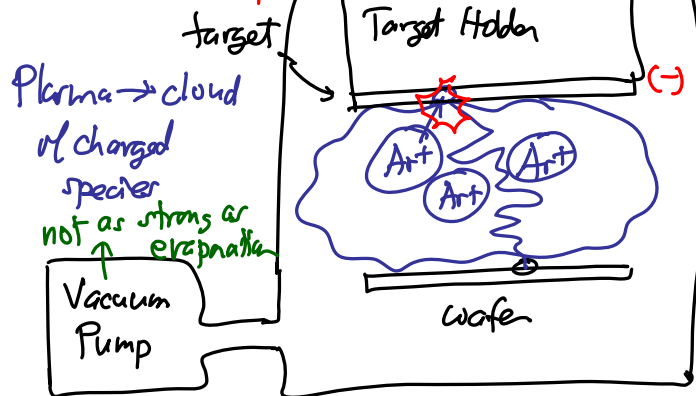


Lecture 12: Film Deposition II

- Announcements:
  - HW#5 due tomorrow at 8 a.m.
- -----
- Lecture Topics:
  - ↳ Film Deposition
    - Evaporation
    - Sputtering
    - Chemical Vapor Deposition
    - CVD Reactions
    - Epitaxial Growth
    - Atomic Layer Deposition (ALD)
  - ↳ Metal Electroplating

• Last Time:

Sputter Deposition



target and wafer take tortuous path to the wafer surface, since pressure is now  $\sim 300 \text{ mTorr}$   
 $\Rightarrow$  get more uniform film that covers steps

Procedure:

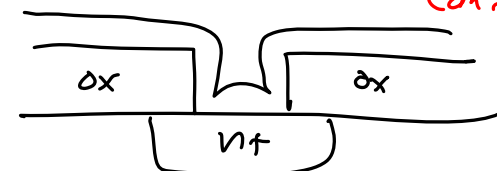
1. Pump down to vacuum ( $\sim 100 \text{ Pa}$ )
 
$$1 \text{ Pa} = 9.87 \times 10^{-6} \text{ atm} \left( \frac{760 \text{ Torr}}{\text{atm}} \right) = 0.0075012 \text{ Torr} \sim 7.5 \text{ mTorr}$$
2. Flow gas e.g., Ar
3. Fire up plasma (create  $\text{Ar}^+$  ions)  
Apply dc bias voltage (or RF for non-conductive targets)
4.  $\text{Ar}^+$  bombard target - dislodge atoms
5. Atoms make their way to the wafer in a more random fashion (take a tortuous path) - better step coverage

(i) @  $100 \text{ Pa} \rightarrow \lambda \approx 60 \mu\text{m}$  for  $4 \text{ \AA}$  particle

(ii) Plus, the target is bigger, i.e., not just a point source (which is what we had in evaporation)

Results better step coverage!

can fill contact via!



Problems:

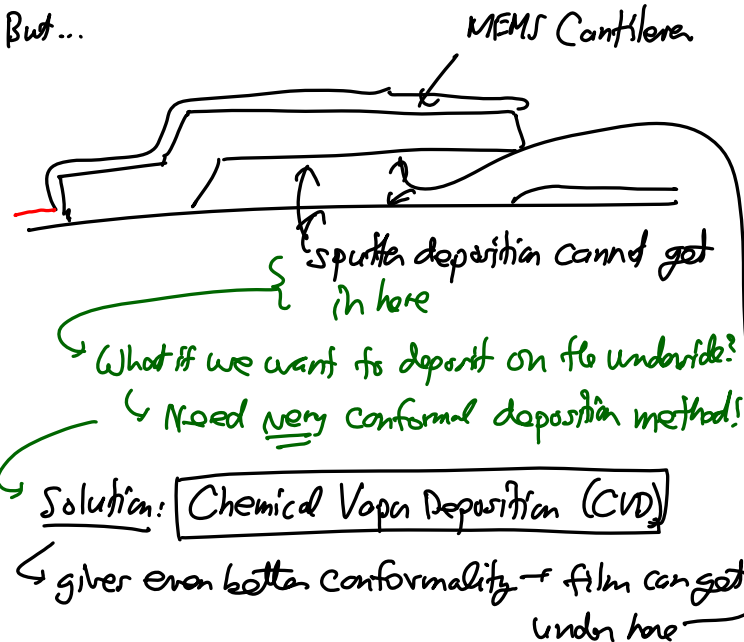
- (1) Get some Ar in the film  $\rightarrow$  lower quality film than evaporation
- (2) Substrate can heat up (up to  $\sim 350^\circ\text{C}$ ), causing nonuniformity across the wafer  $\rightarrow *$

\* but still more uniform than evaporation

Benefits:

- ① Better step coverage
- ② Can use plasma to roughen up the surface to get better adhesion.

But...



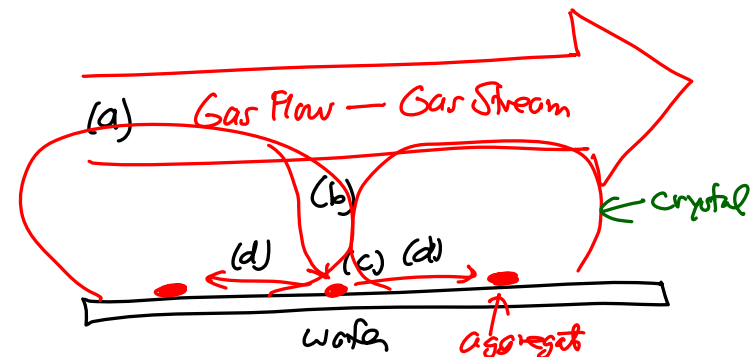
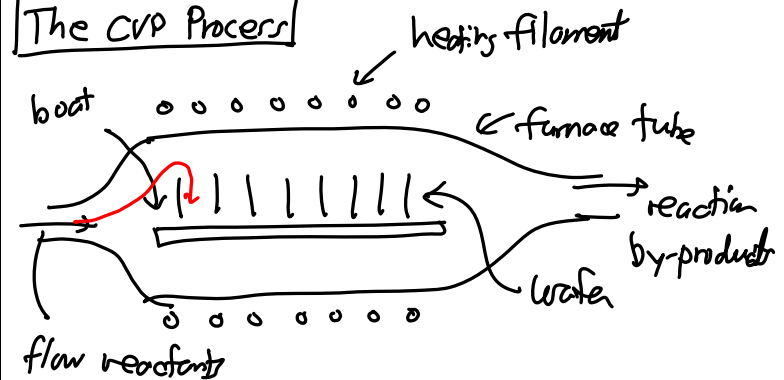
⇒ forms thin films on the surface of the substrate by thermal decomposition and/or reaction of gaseous compounds  
⇒ depositing the desired material directly fr the gas phase onto the substrate

⇒ performed @ pressure where  $\lambda$  is small  
↓  
combine w/ high T

Excellent Conformal Step Coverage!

⇒ types of films: polysilicon,  $\text{SiO}_2$ ,  $\text{Si}_3\text{N}_4$ ,  
 $\text{SiGe}$ , W, Mo, Ta, Ti, refractory metals

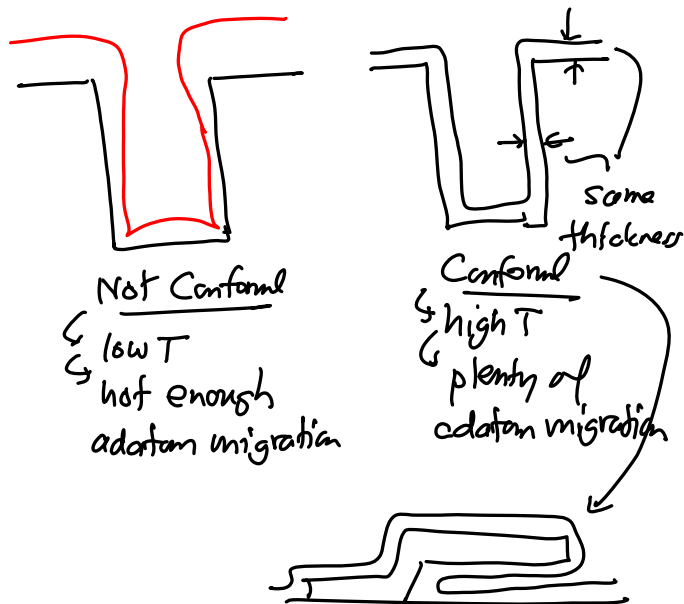
The CVD Process



Step-by-Step:

- Reactant gases (+ inert diluting gases) are introduced into the reaction chamber.
- Gas species move to the substrate
- Reactants adsorbed onto the substrate
- Atoms migrate and react chemically to form films

→ this determines to a large extent whether or not a film is conformal (i.e., better step coverage)

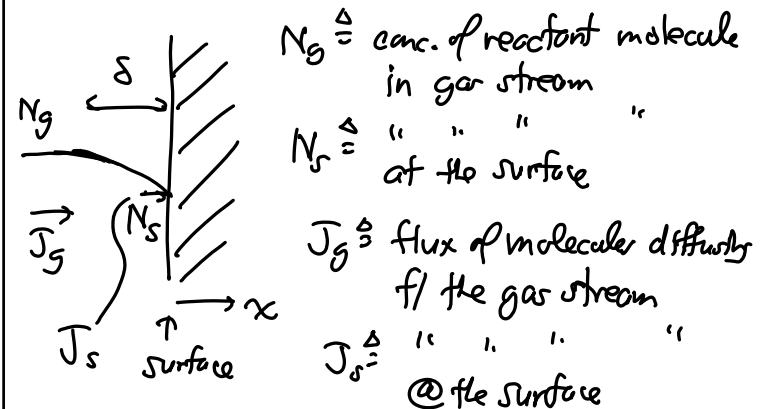


(e) Reaction by-products desorbed and removed from the reaction chamber.

⇒ energy drives the whole process

↳ heat (thermal)  
photons  
electrons (plasma)

Simplified Modeling



Governing Equations:

$$J_s = k_s N_s \quad [k_s \triangleq \text{surface reaction rate constant}]$$

$$J_g = \left( \frac{D_g}{\delta} \right) (N_g - N_s) = h_g (N_g - N_s)$$

effective diffusion coeff. for the gas molecule      Vapour phase mass-transfer coefficient

$$[J_s = J_g = J], [N_s = \frac{J_s}{k_s}]$$

otherwise reactants  
will build up somewhat

$$J = h_g(N_g - \frac{J}{k_s}) = h_g N_g - \frac{h_g J}{k_s}$$

$$J(1 + \frac{h_g}{k_s}) = h_g N_g \Rightarrow J = \frac{k_s h_g}{k_s + h_g} N_g$$

$$J = (k_s || h_g) N_g$$

$$\text{growth rate} = \frac{\text{flux}}{\text{molecules incorporated/unit volume}} \\ \approx \frac{J}{N} = \boxed{(k_s || h_g) \frac{N_g}{N} = \text{growth rate}}$$

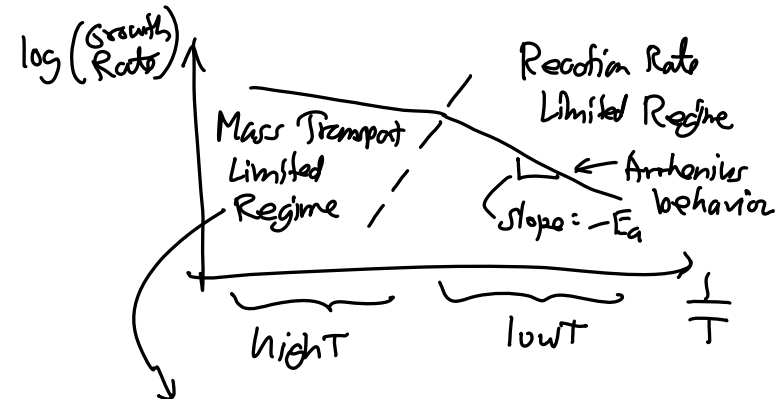
Case:  $k_s \gg h_g \rightarrow$  surface reaction rate  $\gg$  mass xfer rate

$$\boxed{\text{growth rate} = h_g \frac{N_g}{N}} \quad (\text{mass transfer limited})$$

Case:  $h_g \gg k_s \rightarrow$  mass xfer rate  $\gg$  surface reaction rate

$$\boxed{\text{growth rate} = k_s \frac{N_g}{N}} \quad (\text{surface reaction limited}) \\ \sim R_0 e^{-E_a/kT} \quad (\text{Arrhenius character})$$

## Temperature Dependence of Growth Rate



dep. rate less dependent on T, have  
for better thickness control, better  
to operate at high T

- Now, go through Module 3 on Film Deposition, starting at slide 16