微纳光电子材料与器件工艺原理

Film Deposition
Part III: CVD

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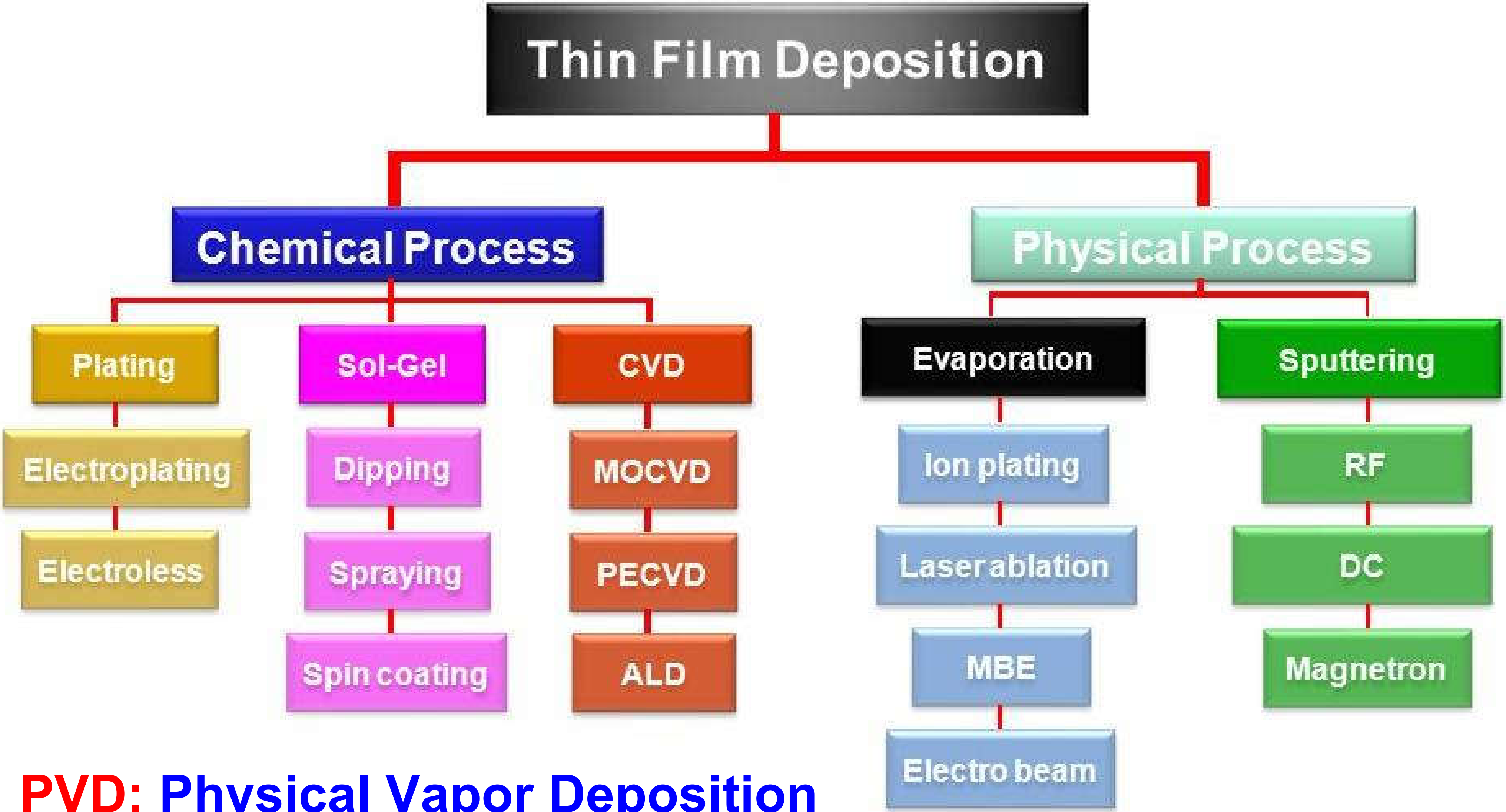
Film Deposition

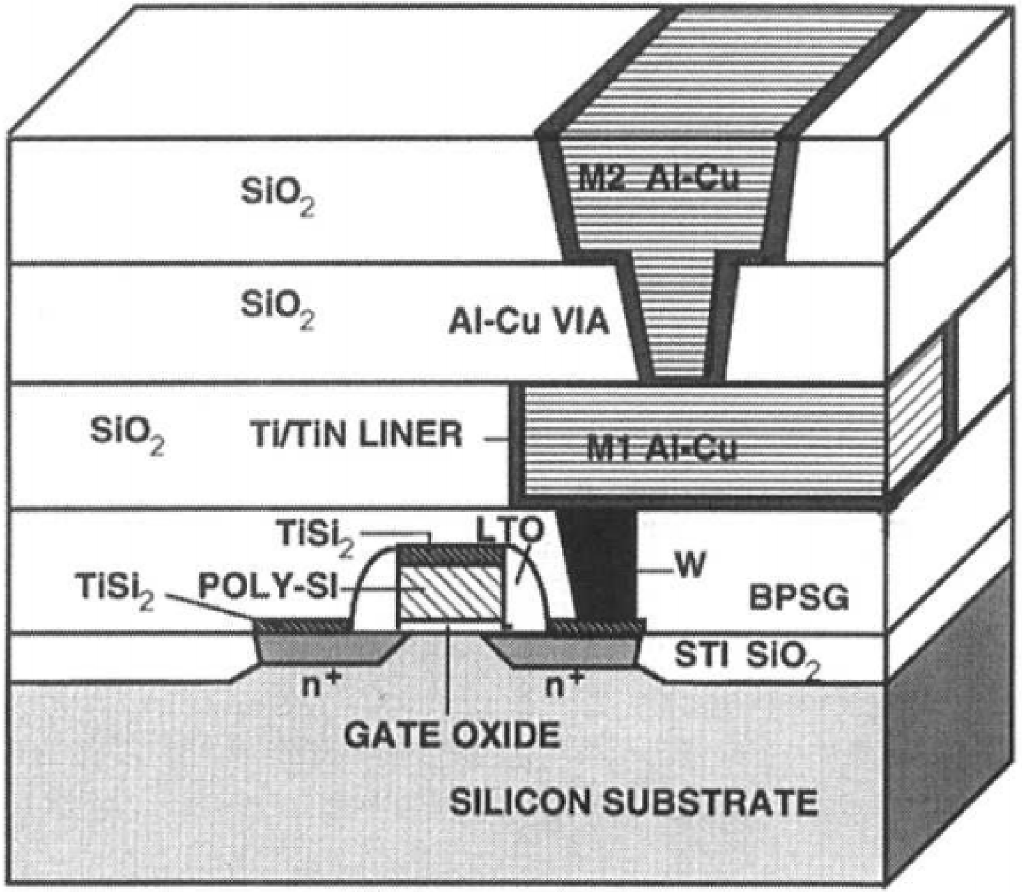


PVD: Physical Vapor Deposition

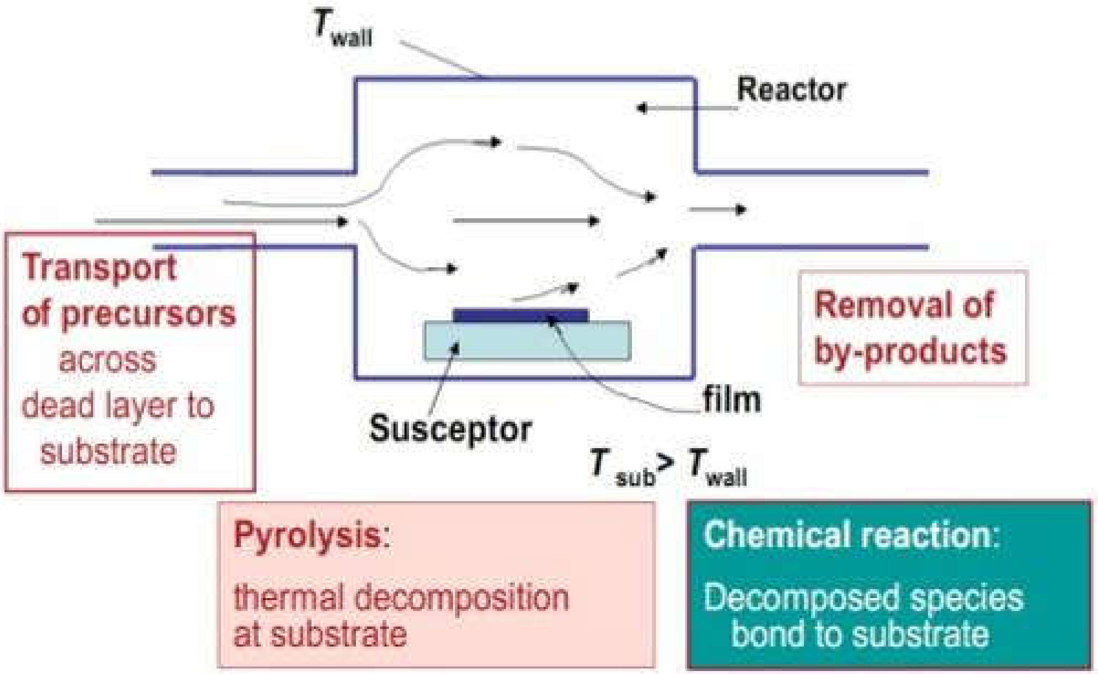
CVD: Chemical Vapor Deposition

Thin Film in CMOS

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

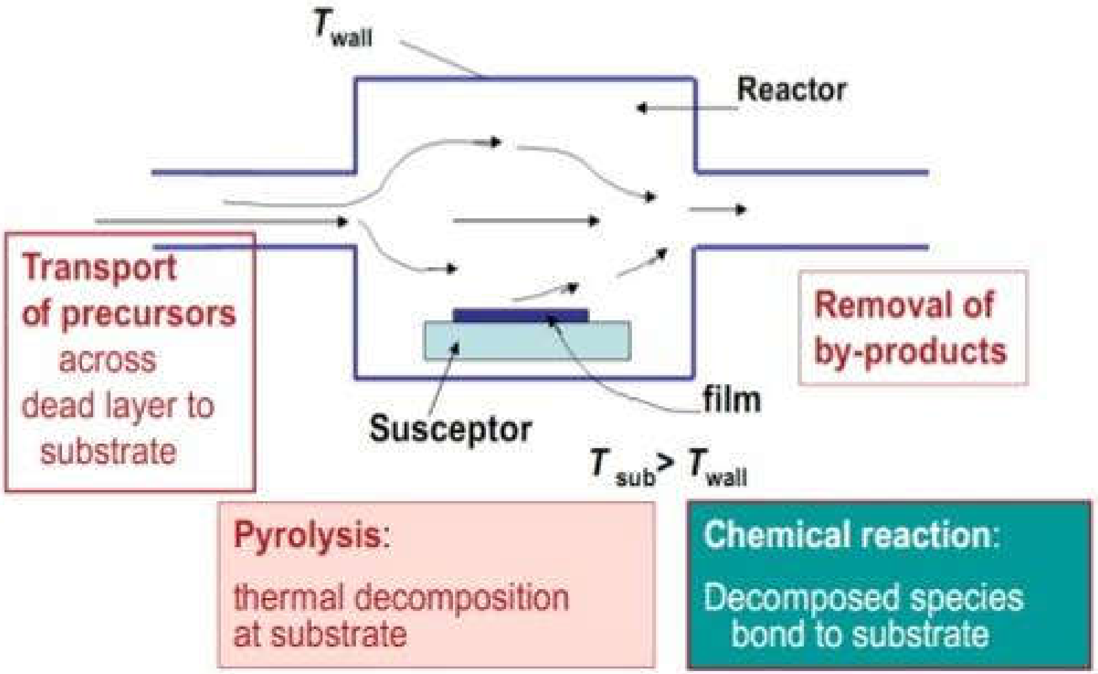


CVD: Chemical Vapor Deposition



- 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:**

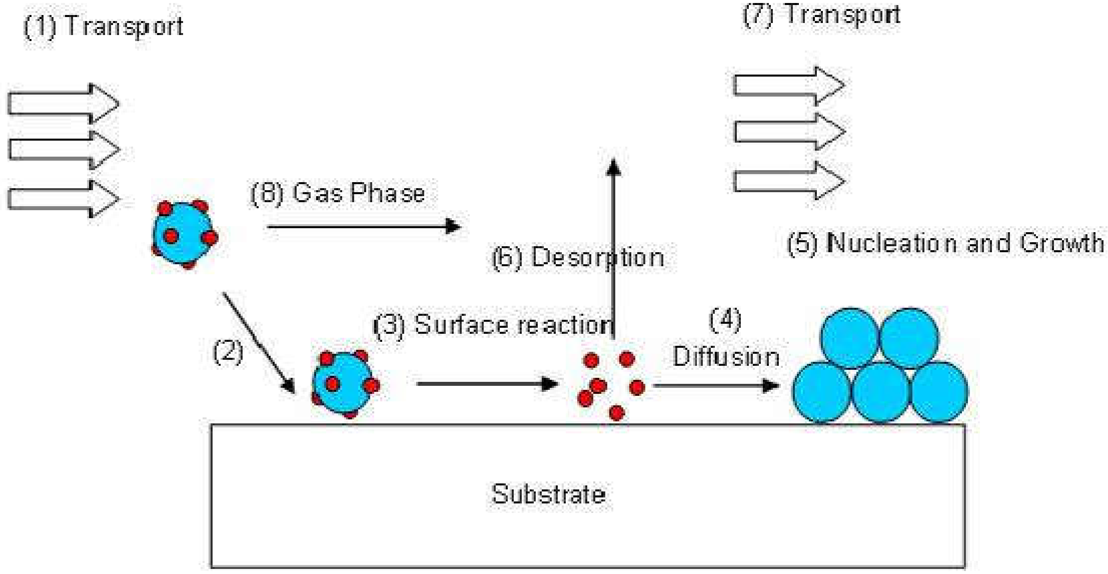
$$SiH_4\ (g) = Si\ (s) + 2H_2\ (g)$$

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

CVD

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

- gas transport
- surface reaction



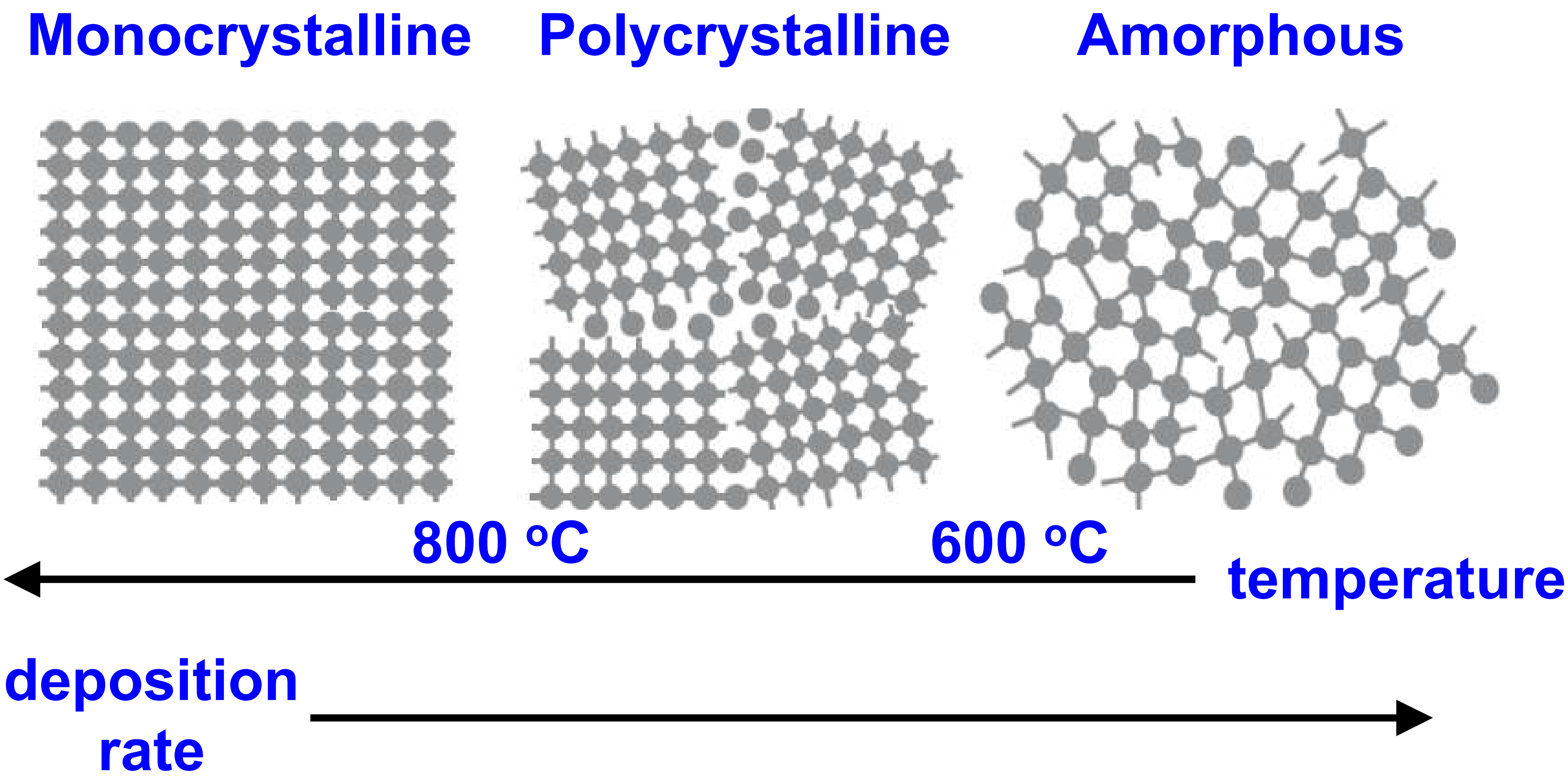
- **Control Parameters**
  - **Film thickness**
  - **Crystallinity**
  - **Film quality (defects, dielectric strength, ...)**

Q: differences between CVD and oxidation?

Crystallinity

Deposit Si on Si

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

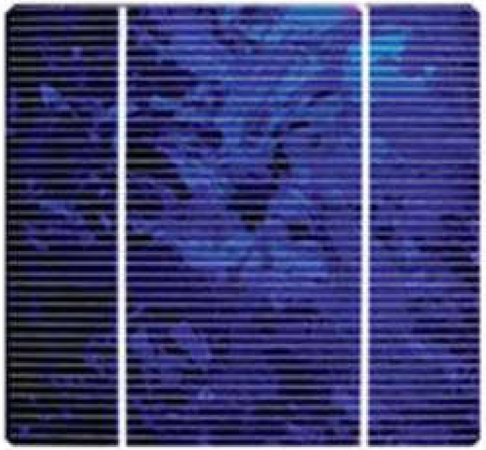


Crystallinity

Silicon Solar Cells

Monocrystalline

Polycrystalline



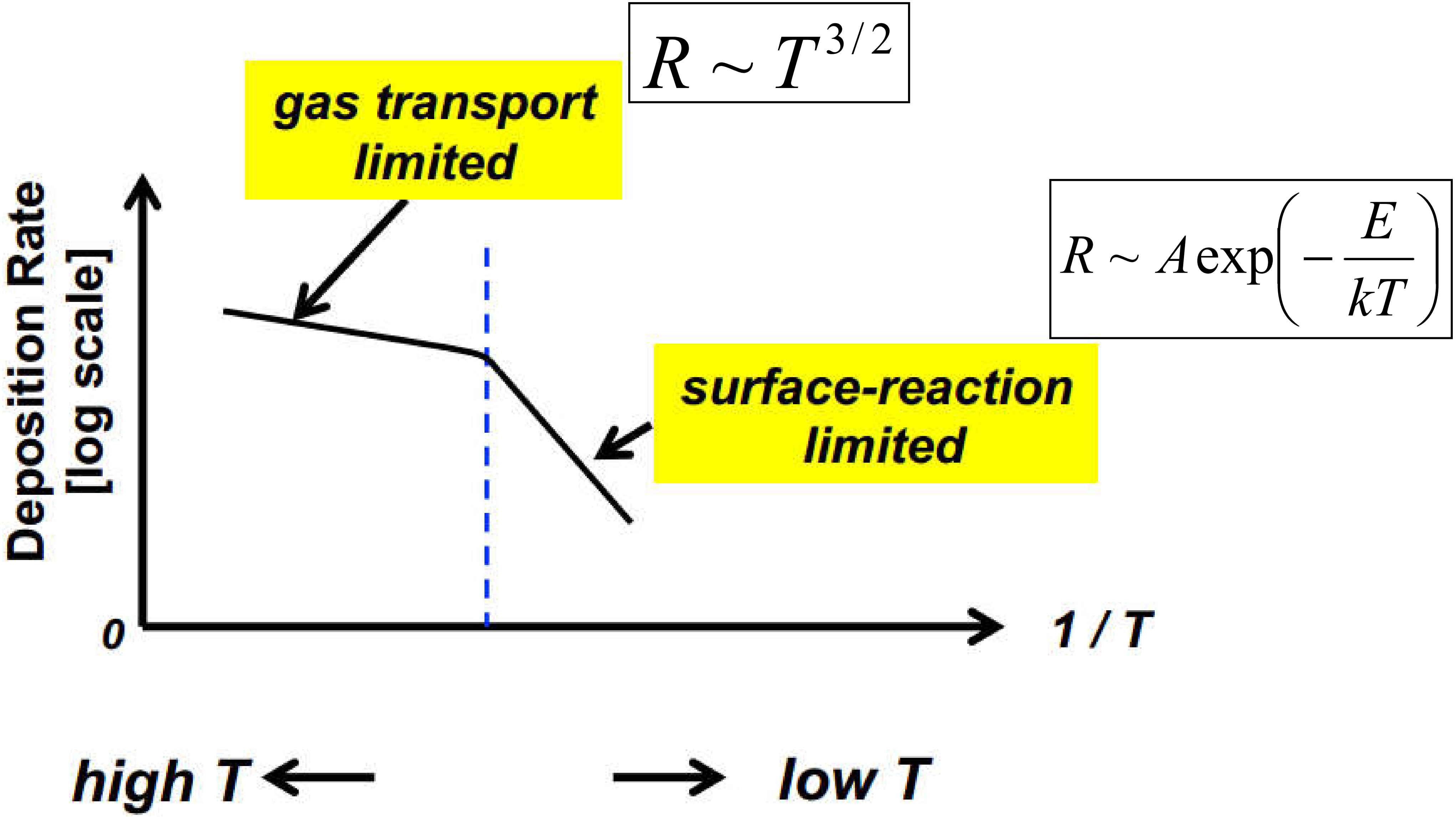
Amorphous

temperature

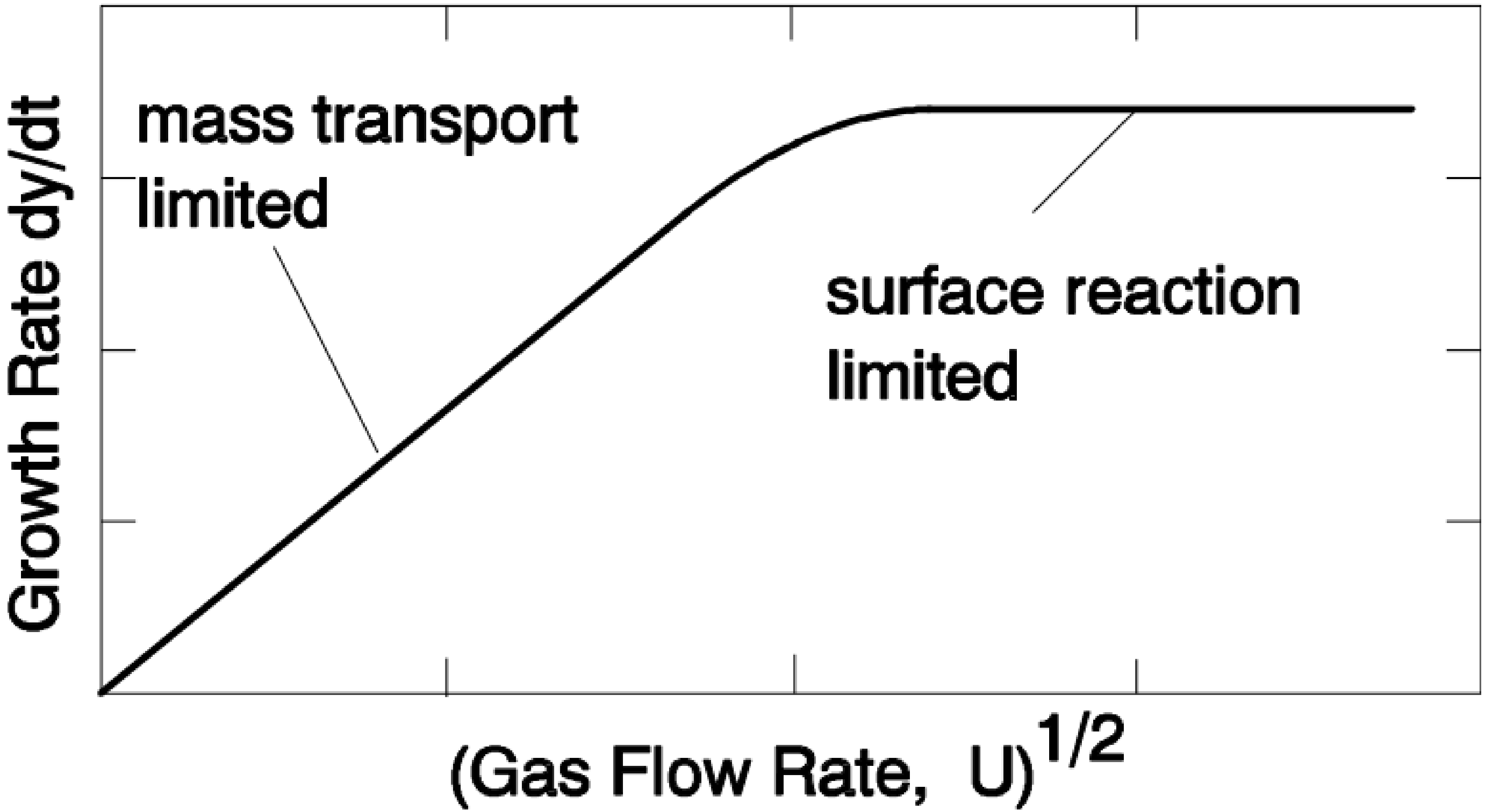
efficiency

price

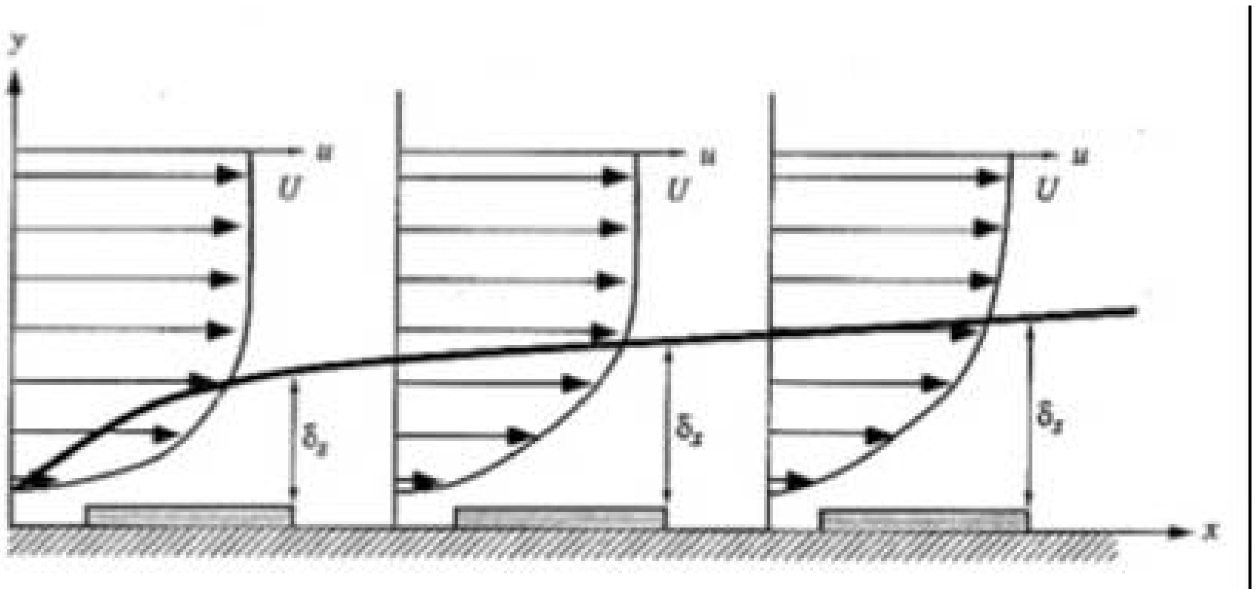
Deposition Rate vs. Temperature

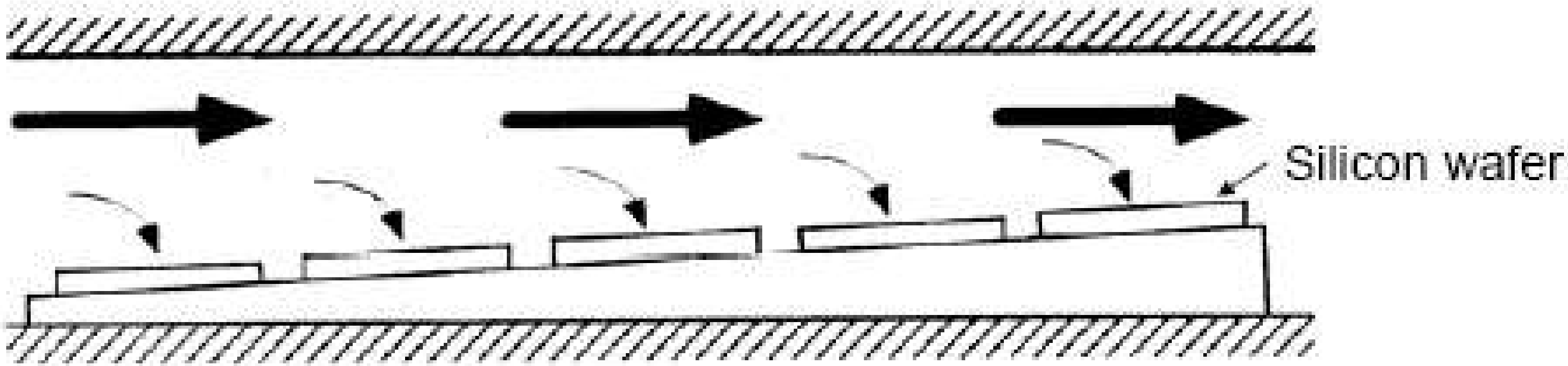


Deposition Rate vs. Gas Flow



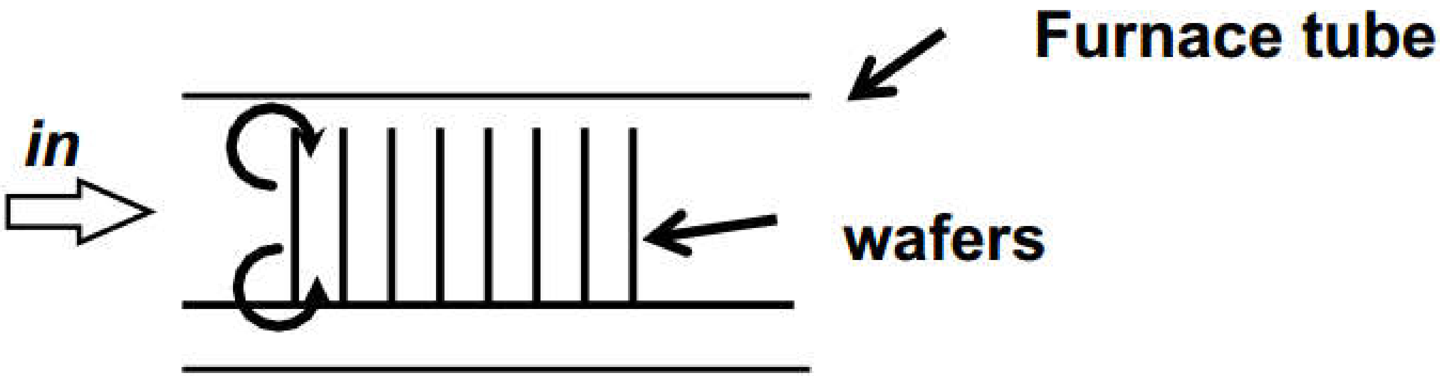
Issues of Gas Transport

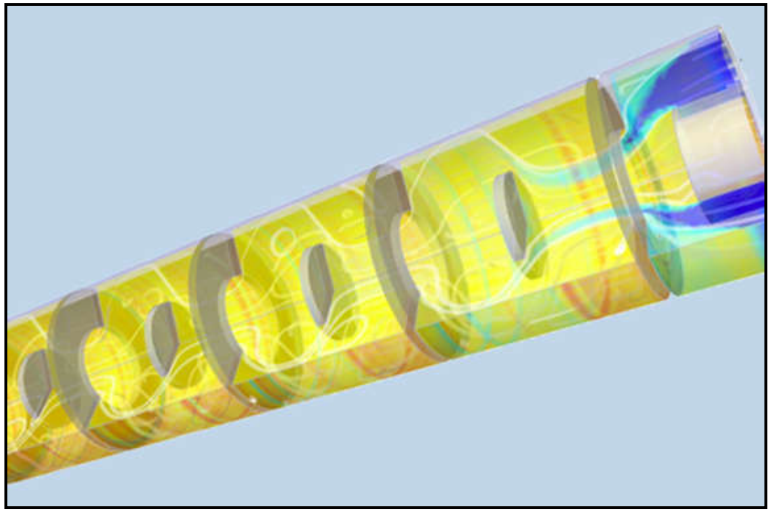




tilt the samples to improve uniformity

Issues of Gas Transport

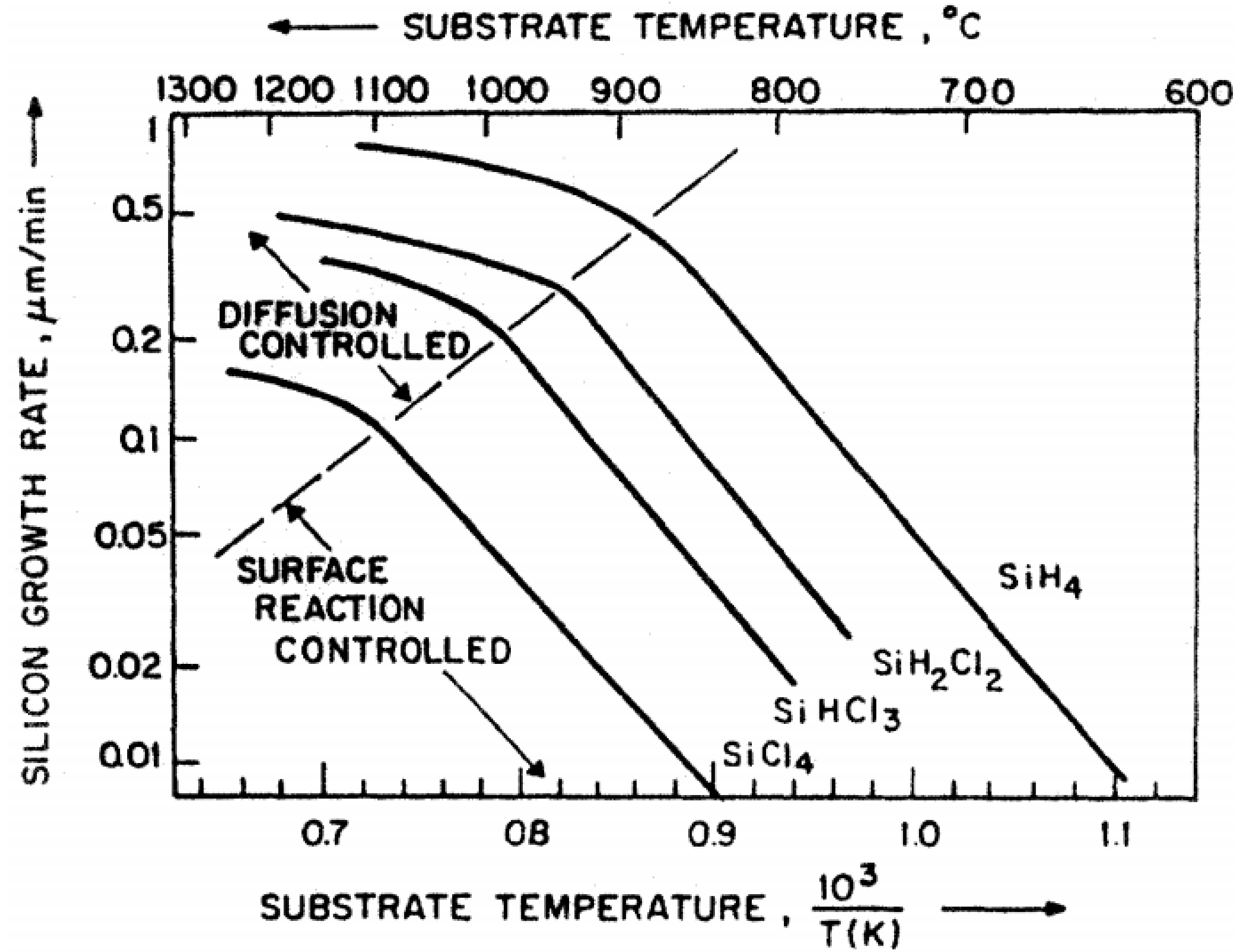




better to operate at surface reaction limited zone
(low T, high flux rate)

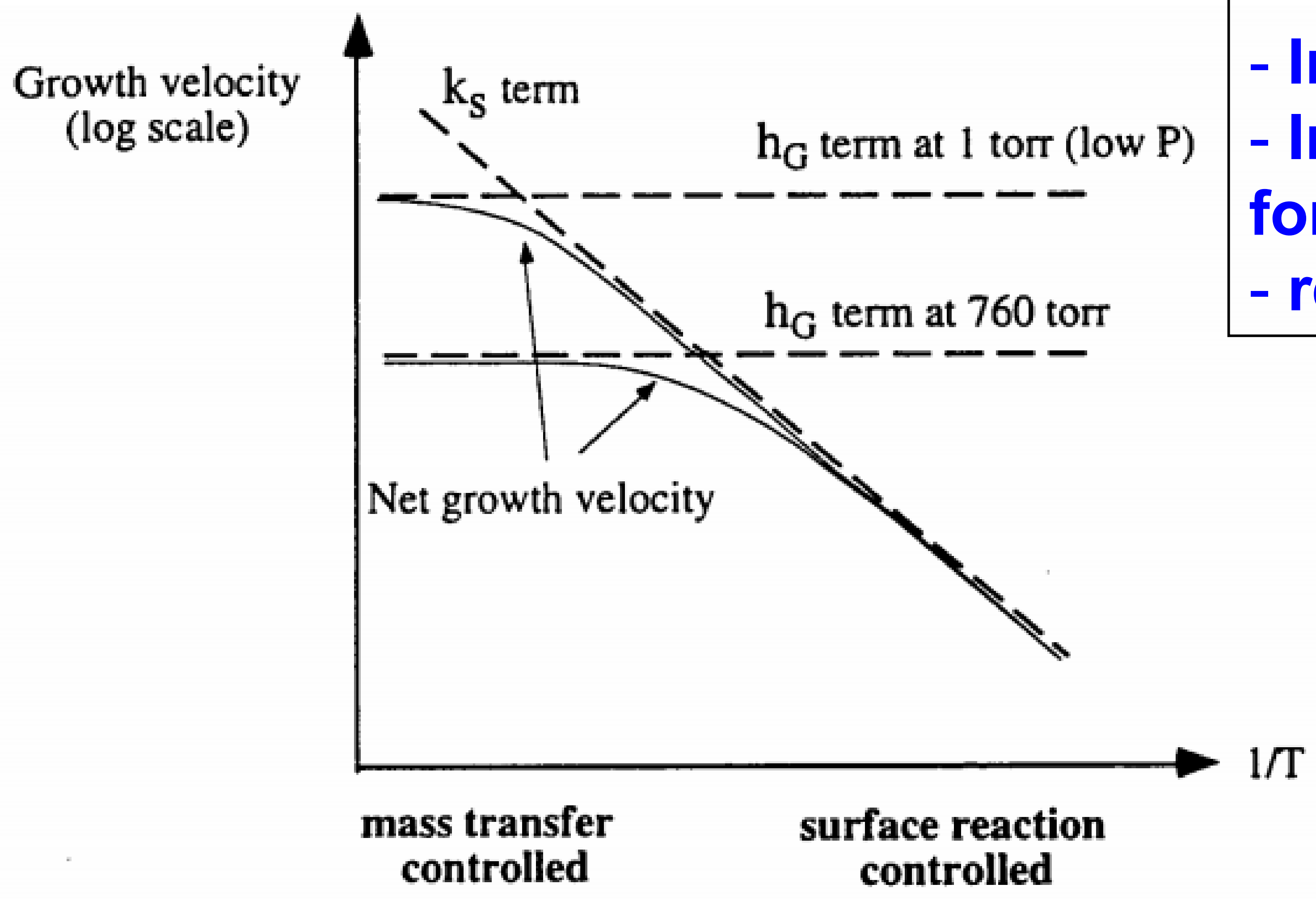
Gas Types

Si CVD



LPCVD

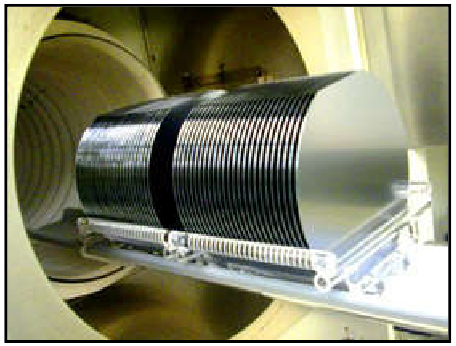
Low Pressure CVD



at low pressure,

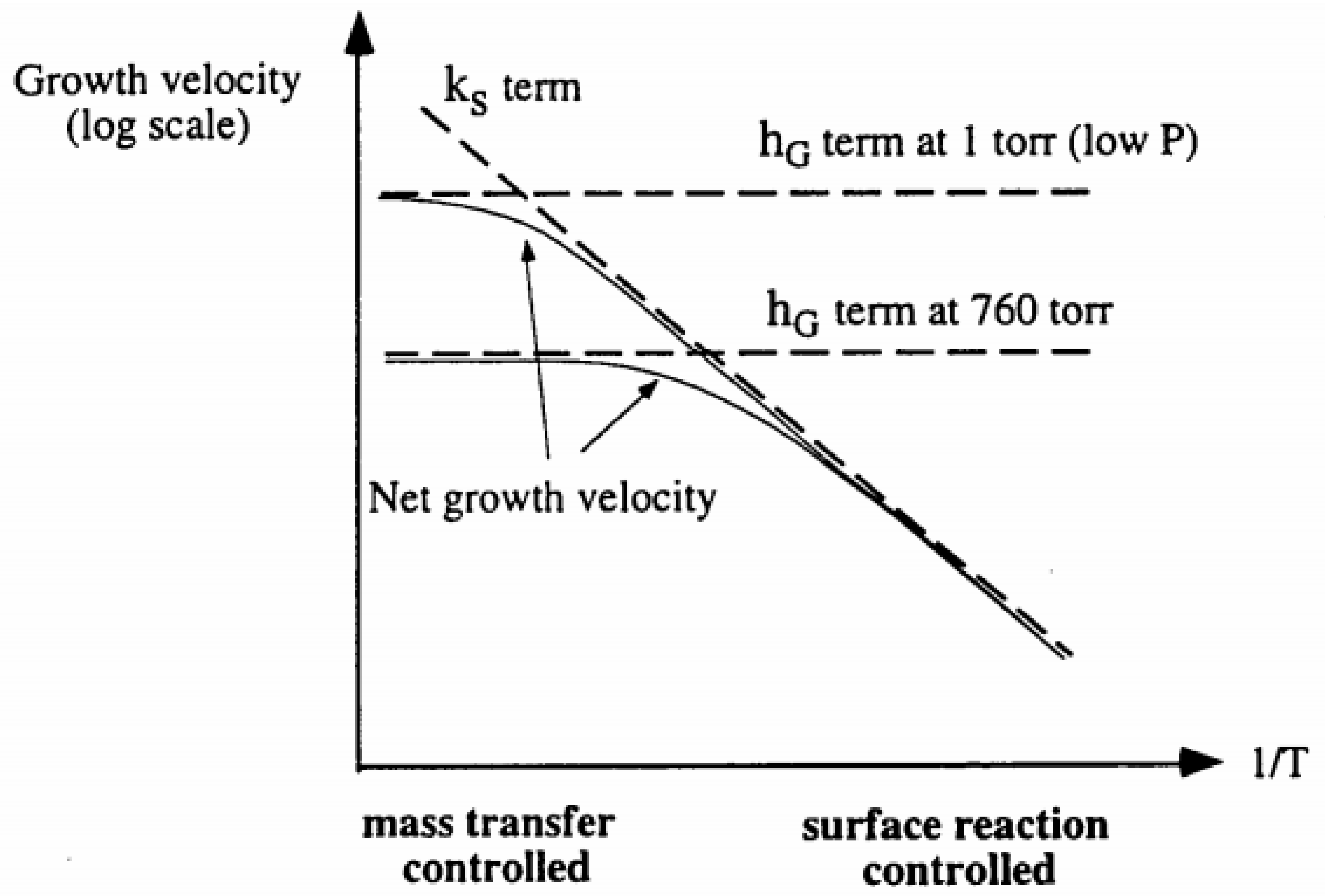
- Increased rate
- Increased zone for surface reaction
- reduce cost

why ??



LPCVD

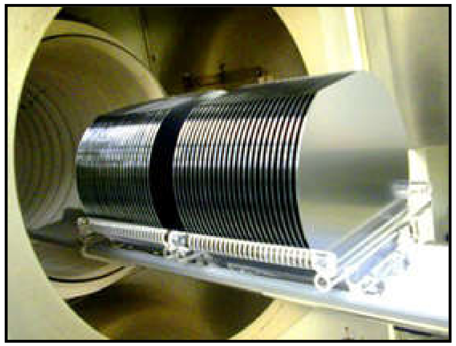
Low Pressure CVD



molecular mean free path λ

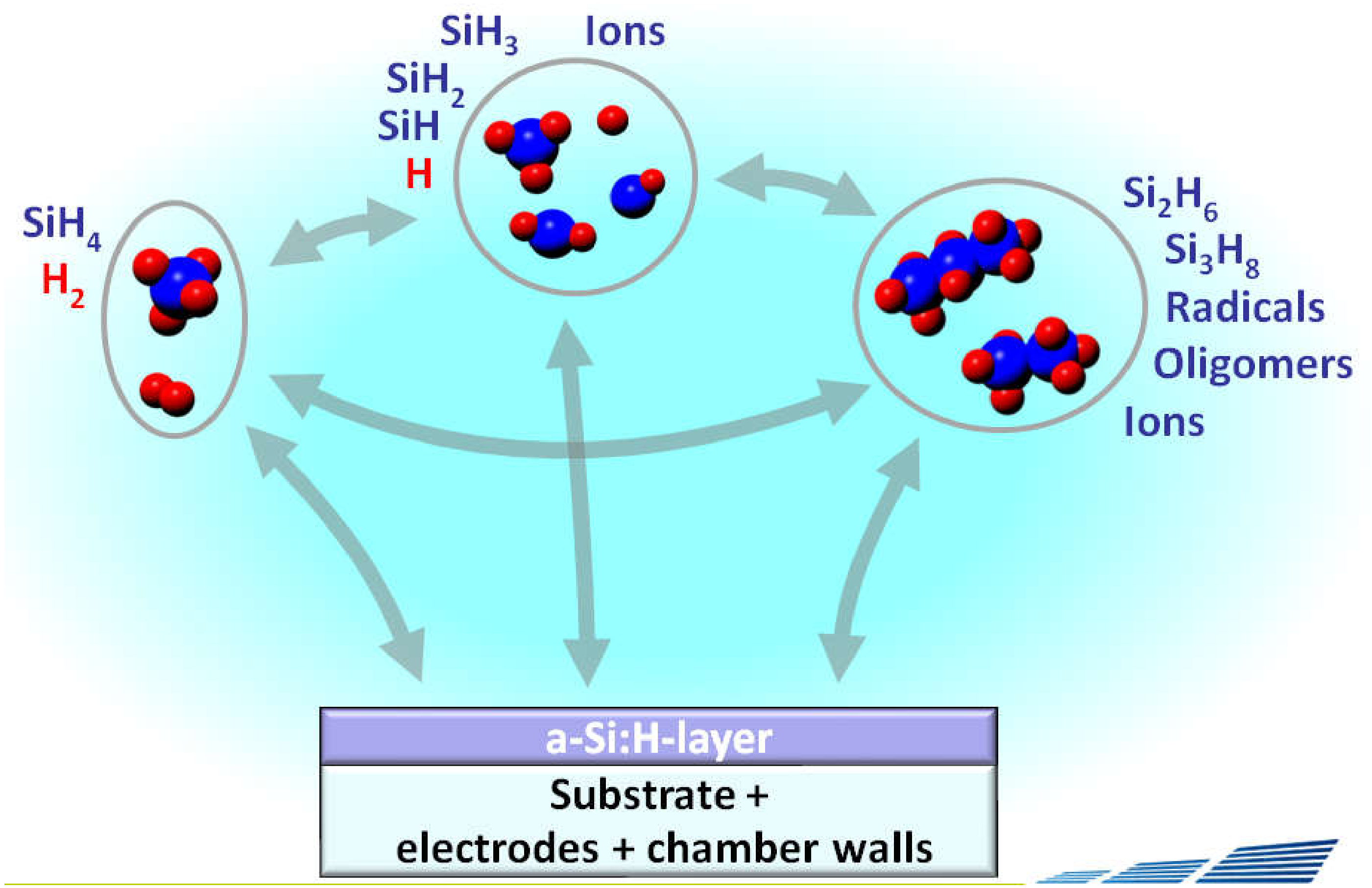
$$\boxed{\lambda = \frac{kT}{\sqrt{2}\pi r^2 p}}$$

$p \downarrow \quad \lambda \uparrow$



PECVD

Plasma Enhanced CVD



plasma enhances the ion energy:

- higher dep. rate
- lower temperature

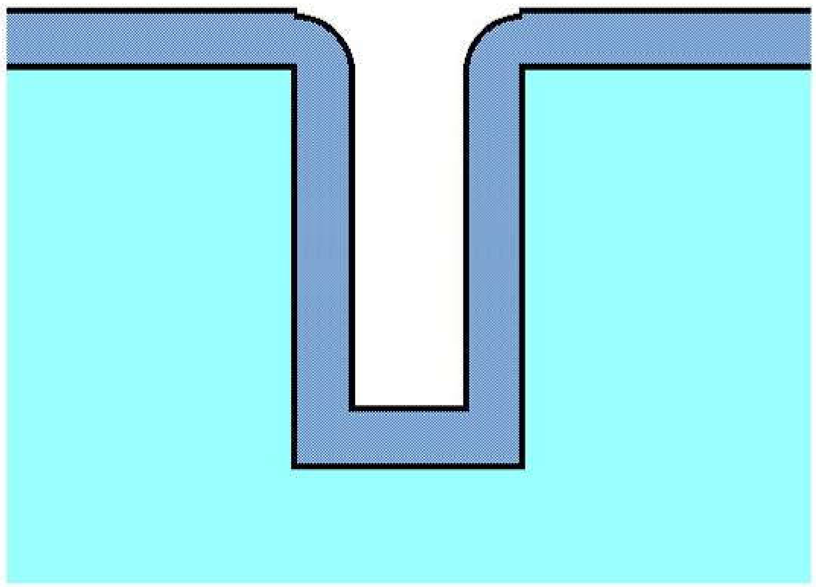
SiO_2 Growth Methods

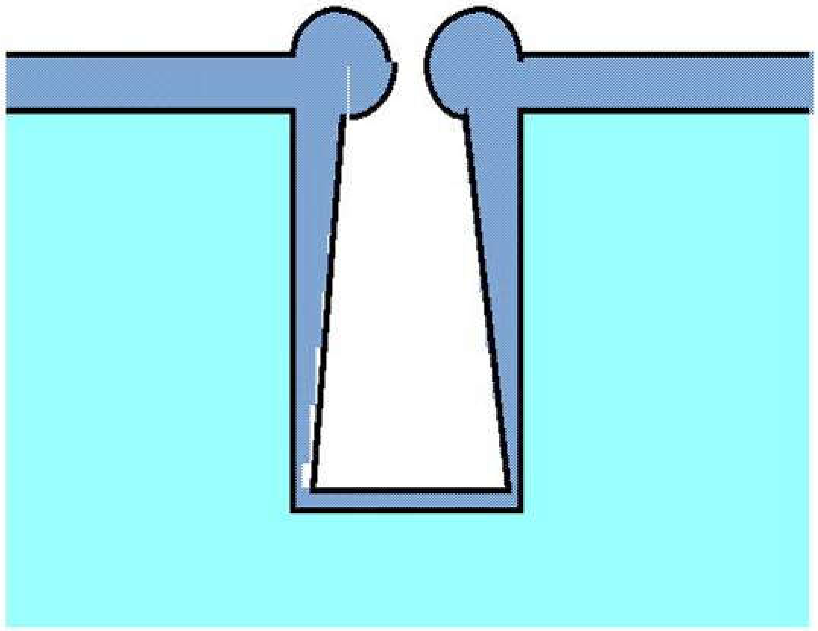
- dry oxidation
  - $Si + O_2$ ~ 1100 °C
- wet oxidation
  - $Si + H_2O$ ~ 1000 °C
- APCVD / LPCVD
  - $SiH_4 + O_2$ 400~600 °C
- PECVD
  - $SiH_4 + N_2O$ 200~400 °C
- Sputter or Evaporation
  - substrate at room temperature

growth temperature

film quality

Step Coverage





surface reaction controlled

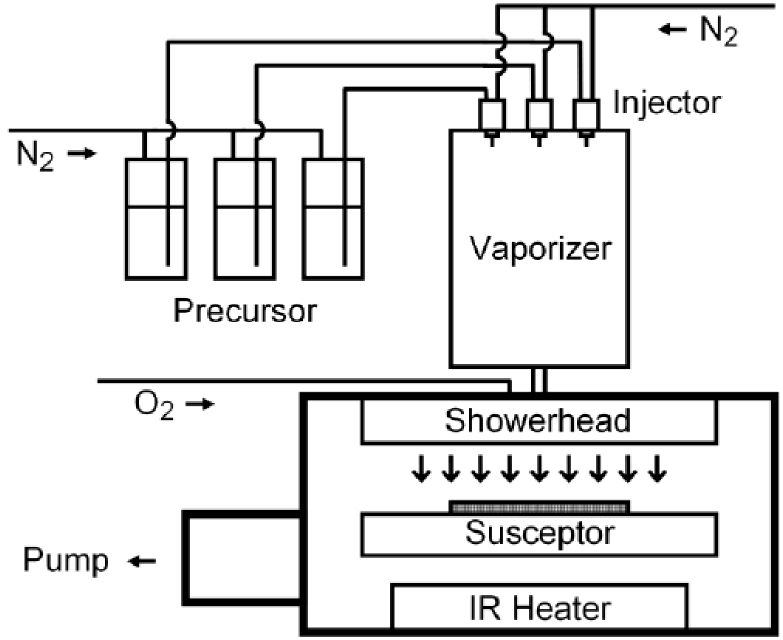
- LPCVD, UHVCVD, oxidation
- ALD
- ...

diffusion/transport controlled

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

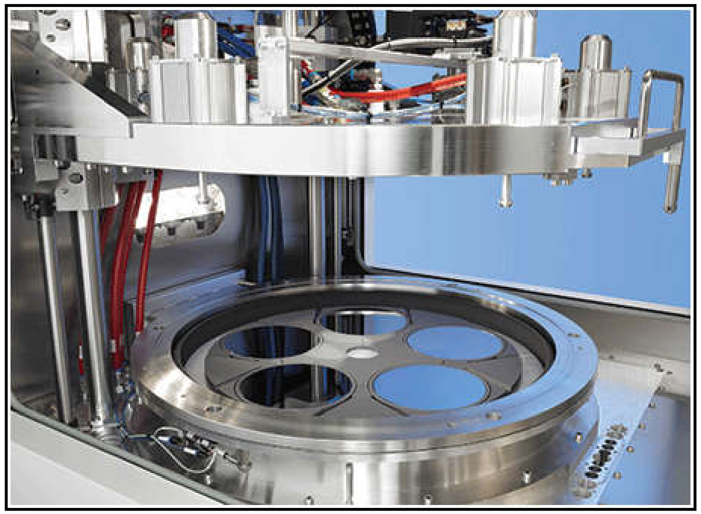
MOCVD

Metal-Organic CVD

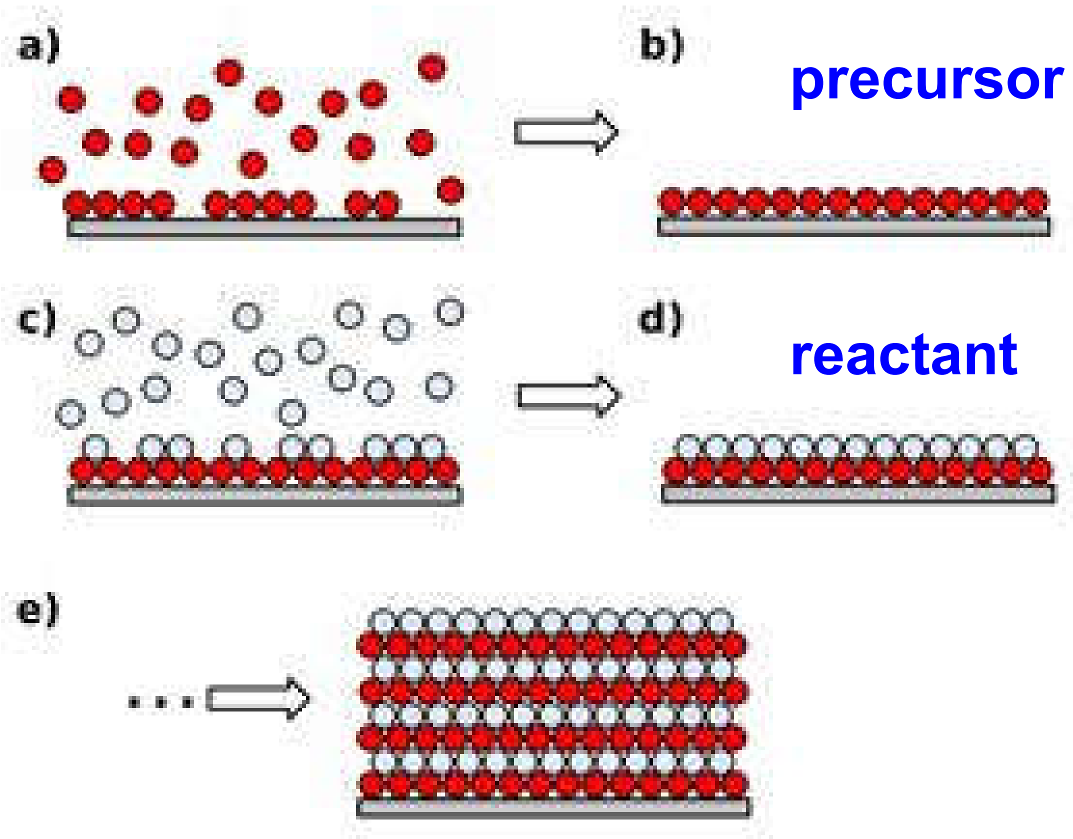


$Ga(CH_3)_3$ (g) + AsH_3 (g) = GaAs (s) + $3CH_4$ (g)

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



ALD: Atomic Layer Deposition

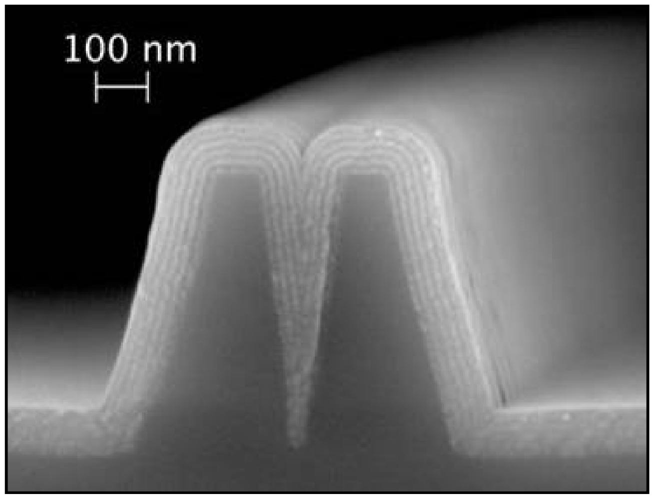


$$2Al(CH_3)_3 + 3H_2O = Al_2O_3 + 6CH_4$$

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

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

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

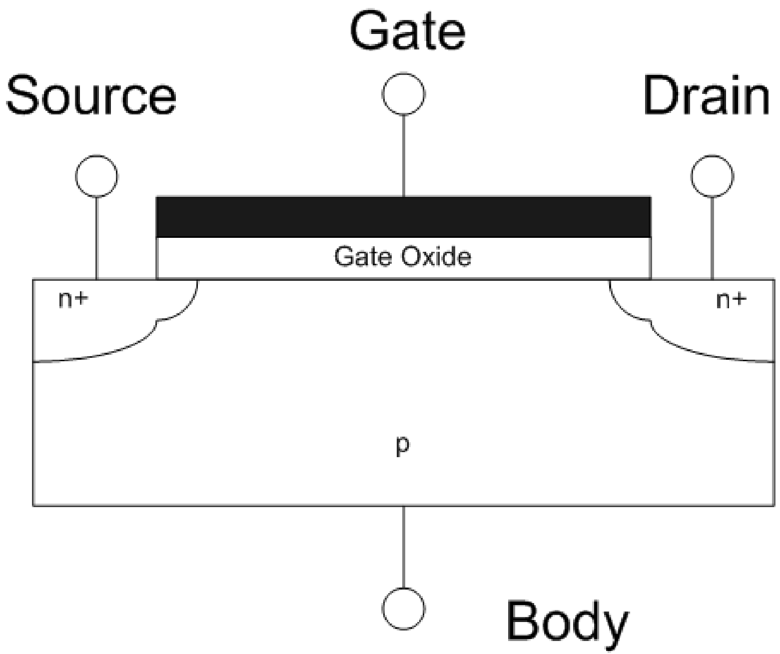


TiO_2 / Al_2O_3 multilayer

ALD: Atomic Layer Deposition

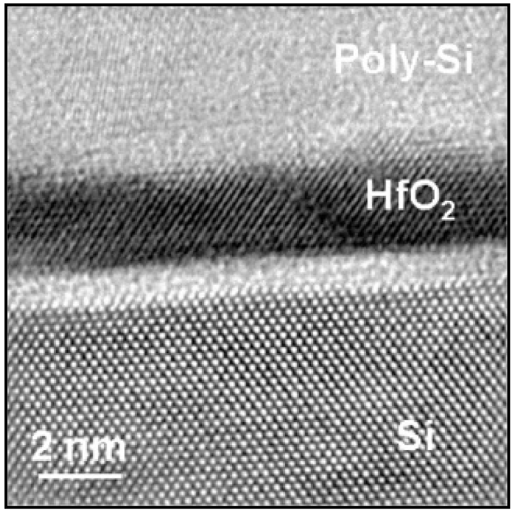
$$I_{D,Sat} = \frac{W}{L}\mu C \frac{(V_G - V_{th})^2}{2}$$

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



thickness t is already ~ nm

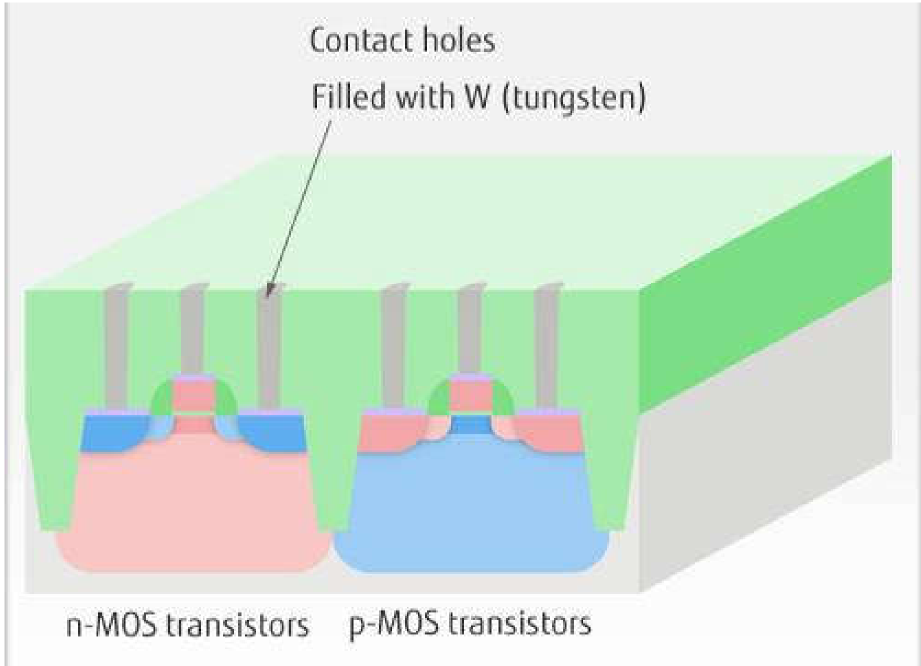
high κ -> large C -> large I_D



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)

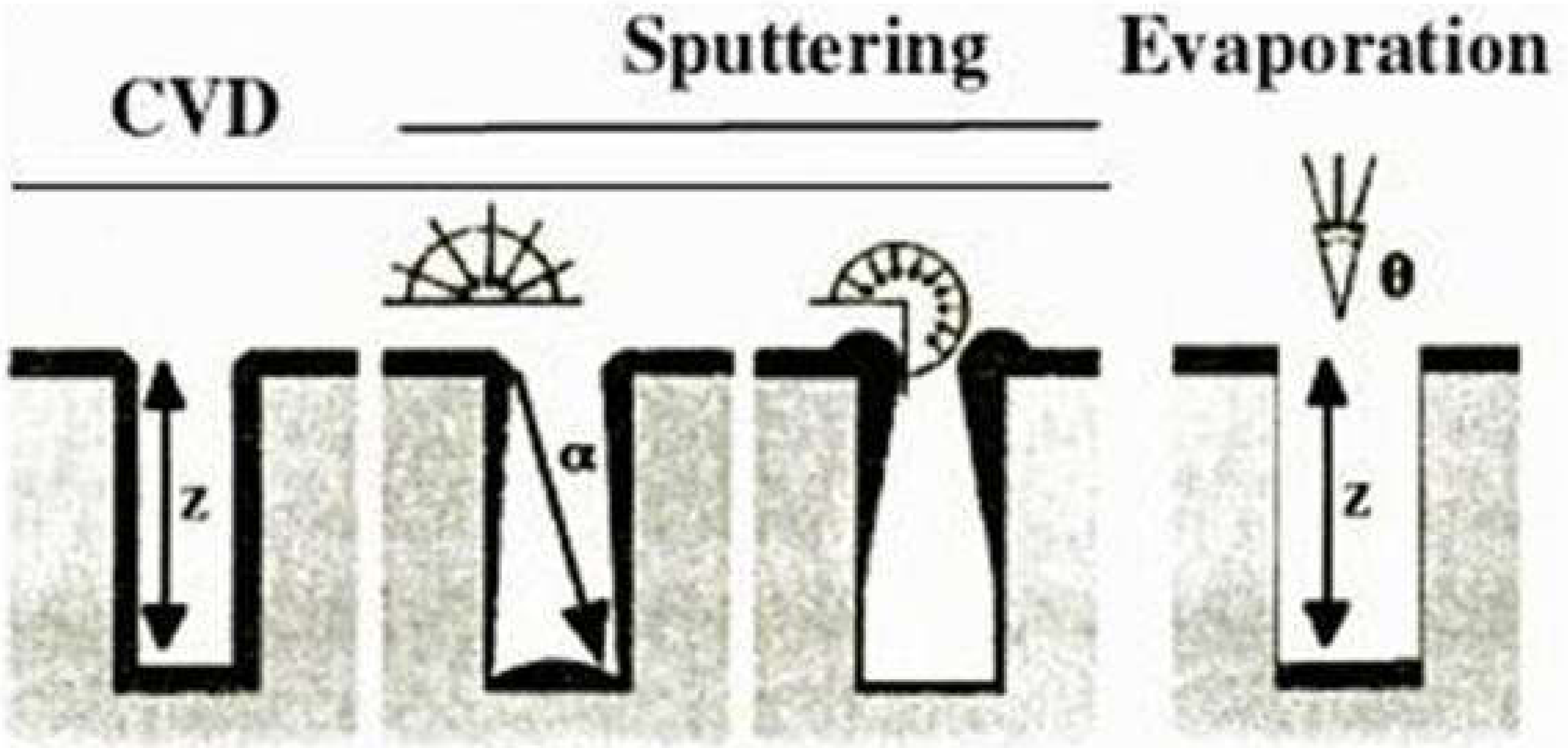
non-selective (everywhere)

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

selective, only on Si, not SiO_2

Q: why do we use CVD for W vias?

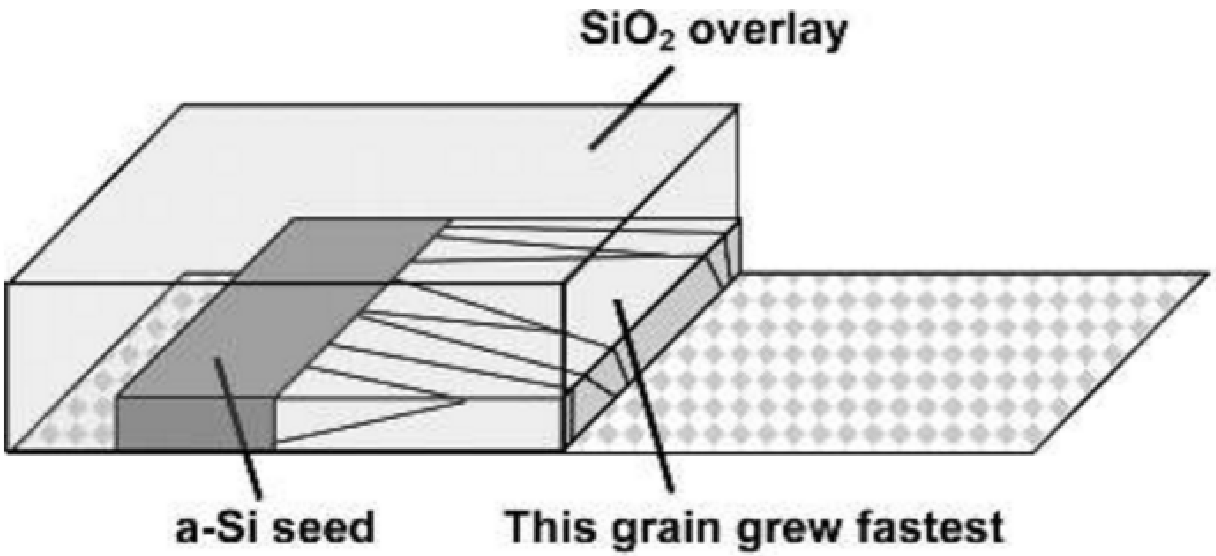
Step Coverage

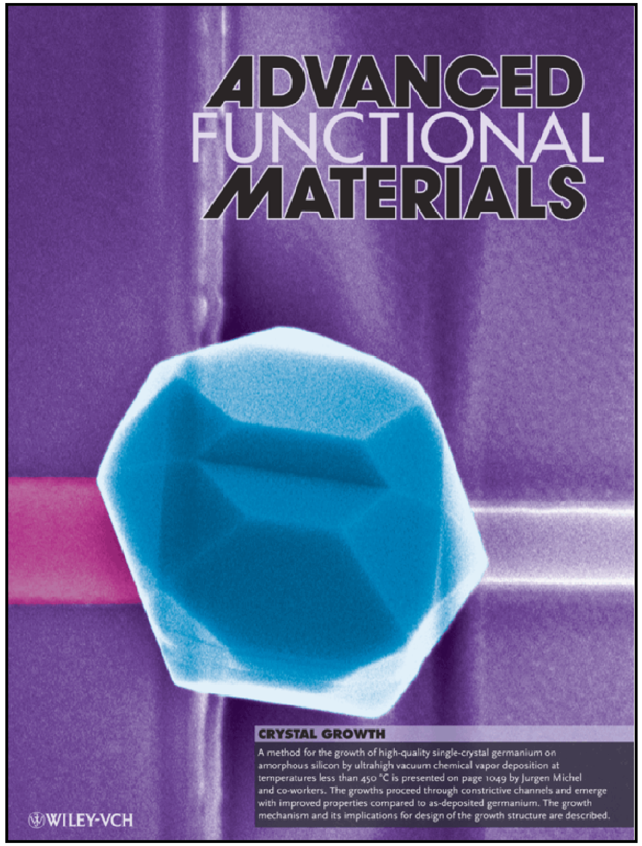


surface reaction → ***ballistic transport***

Selective Deposition

Grow Ge single crystals on amorphous substrate





UHVCVD

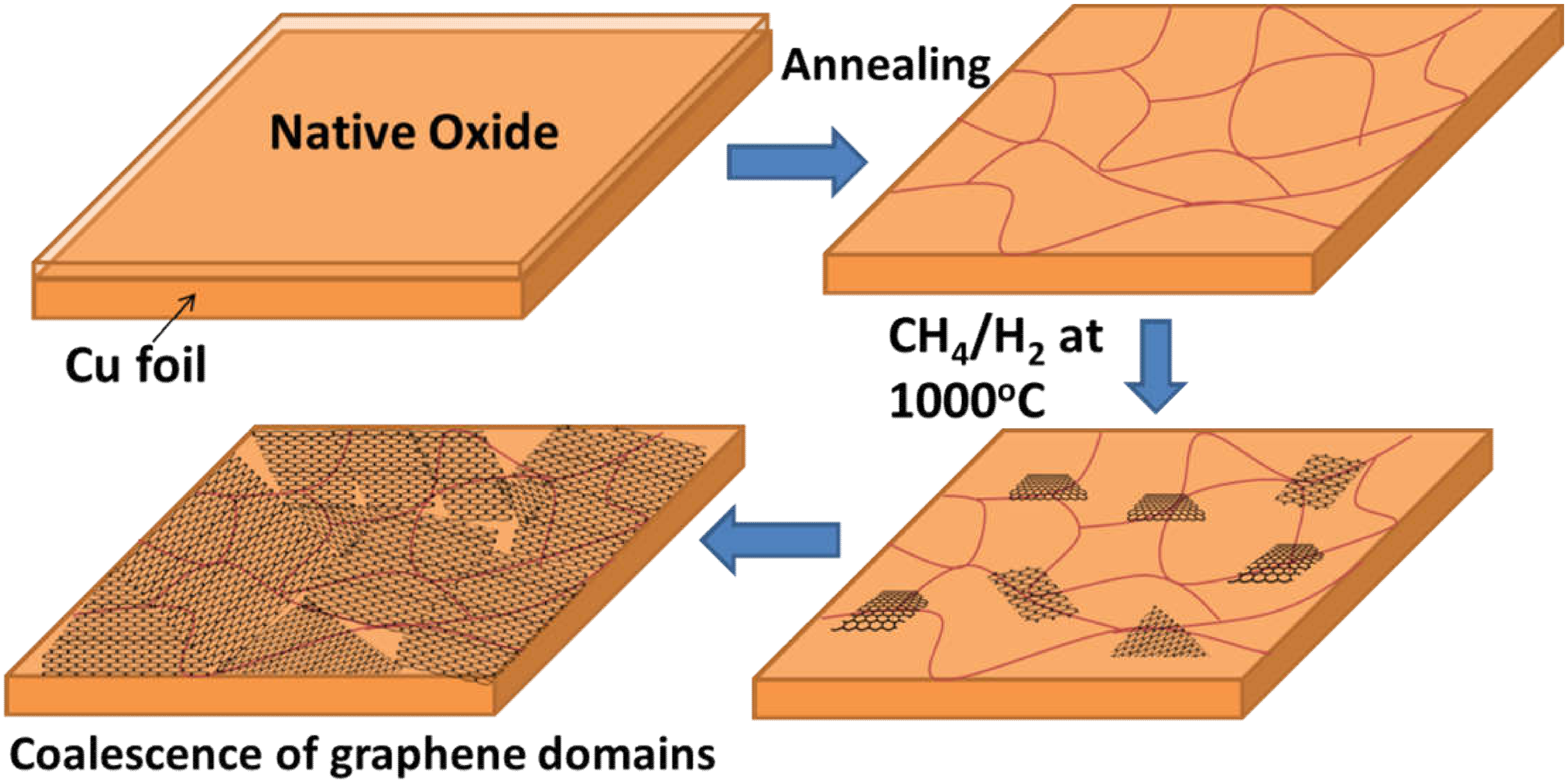
GeH_4 (g) = Ge (s) + $2H_2$ (g)

selective, only on Si, not SiO_2

GeO is not stable

K. McComber, *et al.*, *Adv. Func. Mater.* **22,** 1049 (2012)

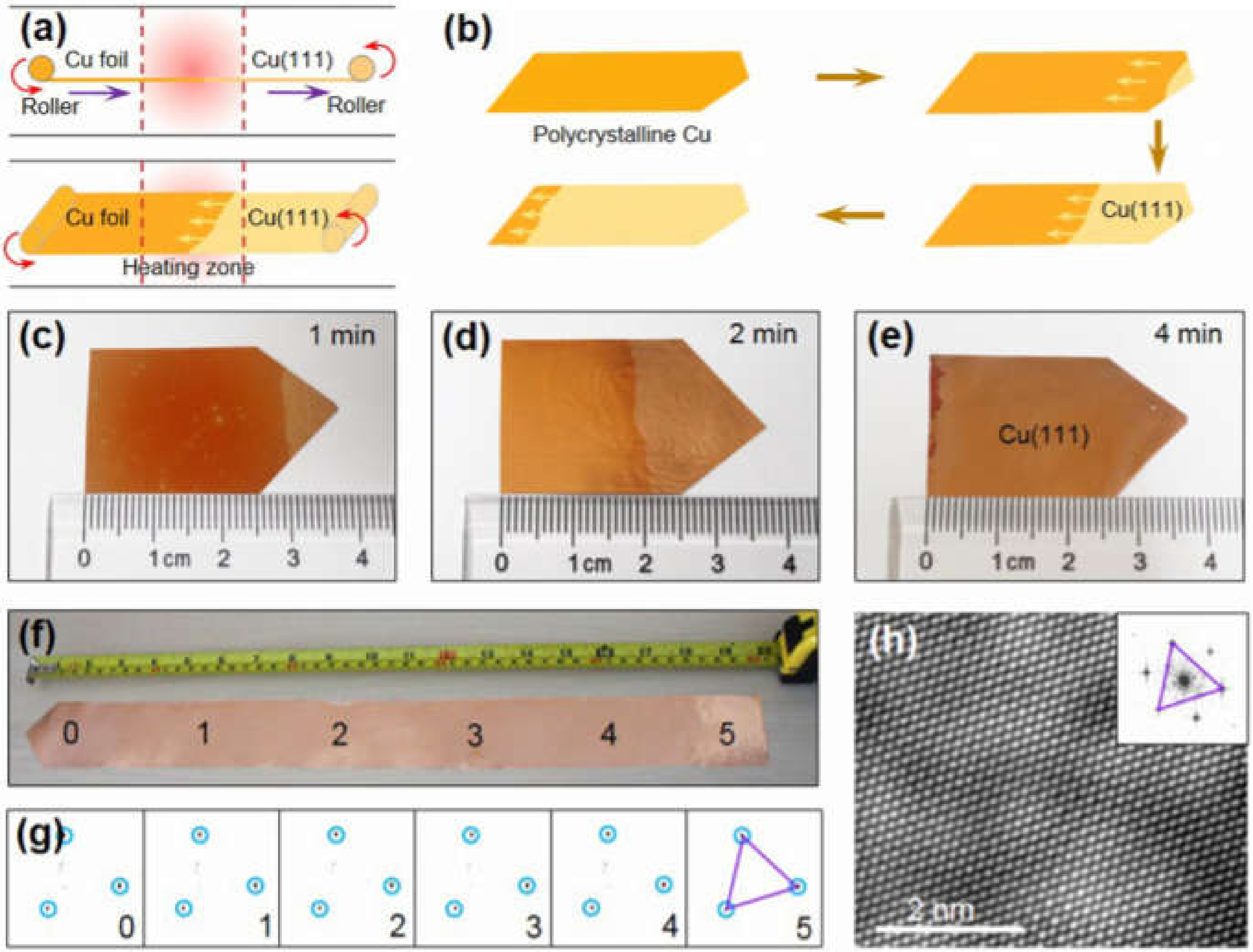
Graphene by CVD



Grephene likes to nucleate at Cu grain boundaries

How to get single crystal graphene?

Graphene by CVD

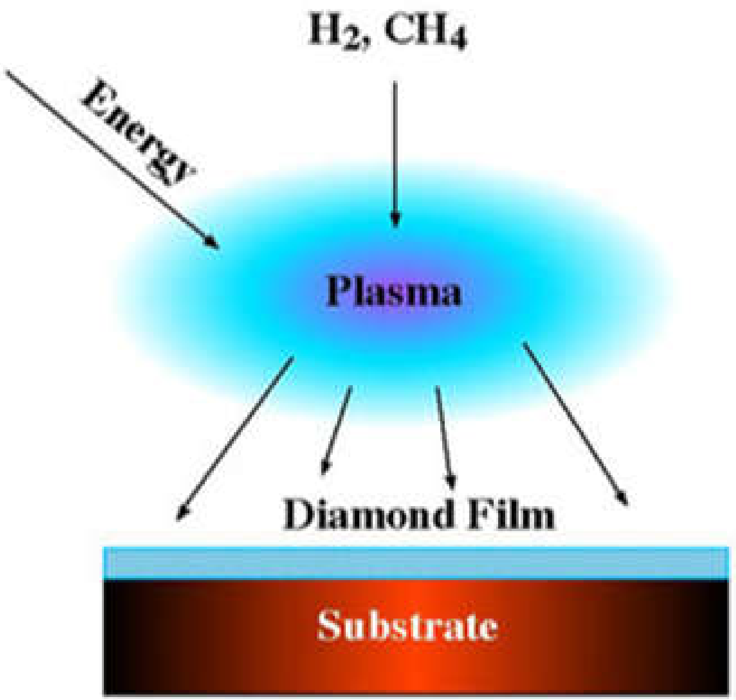


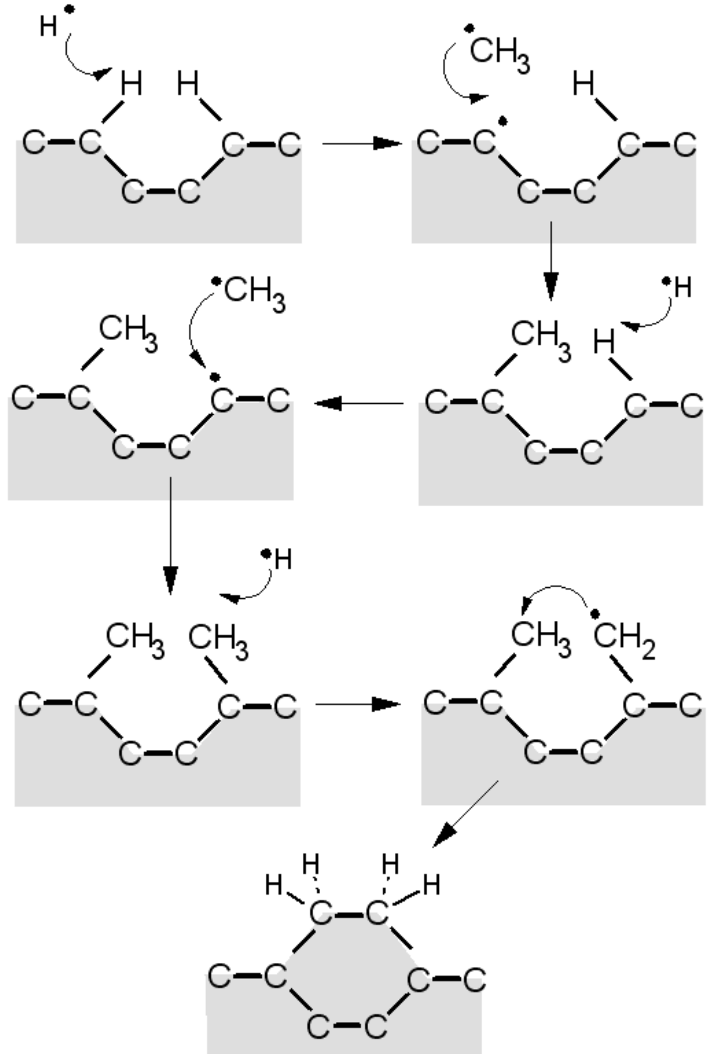
Single Crystal Substrate

↓

Single Crystal Graphene

Diamond by CVD





Thank you for your attention