Lecture 11: Film Deposition

- **Announcements:**
  - Modifications to lab procedure online
- ---------------------------------------
- **Lecture Topics:**
  - Dopant Redistribution During Oxidation
  - Film Deposition
    - Evaporation
    - Sputtering
    - Chemical Vapor Deposition
    - CVD Reactions
    - Epitaxial Growth
    - Atomic Layer Deposition (ALD)
  - Chemical Mechanical Polishing (CMP)
- ---------------------------------------
- **Last Time:** oxidation modeling

$$X_{ox}(t) = \frac{A}{2}\left\{\left[1+\frac{4B}{A^2}(t+\tau)\right]^{\frac{1}{2}}-1\right\}$$

where $A = \frac{2D}{k_s}$

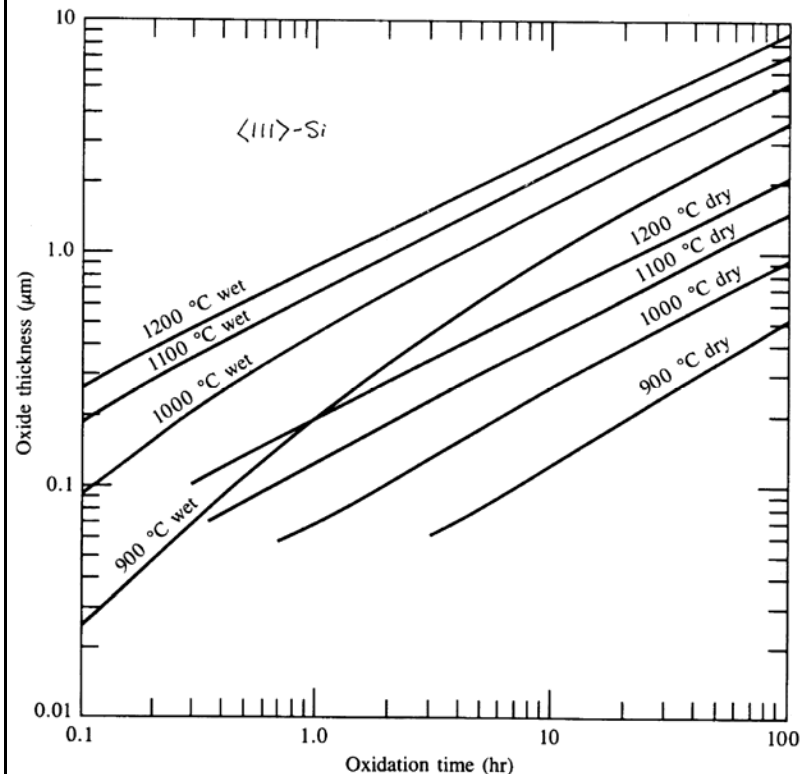
$B = \frac{2DN_0}{M}$

$\tau = \frac{X_i^2}{B} + \frac{X_i}{(B/A)}$

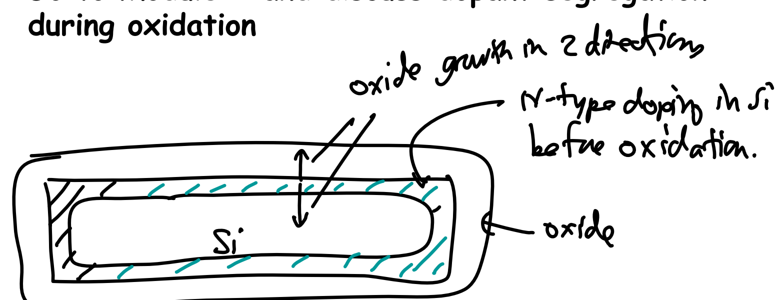
X_i = initial oxide thickness

Box $\left(\frac{B}{A}\right)$ ~~B~~ $= D_0 \exp\left(-\frac{E_A}{kT}\right)$ ⇒ governed by an Arrhenius relationship

- **Oxidation Graphs:**



- Go to Module 2 and discuss dopant segregation during oxidation

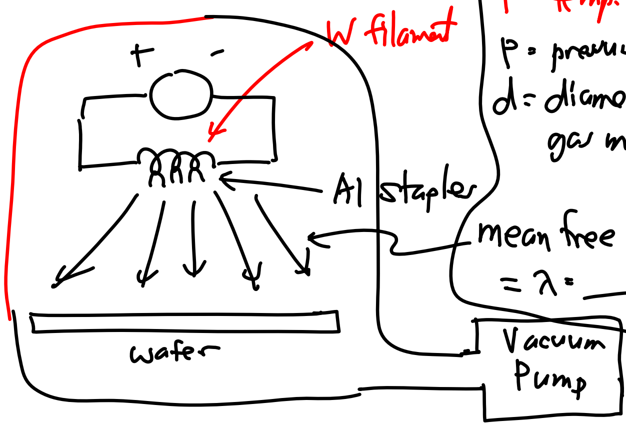


Question: What happens to surface dopant conc. after oxide growth?

Evaporation

⇒ heat a metal (Al, Au) to the pt. of vaporization
↳ evaporate metal & form a film covering the wafer surface
↳ do under vacuum for better control of film comp.

Filament Evaporation System



k: Boltzmann const.
T: temp.
P = pressure
d = diameter of gas molecule

mean free path $= \lambda = \frac{kT}{\sqrt{2}\pi P d^2}$

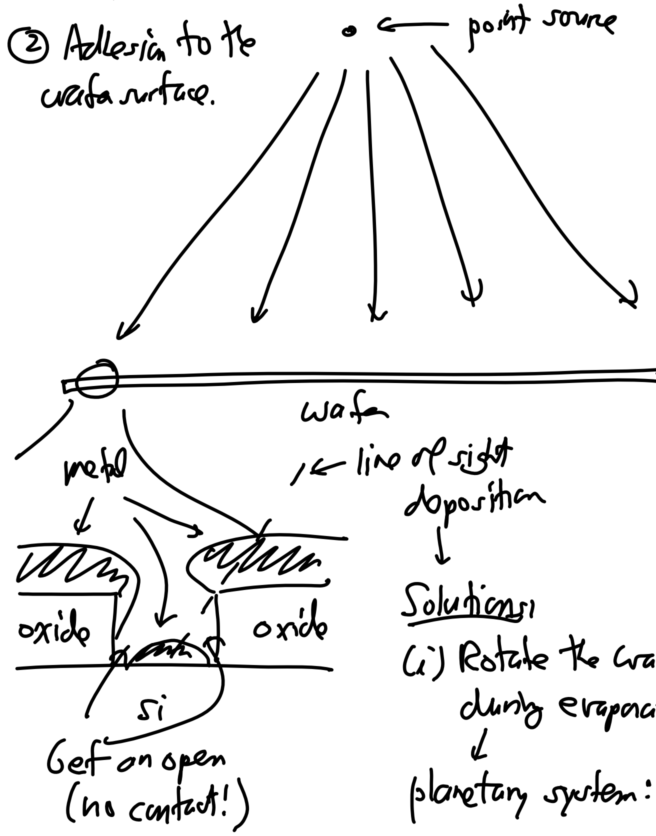
Procedure:

⓪ pump down to vacuum → reduce film contamination & allows better thickness control
① heat W filament → melt Al, wet filament
② raise temperature → evaporate Al

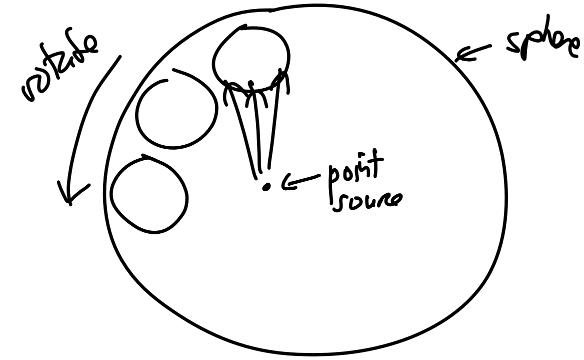
⇒ λ can be ~60 m for a 4Å particle @ 10^{-4} Pa ($= 0.75\,\mu$Torr)
↳ thus, get straight line path from Al staple @ filament to wafer

Problem: ① Shadowing & Step Coverage

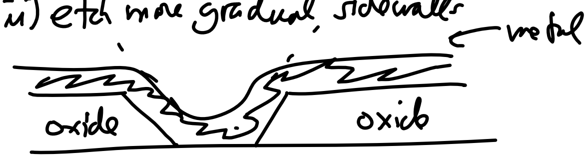
② Adhesion to the wafer surface.



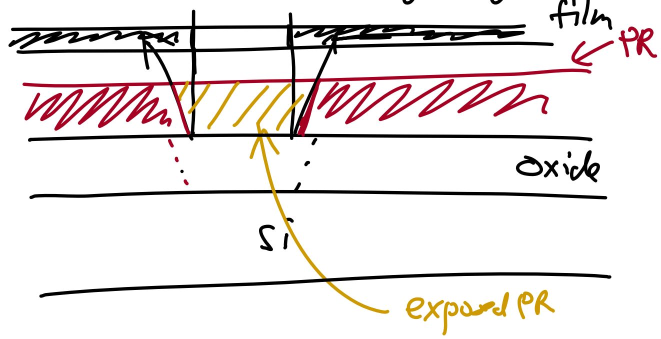
↙ line of sight deposition
↓
Solutions:
(i) Rotate the wafer during evaporation
↓
planetary system:



(iii) etch more gradual sidewalls

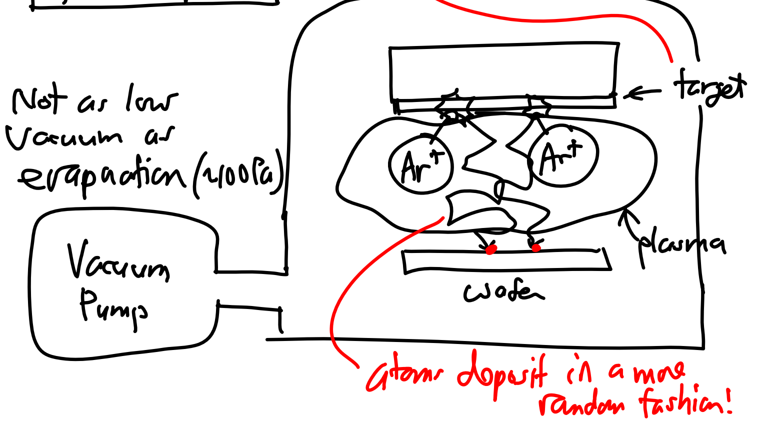


→ much less shadowing → get conformal film



⇒ if line of sight still a problem, then

Sputter Deposition



Procedure:

1. Pump down to vacuum (~100 Pa)
   $1 \text{ Pa} = 9.87\times10^{-6} \text{ atm} \left(\frac{760 \text{ torr}}{\text{atm}}\right) = 0.0075012 \text{ Torr}$
2. Flow gas (e.g., Ar)
3. Fire up plasma (create Ar^+ ions)
   ↳ apply dc-bias (or RF for non-conductive targets)
4. Ar^+ ions bombard target → dislodge atoms
5. Atoms make their way to the wafer in a more random fashion
   (@ 100 Pa → $\lambda \sim 60\,\mu m$ for a 4Å particle
   ↳ plus, the target is biased)

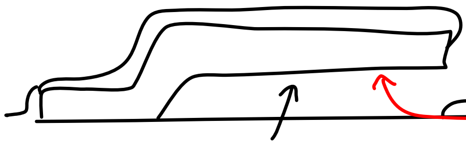
⇒ Result: Better step coverage!

Problems:

(1) Get some Ar in the film → lower quality film
(2) substrate can heat up (up to ~350°C), causing non-uniformity across the wafer
   ↳ although it's still more uniform than evaporation

Other Benefits:

① ————
② Can use plasma to roughen up surface to get better adhesion.



Solution: Chemical Vapor Deposition (CVD)

→ for even better conformality → film can get under here

Forms thin films on the surface of the substrate by thermal decomposition and/or reaction of gaseous compounds.

↳ desired material is deposited directly from the gas phase onto the substrate surface

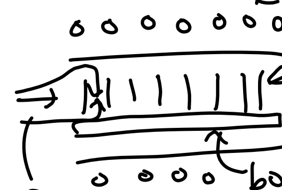
performed @ pressures for which λ is small, combine this w/ relatively high T

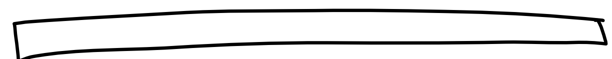
⇓

Excellent Conformal Step Coverage!

→ types of films: polysilicon, SiO_2, Si_3N_4, SiGe, W, Mo, Ta, Ti, refractory metals

The CVD Process





Step-by-Step:

(a) Reactant gases (+ inert diluting gases) are introduced into the reaction chamber.

(b)