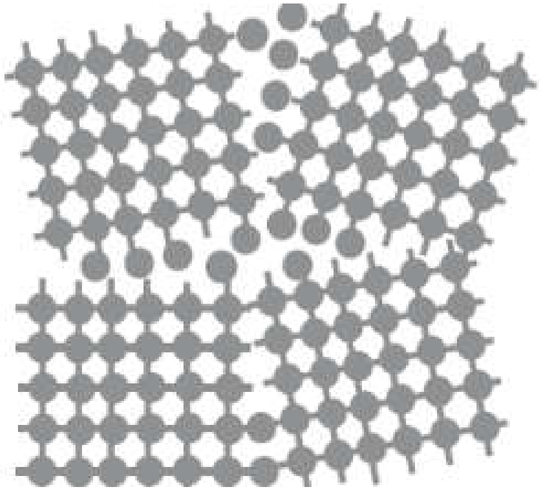
Deposit Si on Si

$SiH_4\ (g) = Si\ (s) + 2H_2\ (g)$

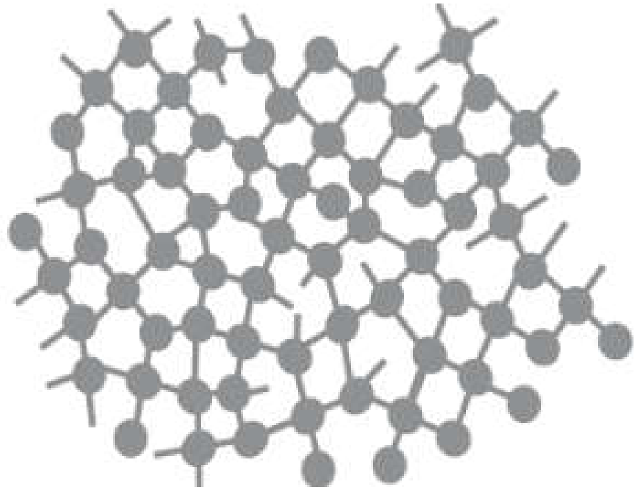
Monocrystalline



Polycrystalline



Amorphous



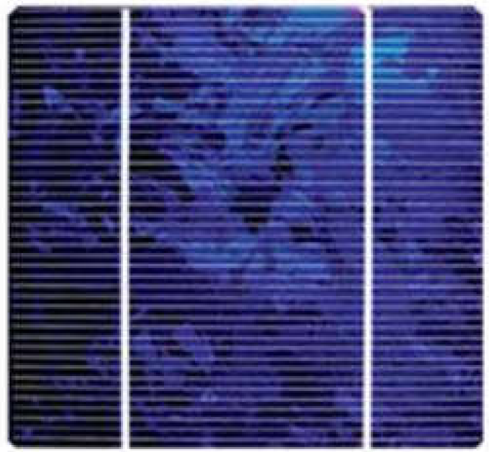
800 °C ← 600 °C temperature

deposition rate →

Crystallinity

Silicon Solar Cells

Monocrystalline Polycrystalline Amorphous



← temperature

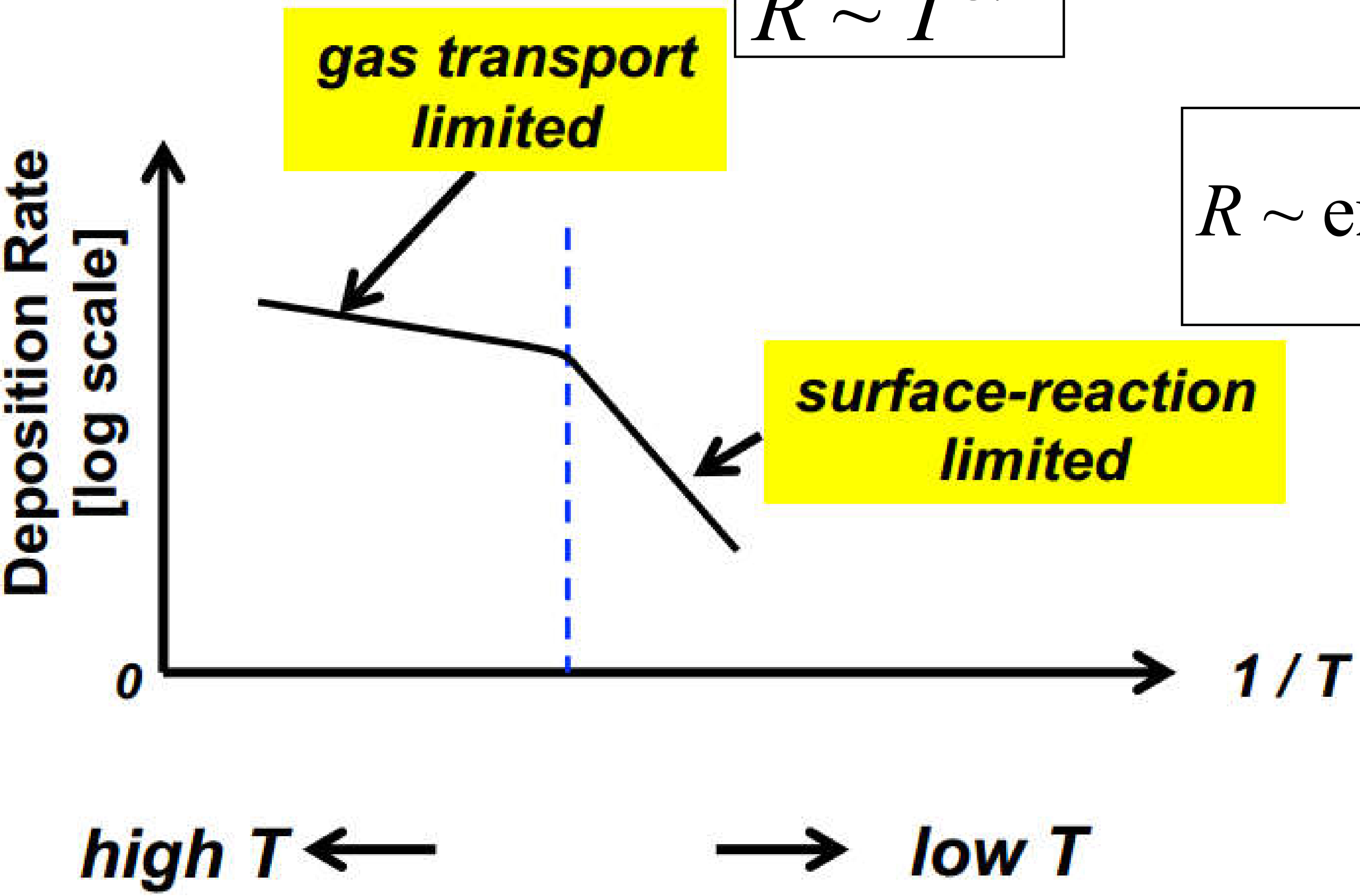
← efficiency

← price

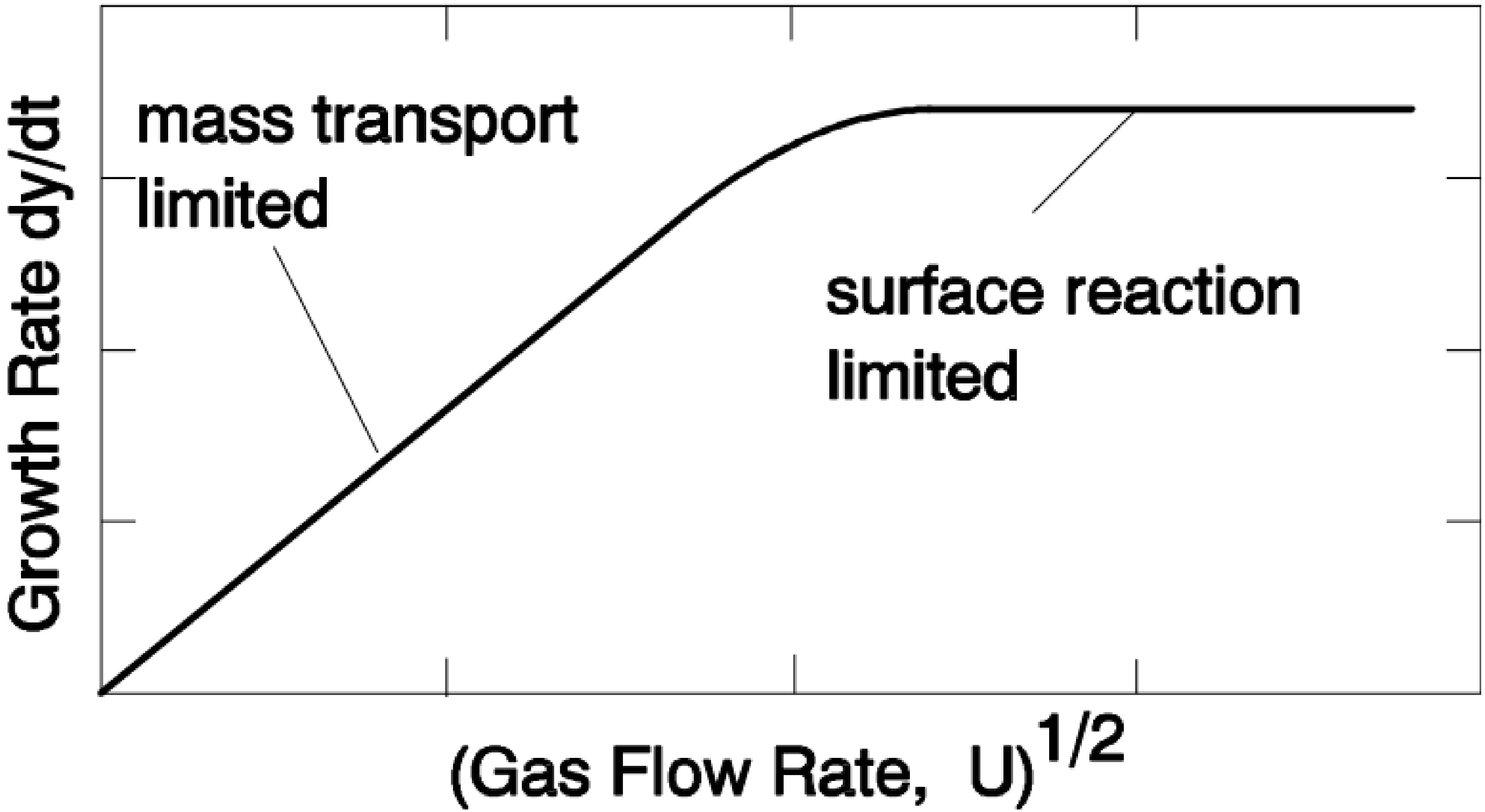
Deposition Rate vs. Temperature

$$R \sim T^{3/2}$$

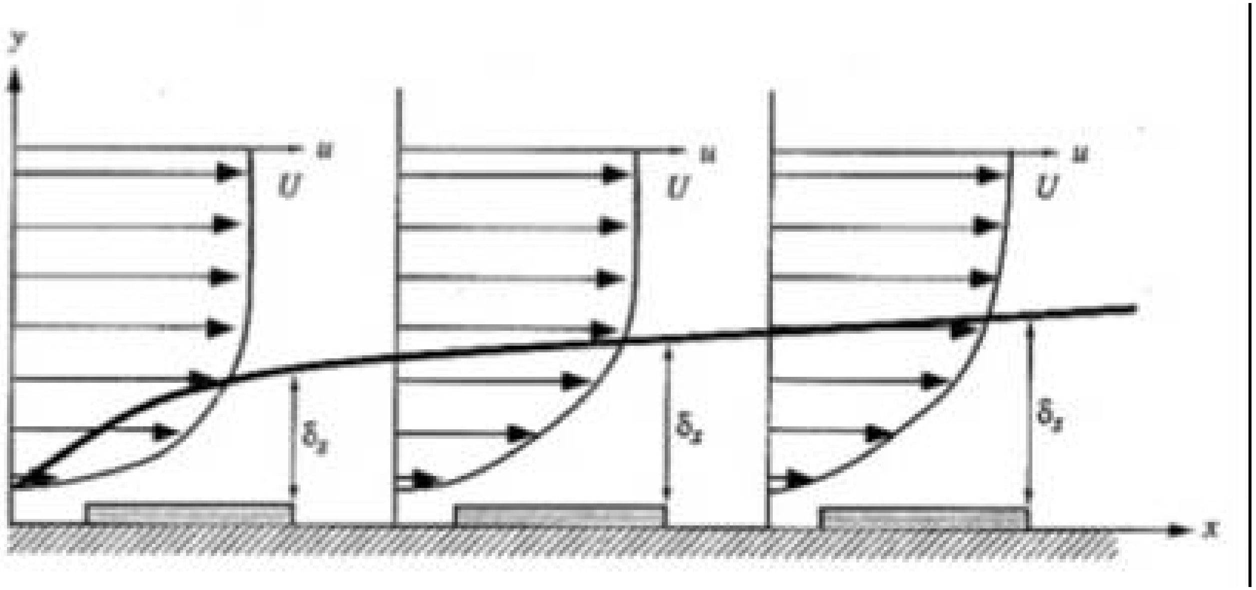
$$R \sim \exp\left(-\frac{E}{kT}\right)$$

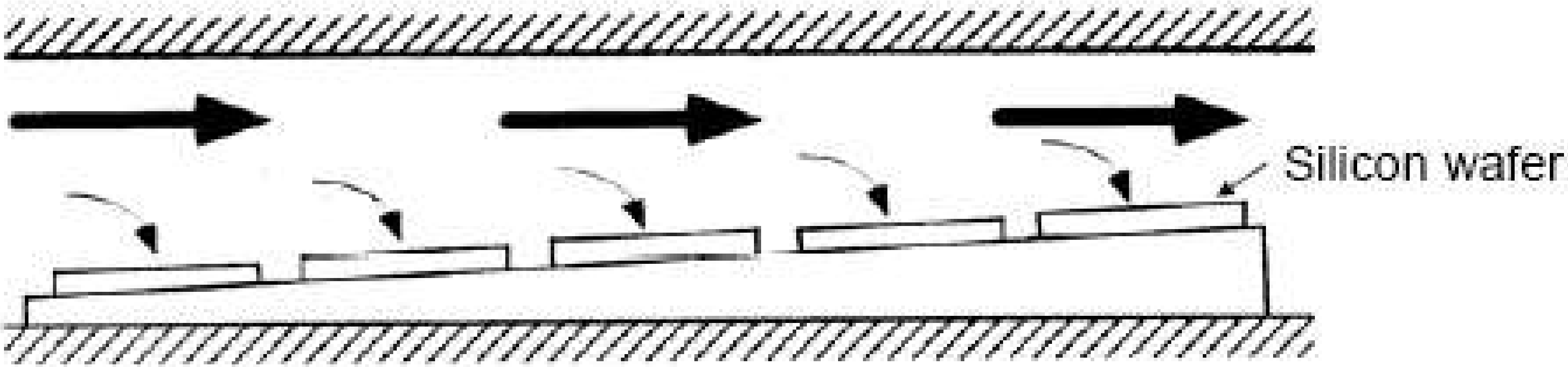


Deposition Rate vs. Gas Flow



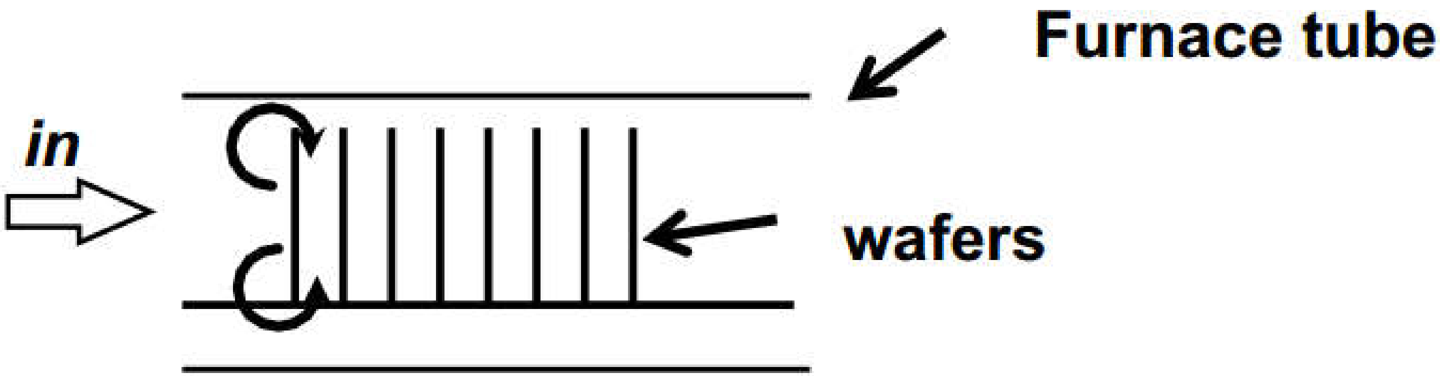
Issues of Gas Transport

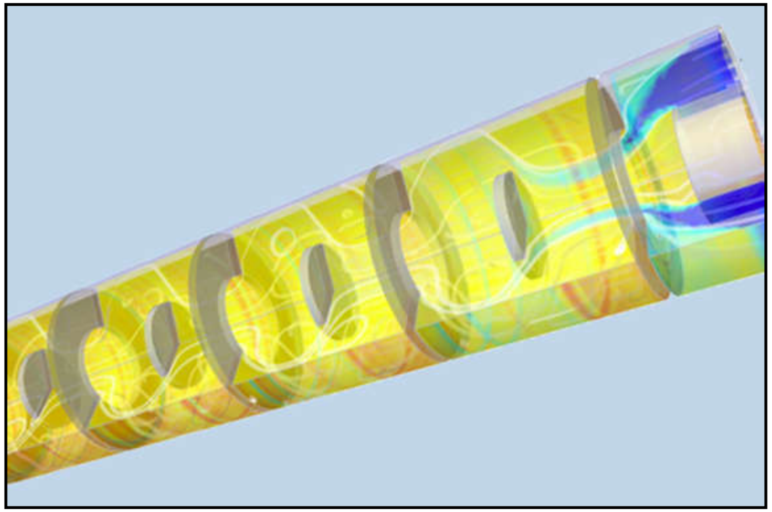




tilt the samples to improve uniformity

Issues of Gas Transport

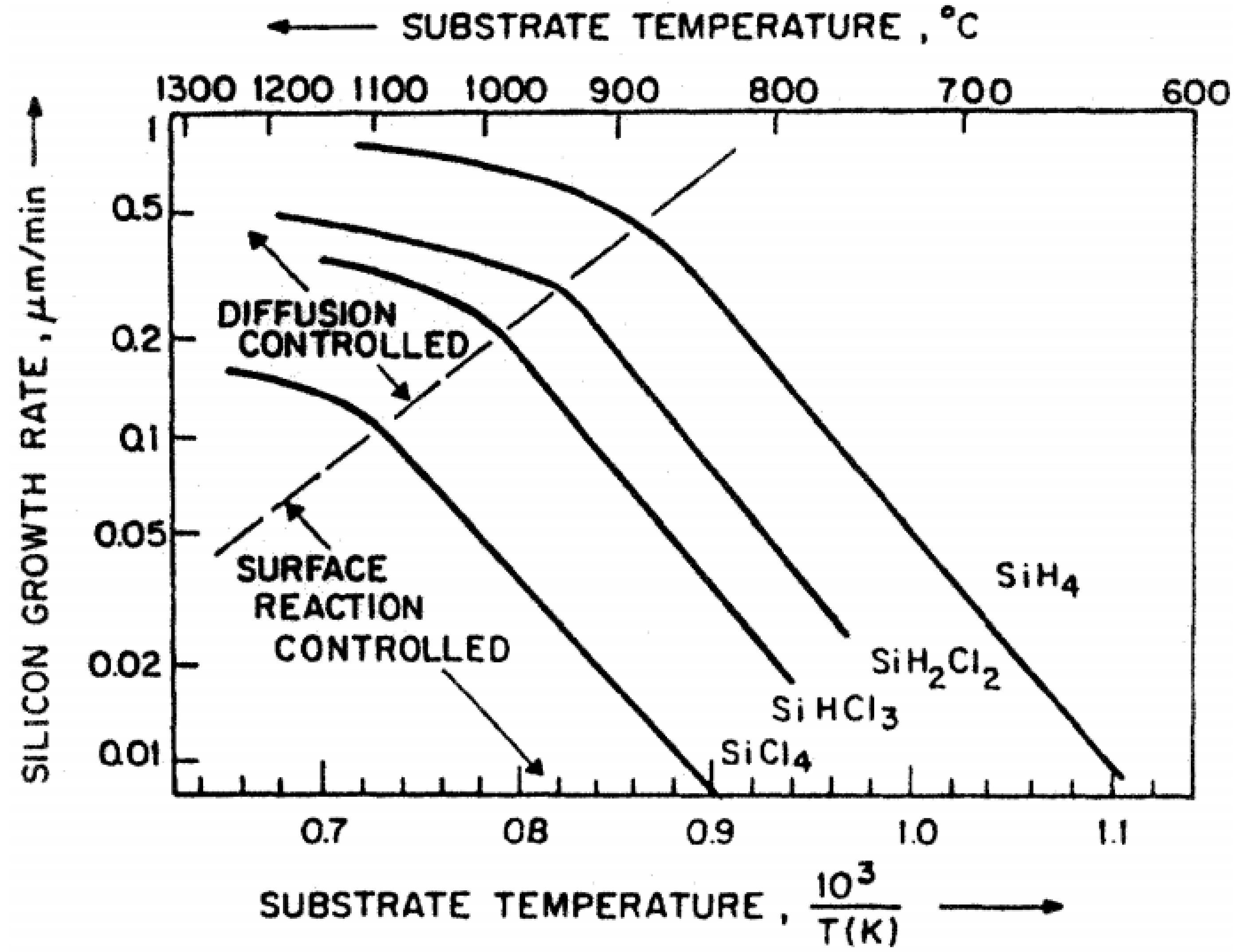




better to operate at surface reaction limited zone (low T, high flux rate)

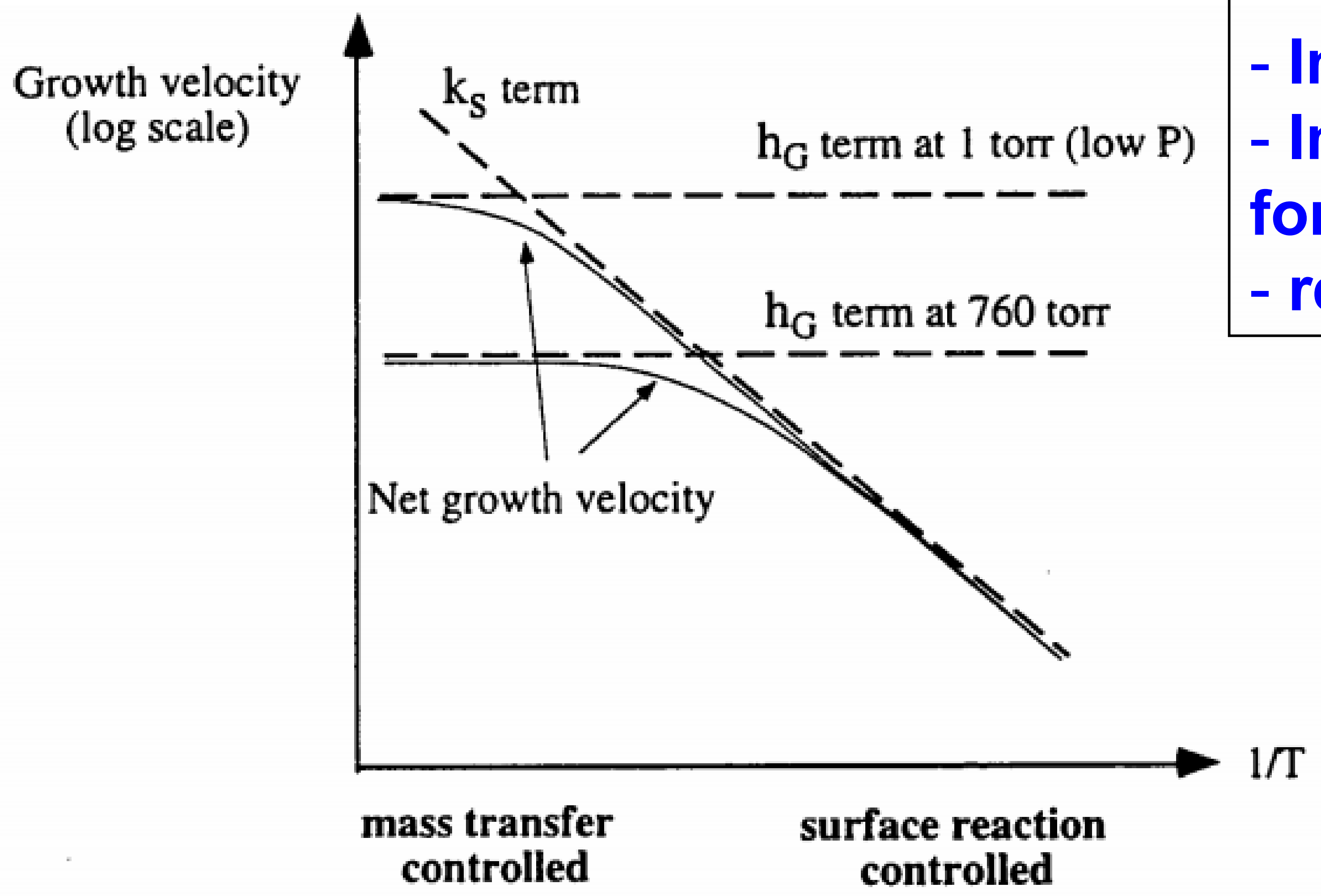
Gas Types

Si CVD



LPCVD

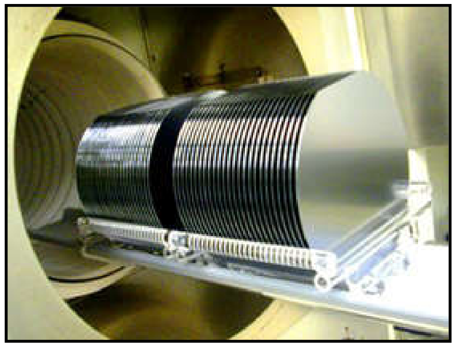
Low Pressure CVD



at low pressure,

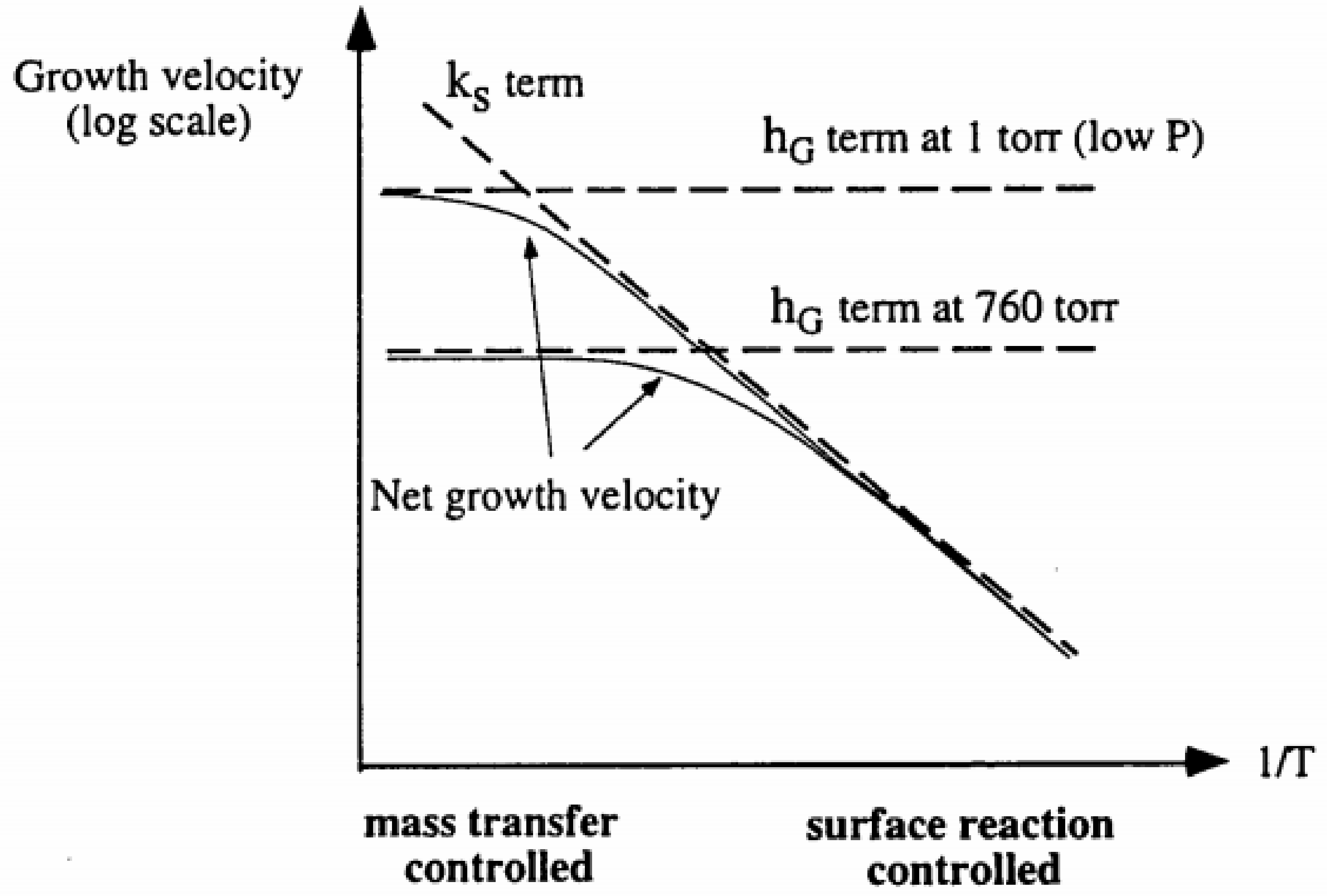
- **Increased rate**
- **Increased zone for surface reaction**
- **reduce cost**

why ??



LPCVD

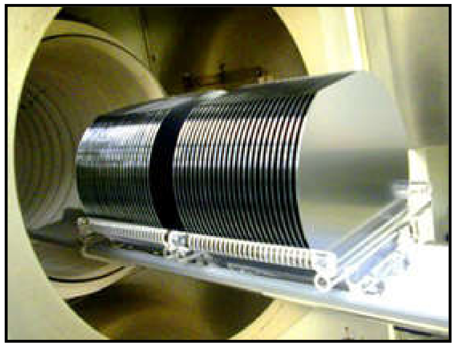
Low Pressure CVD



molecular mean free path λ

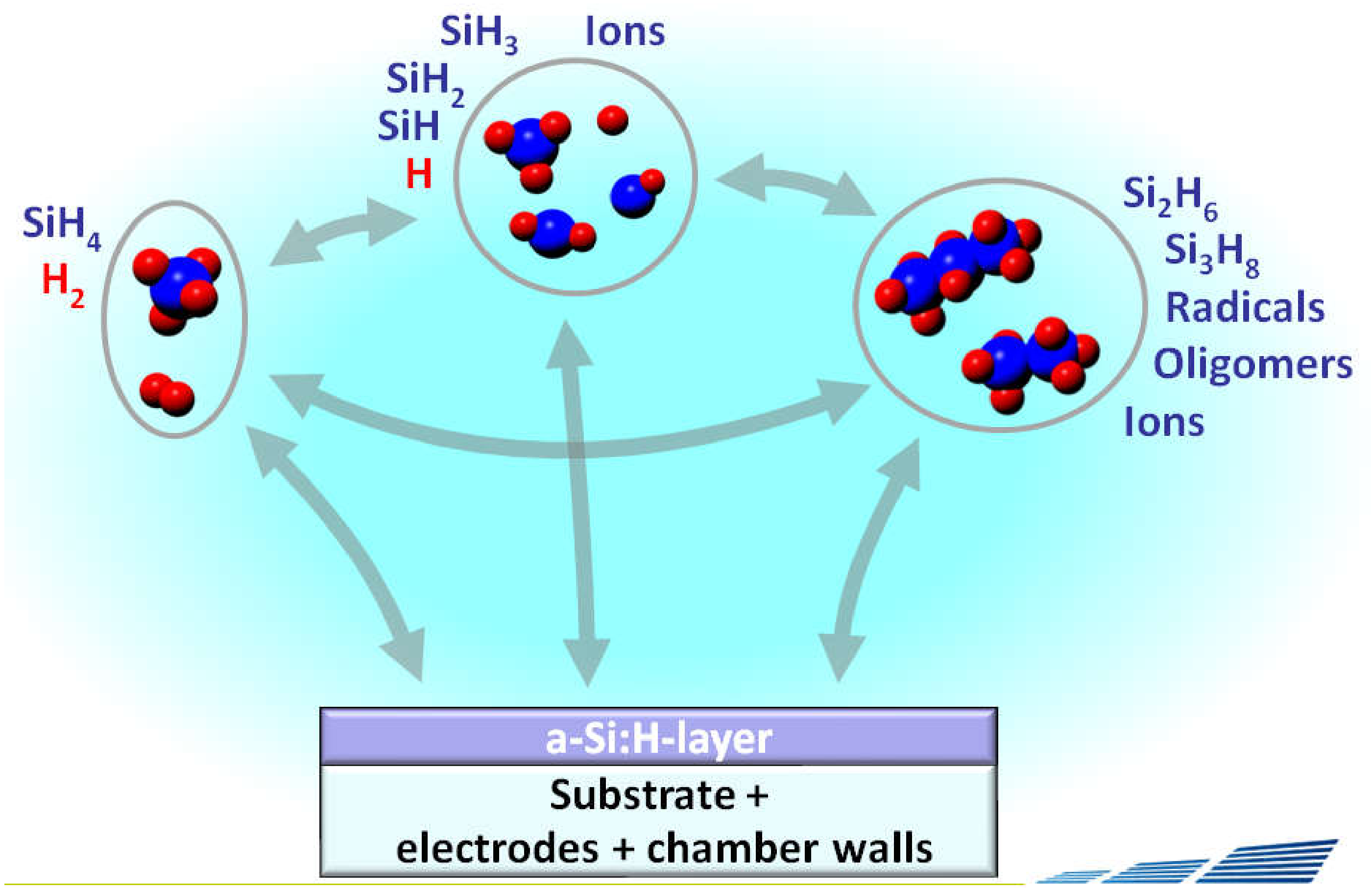
$$\lambda = \frac{kT}{\sqrt{2}\pi r^2 p}$$

$p \downarrow$ $\lambda \uparrow$



PECVD

Plasma Enhanced CVD



plasma enhances the ion energy:

- higher dep. rate
- lower temperature

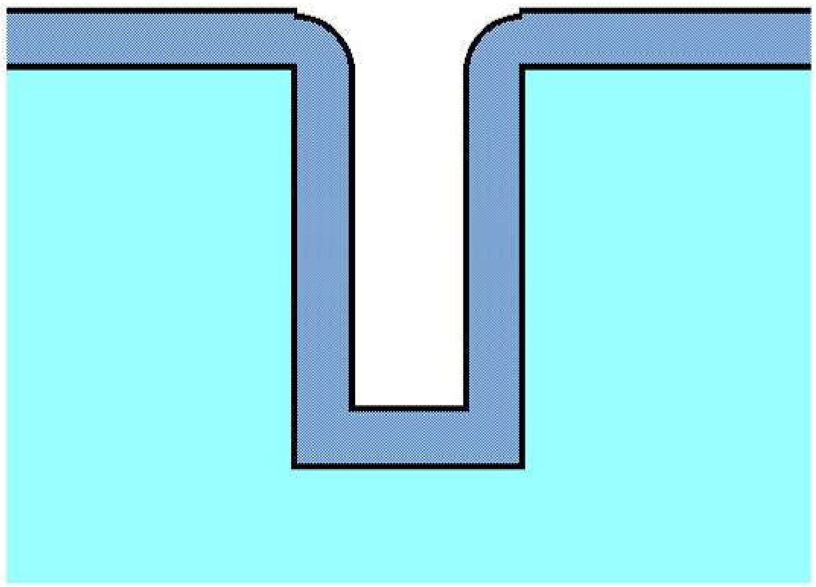
SiO_2 Growth Methods

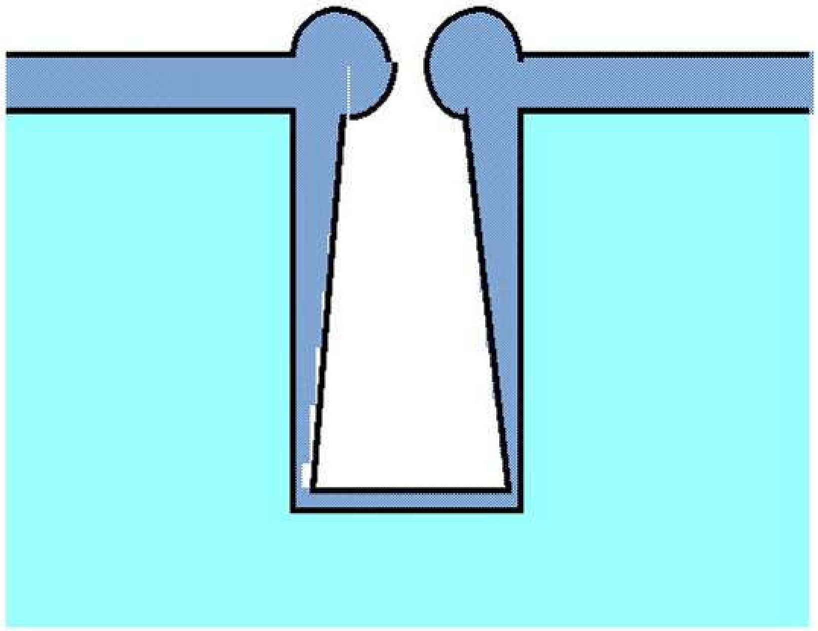
- **dry oxidation**
  - $Si + O_2$ ~ 1100 °C
- **wet oxidation**
  - $Si + H_2O$ ~ 1000 °C
- **APCVD / LPCVD**
  - $SiH_4 + O_2$ 400~600 °C
- **PECVD**
  - $SiH_4 + N_2O$ 200~400 °C
- **Sputter or Evaporation**
  - substrate at room temperature

↑ growth temperature

↑ film quality

Step Coverage





surface reaction controlled

- LPCVD, UHVCVD, oxidation
- ALD
- ...

diffusion/transport controlled

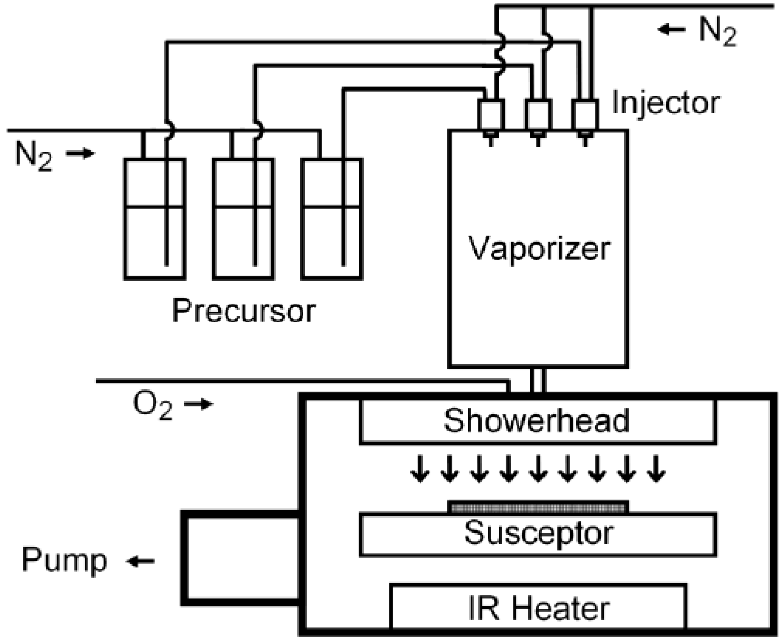
- PECVD
- PVD (sputter, evaporation)
- ...

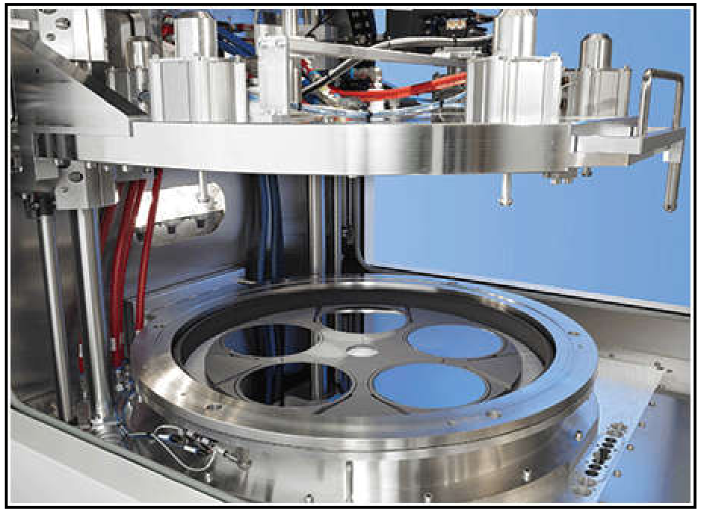
MOCVD

Metal-Organic CVD

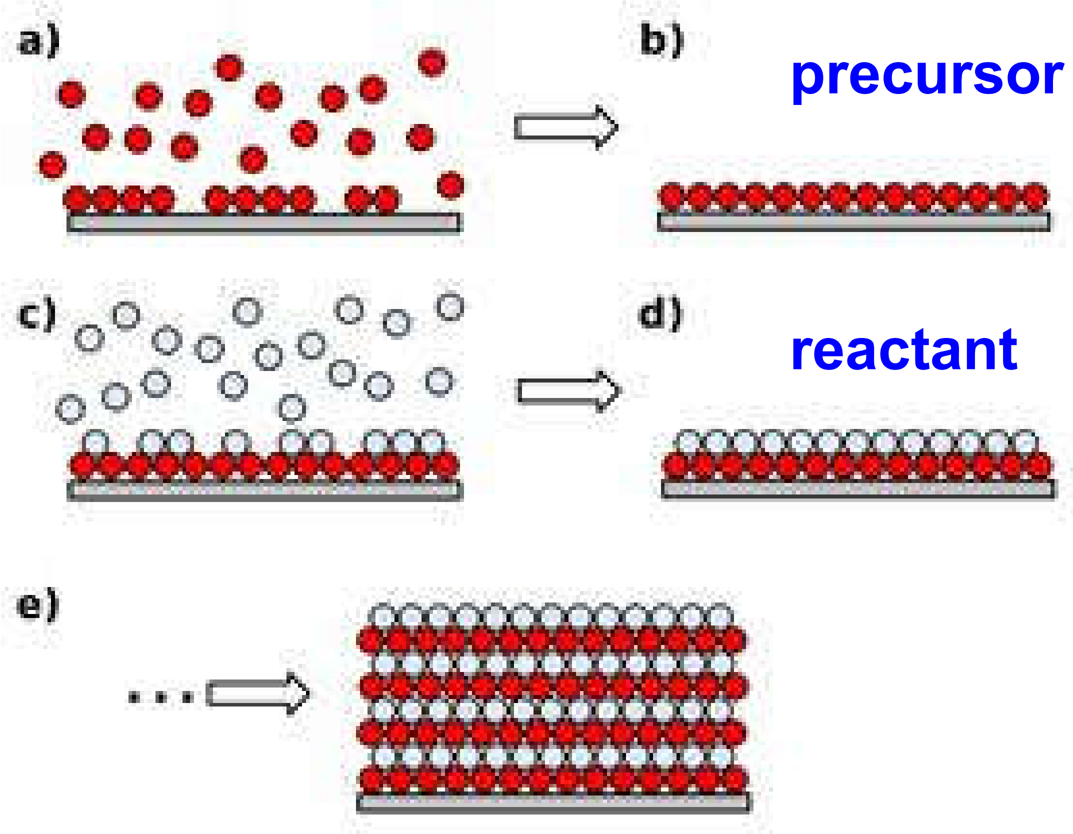
$Ga(CH_3)_3$ (g) + AsH_3 (g) = $GaAs$ (s) + $3CH_4$ (g)

$Ga(CH_3)_3$ (g) + NH_3 (g) = GaN (s) + $3CH_4$ (g)





ALD: Atomic Layer Deposition

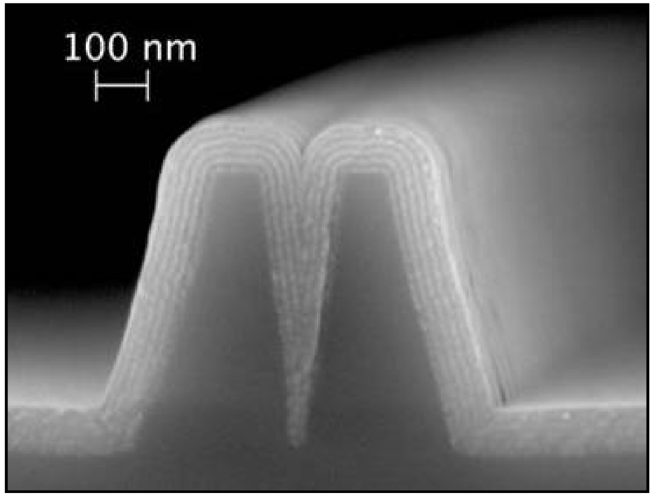


$2Al(CH_3)_3 + 3H_2O = Al_2O_3 + 6CH_4$

$Si(OCH_2CH_3)_4 + H_2O = SiO_2 + ...$

$Hf(N(C_2H_5)(CH_3))_4 + H_2O = HfO_2 + ...$

- *self limited growth*
- *layer by layer*
- *high uniformity*
- *accurate thickness control*

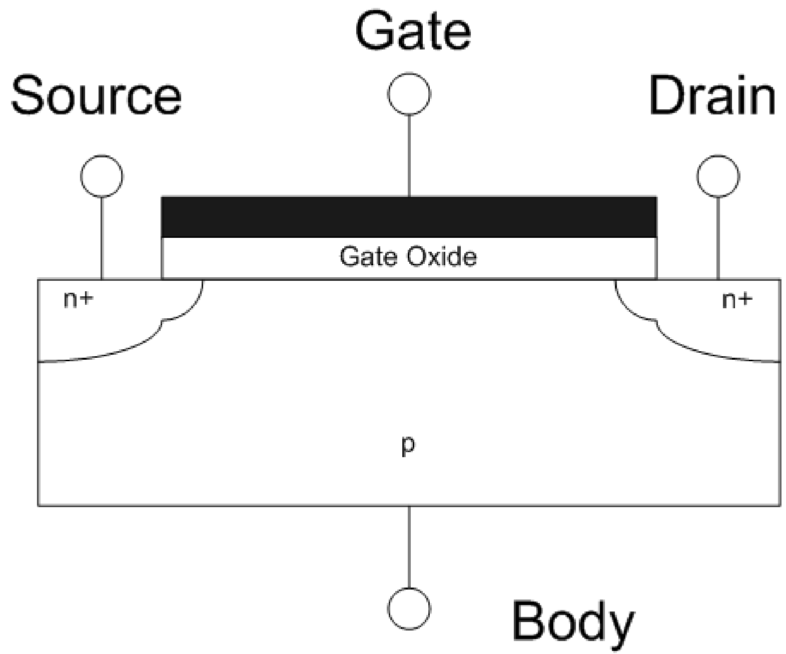


TiO_2 / Al_2O_3 multilayer

ALD: Atomic Layer Deposition

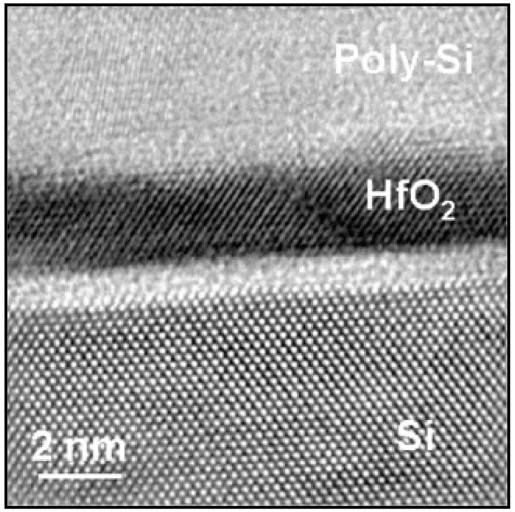
$$I_{D,Sat} = \frac{W}{L}\mu C \frac{(V_G - V_{th})^2}{2}$$

$$C = \frac{\kappa\varepsilon_0 A}{t}$$



thickness t is already ~ nm

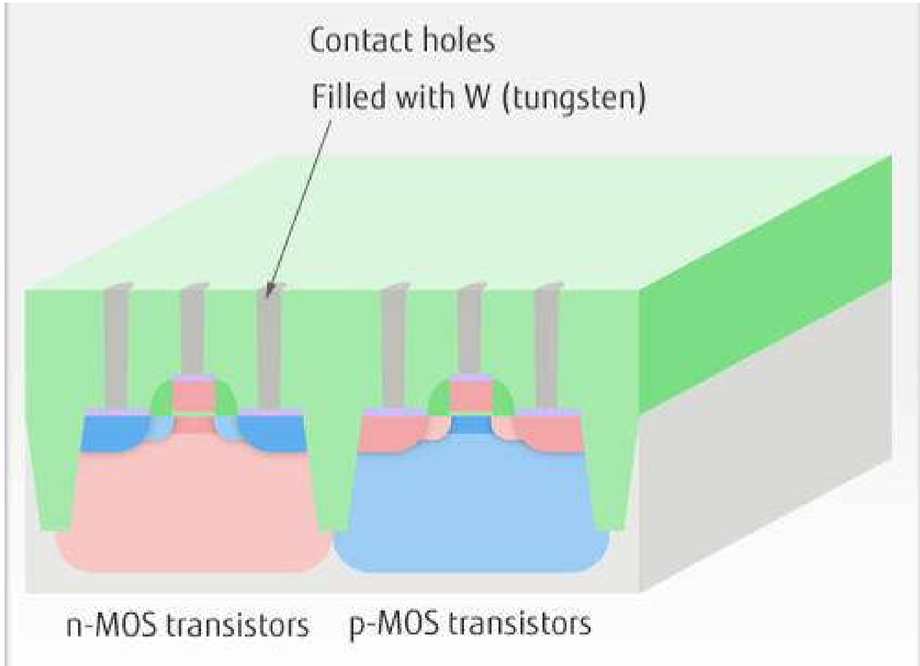
high κ -> large C -> large I_D



Film Type	Thermal SiO_2	Al_2O_3	Ta_2O_5	ZrO_2	HfO_2
Dielectric Constant	3.95	9	26	25	25–40
Bandgap (eV)	8.9	8.7	4.5	7.8	5.7
Barrier Height to Silicon	3.2	2.8	1–1.5	1.4	1.5
Deposition Technique	Thermal Growth	CVD	CVD	CVD	CVD

Selective Deposition

Tungsten (W) via by CVD



$$WF_6\ (g) + 3H_2\ (g) = W\ (s) + 6HF\ (g)$$

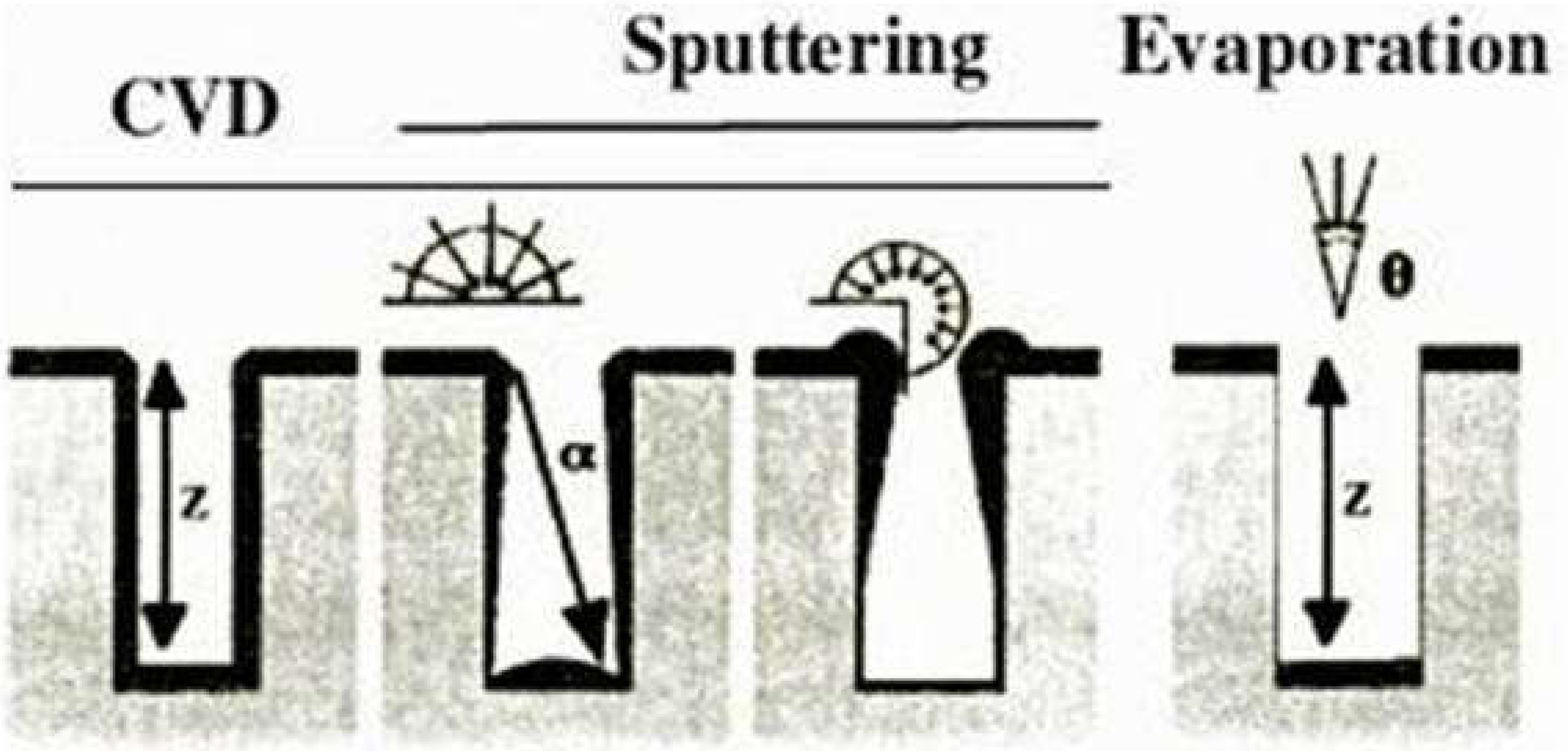
non-selective (everywhere)

$$2WF_6\ (g) + 3Si\ (s) = 2W\ (s) + 3SiF_4\ (g)$$

selective, only on Si, not SiO_2

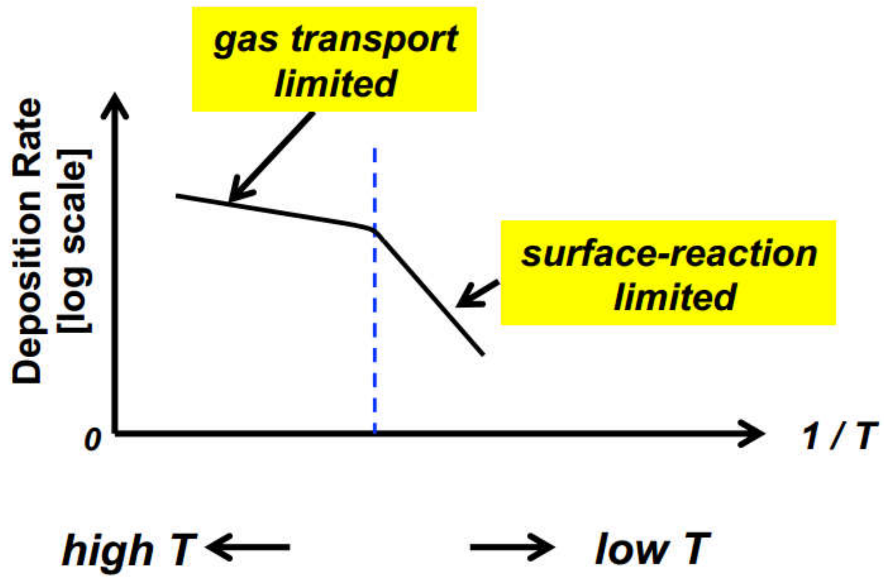
Q: why do we use CVD for W vias?

Step Coverage

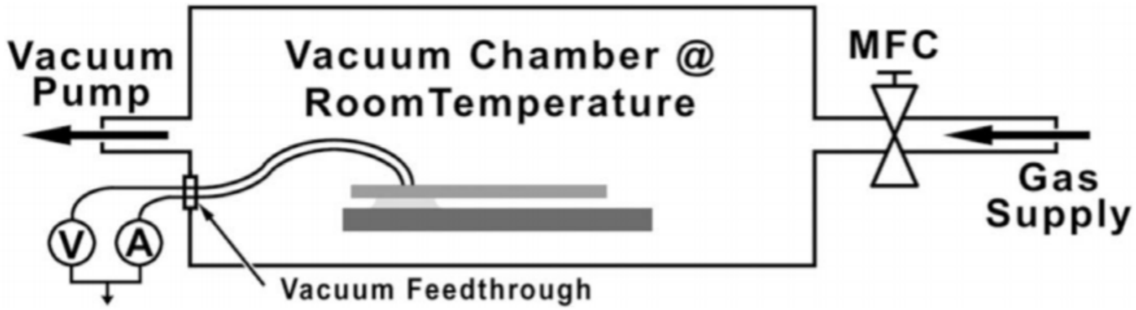


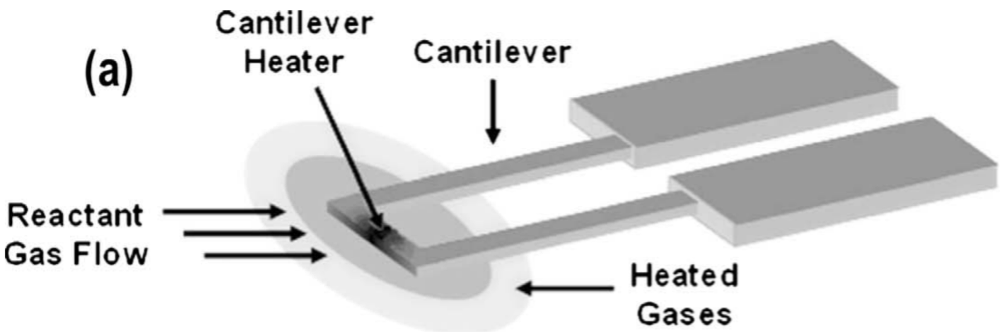
surface reaction → ***ballistic transport***

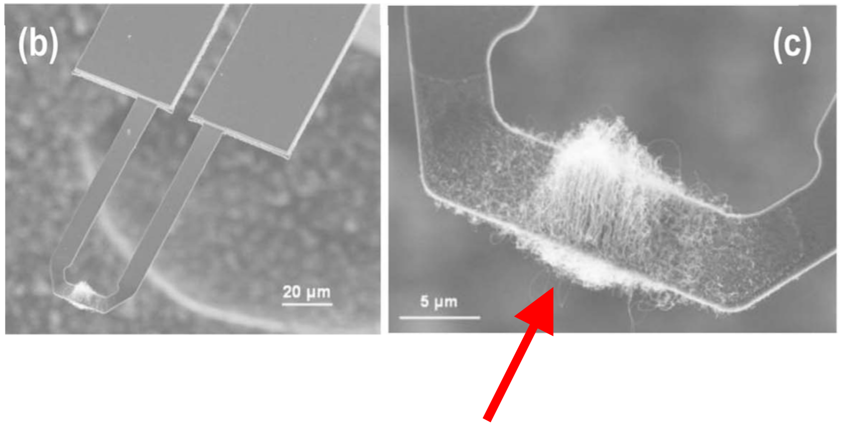
Localized CVD



higher T --> higher rate

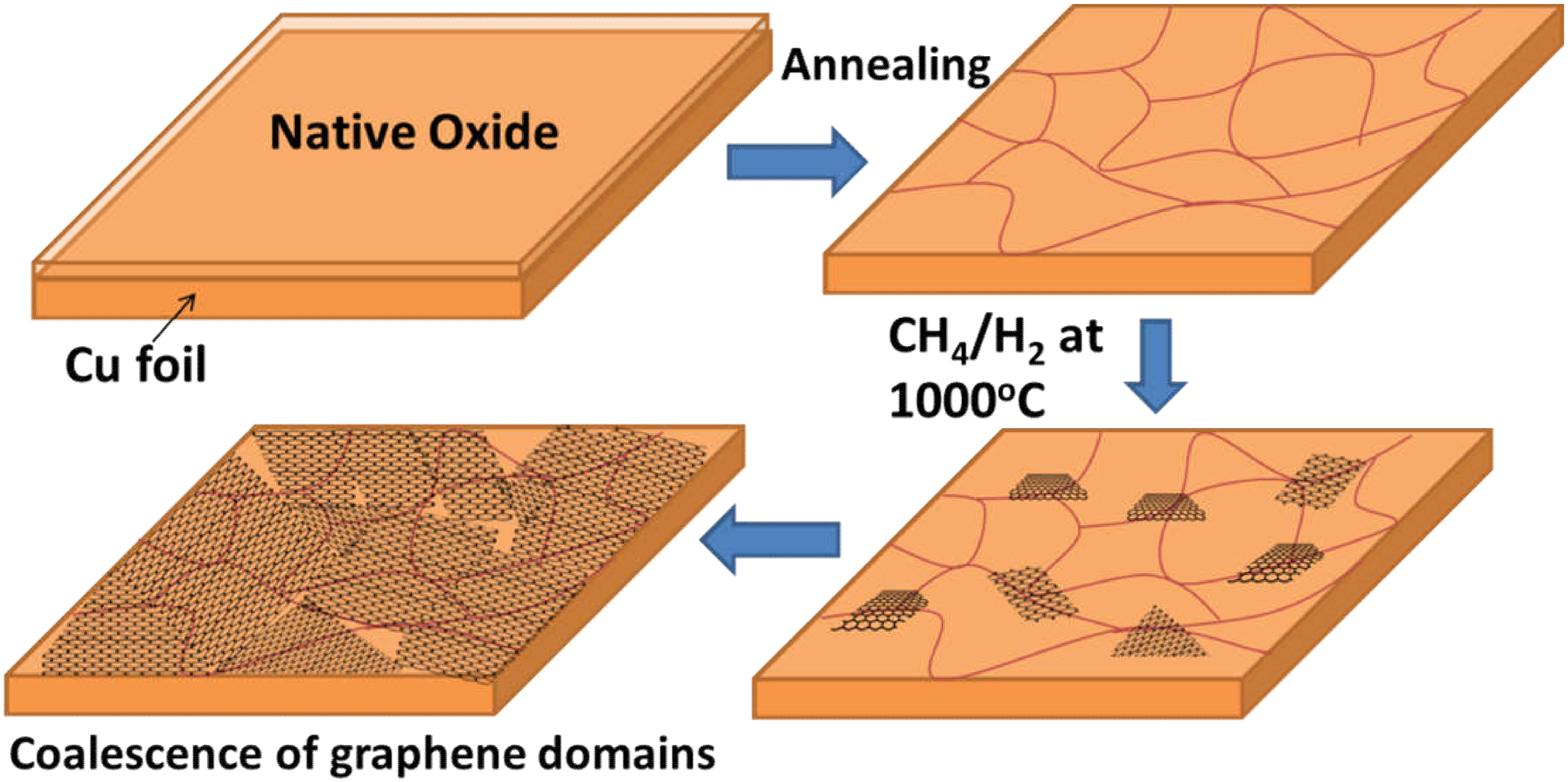






B. Sosnowchik, *et al.*, *J. Appl. Phys.* **107,** 051101 (2010)

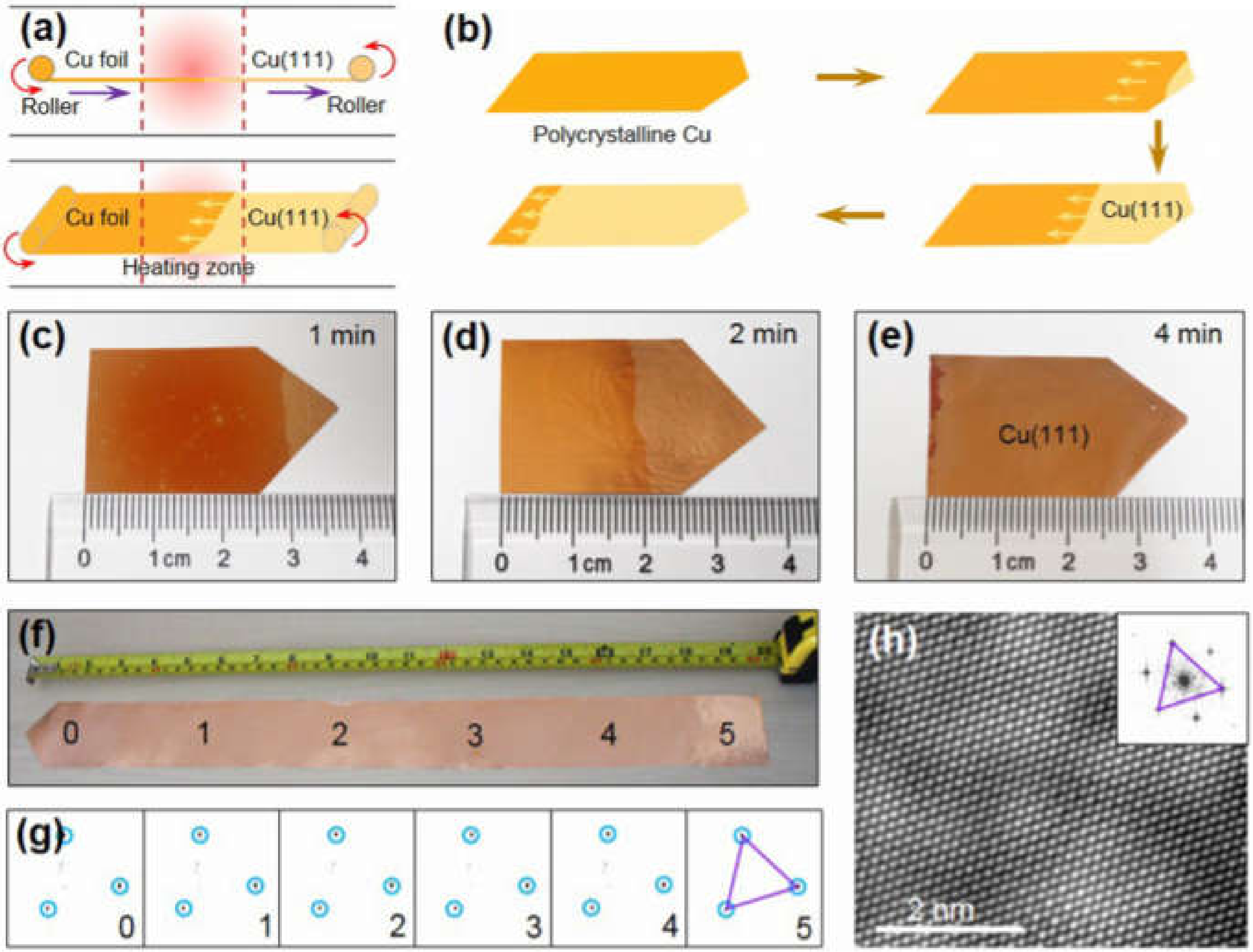
Graphene by CVD



Grephene likes to nucleate at Cu grain boundaries

How to get single crystal graphene?

Graphene by CVD



Single Crystal Substrate

↓

Single Crystal Graphene

X. Xu, *et al.*, *Science Bulletin* **62,** 1074 (2017)

Diamond by CVD