Section 5: Thin Film Deposition

part 1 : sputtering and evaporation

Jaeger Chapter 6

Vacuum Basics

1. Units

- 1 atmosphere = 760 torr = 1.013×10^5 Pa
- 1 bar = 10^5 Pa = 750 torr
- 1 torr = 1 mm Hg
- 1 mtorr = 1 micron Hg
- 1Pa = 7.5 mtorr = 1 newton/m^2
- 1 torr = 133.3 Pa

2. Ideal Gas Law: PV = NkT

- k = 1.38E-23 Joules/K
  = 1.37E-22 atm cm^3/K
- N = # of molecules *(note the typo in your book)*
- T = absolute temperature in K

3. Dalton's Law of Partial Pressure

For mixture of non-reactive gases in a common vessel, each gas exerts its pressure independent of others.

$P_{total} = P_1 + P_2 + \ldots + P_N$ (Total P = Sum of partial pressure)

$N_{total} = N_1 + N_2 + \ldots + N_N$

$P_1V = N_1kT$

$P_2V = N_2kT$

....

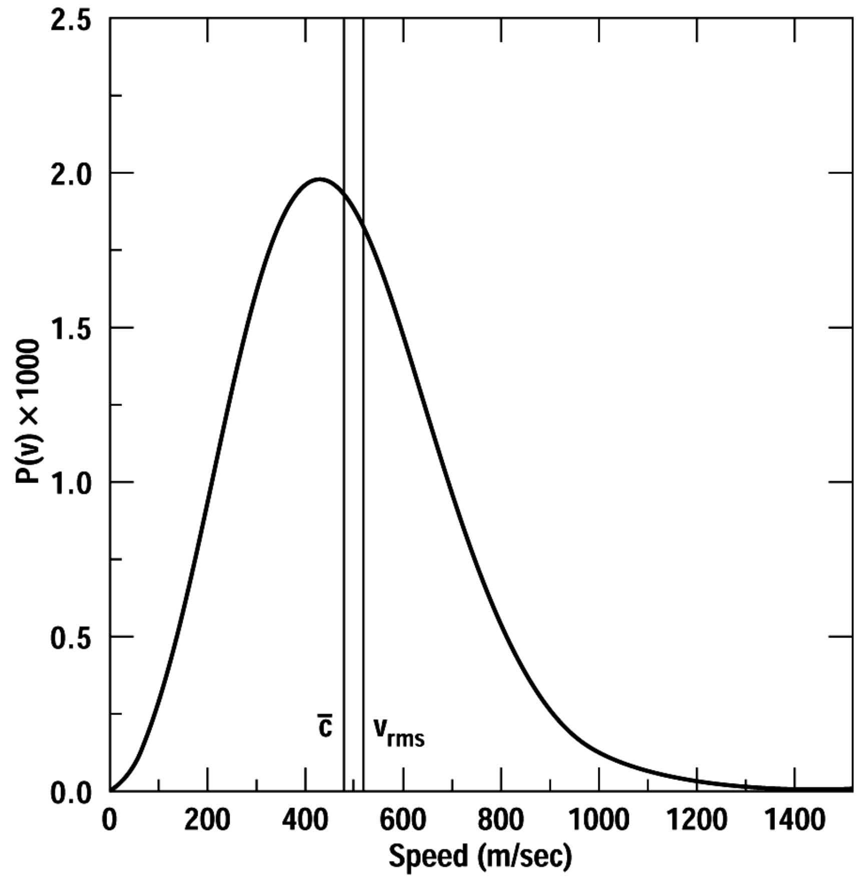
$P_NV = N_NkT$

4. Average Molecular Velocity

Assumes Maxwell-Boltzman Velocity Distribution

$$\overline{v} = (8kT/\pi m)^{1/2}$$

where m = molecular weight of gas molecule



5. Mean Free Path between collisions

$$\lambda = \frac{kT}{\sqrt{2}\,\pi d^2 P}$$

where n = molecular density = N/V,

d = molecular diameter

[Note] For air at 300 °K, $\lambda = \frac{6.6}{P(\text{in Pa})} = \frac{0.05}{P(\text{in torr})}$

with λ in mm

6. Impingement Rate

Φ = # of molecules striking unit surface /unit time.

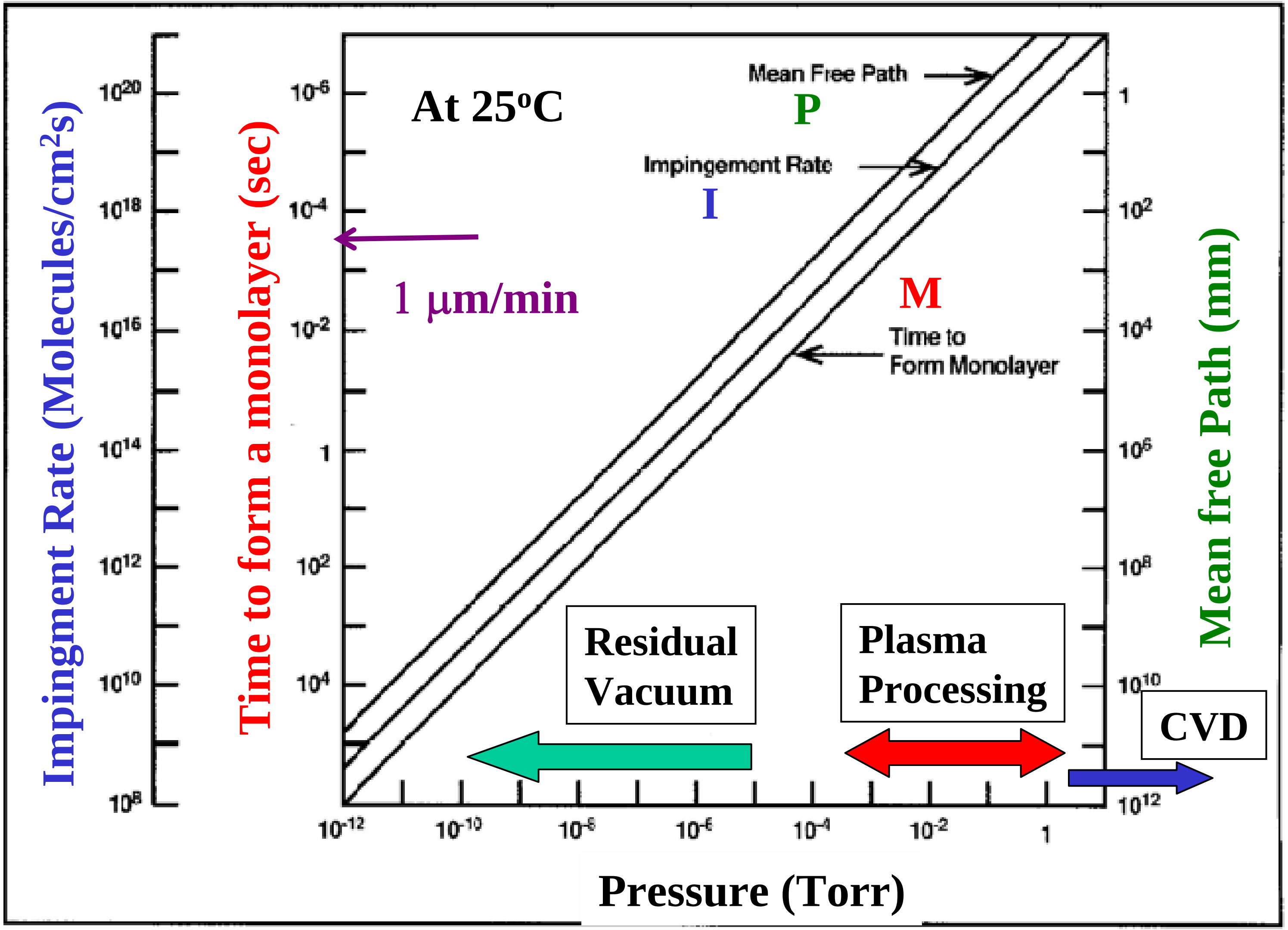
$$= 3.5\times10^{22}\times\frac{P}{\sqrt{MT}}$$

in #/cm^2-sec
with P in torr, M is the molecular weight

Question

How long does it take to form a monolayer of gas on the surface of a substrate?

Vacuum Basics (Cont.)



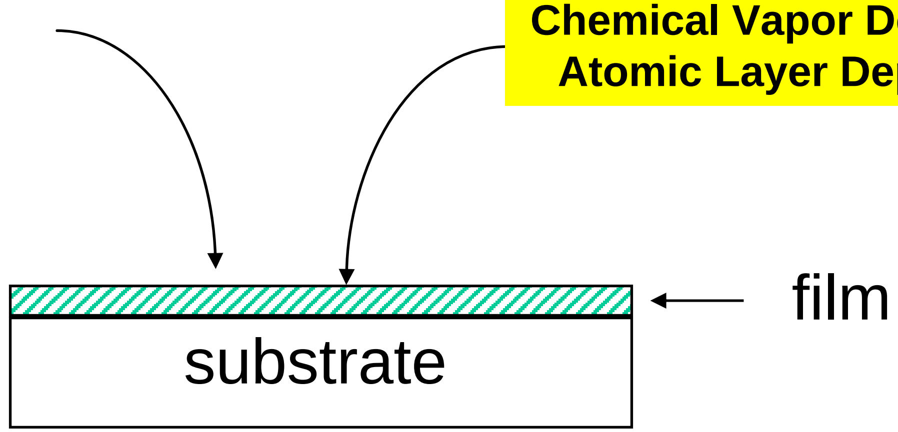
Thin Film Deposition

Physical Methods

- **Evaporation**
- **Sputtering**

Chemical Methods

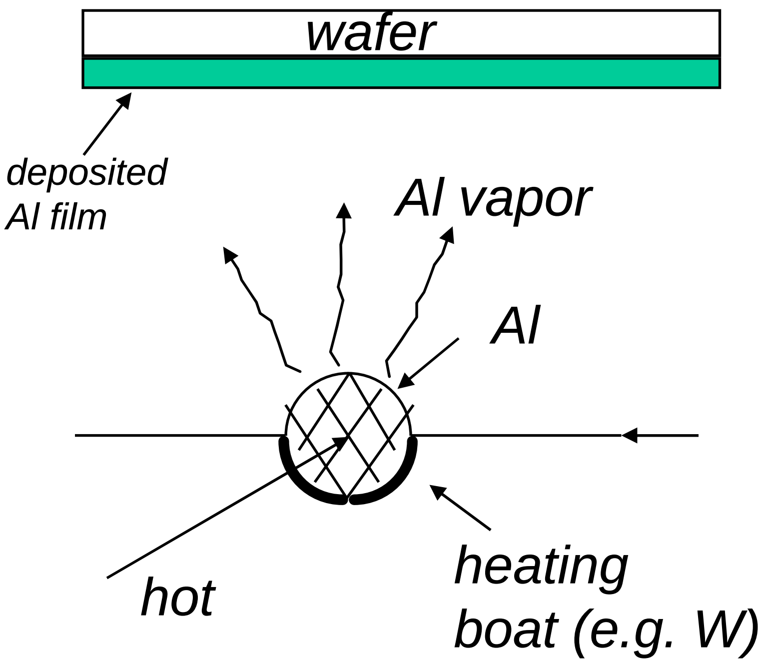
- **Chemical Vapor Deposition (CVD)**
- **Atomic Layer Deposition (ALD)**



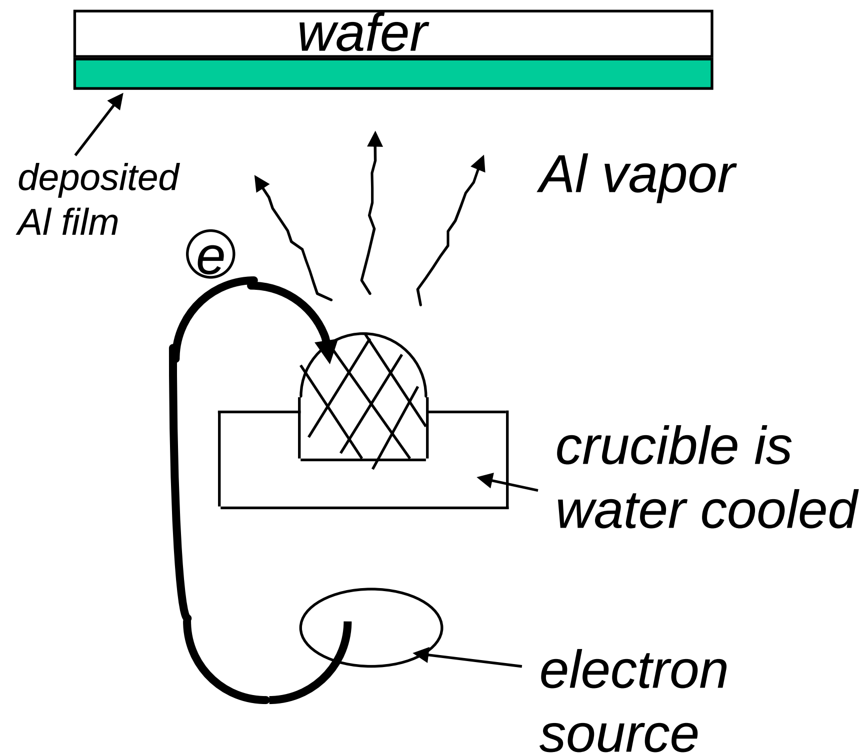
<u>Applications:</u>

Metalization (e.g. Al, TiN, W, silicide)
Poly-Si
dielectric layers; surface passivation.

Evaporation



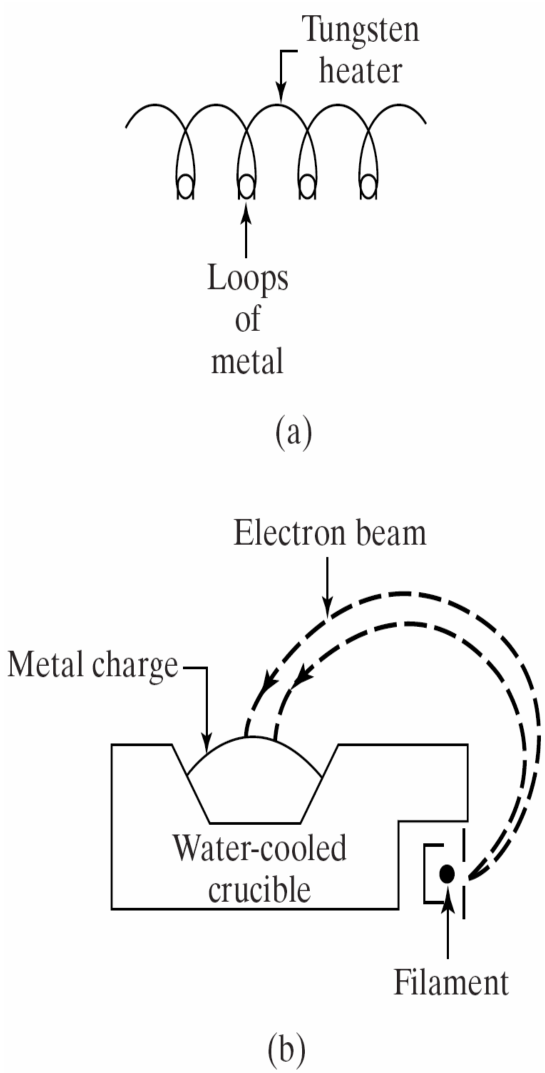
Thermal Evaporation



Electron Beam Evaporation

Gas Pressure: < 10^{-5} Torr

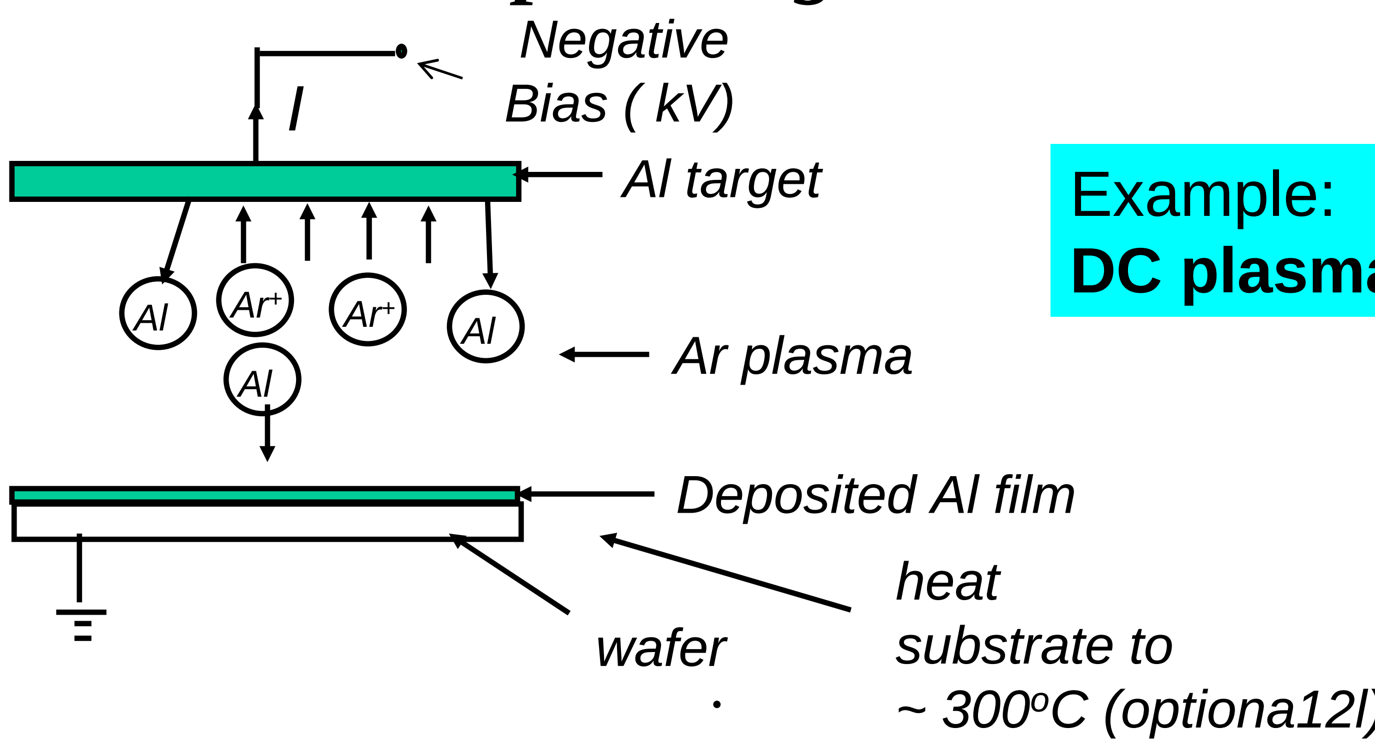
Evaporation: Filament & Electron Beam



(a) Filament Evaporation with Loops of Wire Hanging from a Heated Filament

(b) Electron Beam is Focused on Metal Charge by a Magnetic Field

Sputtering



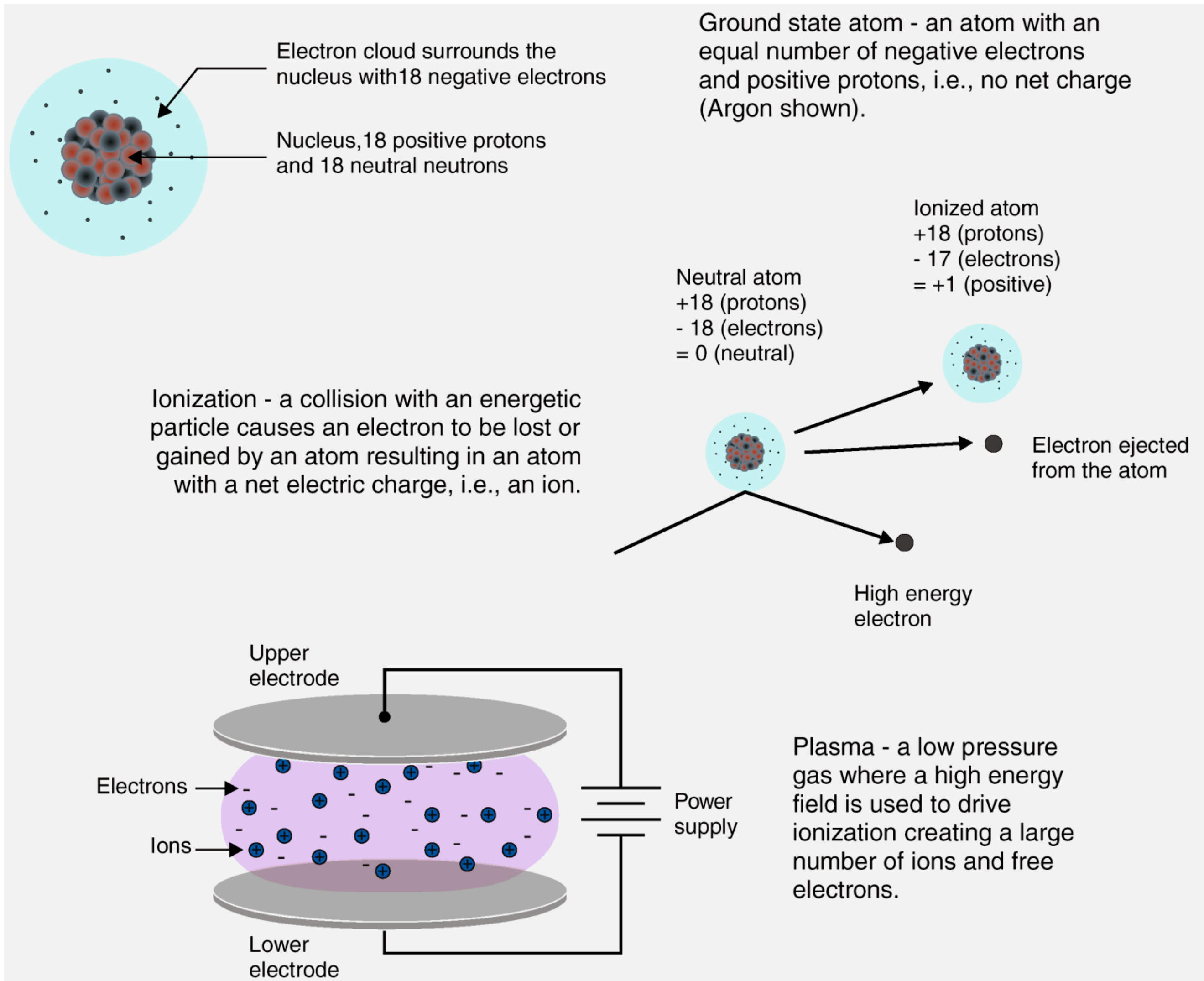
Example:
DC plasma

Gas Pressure ≅ 1-10 m Torr

Deposition rate = $constant \bullet I \bullet S$ ← *sputtering yield*

↑ *ion current*

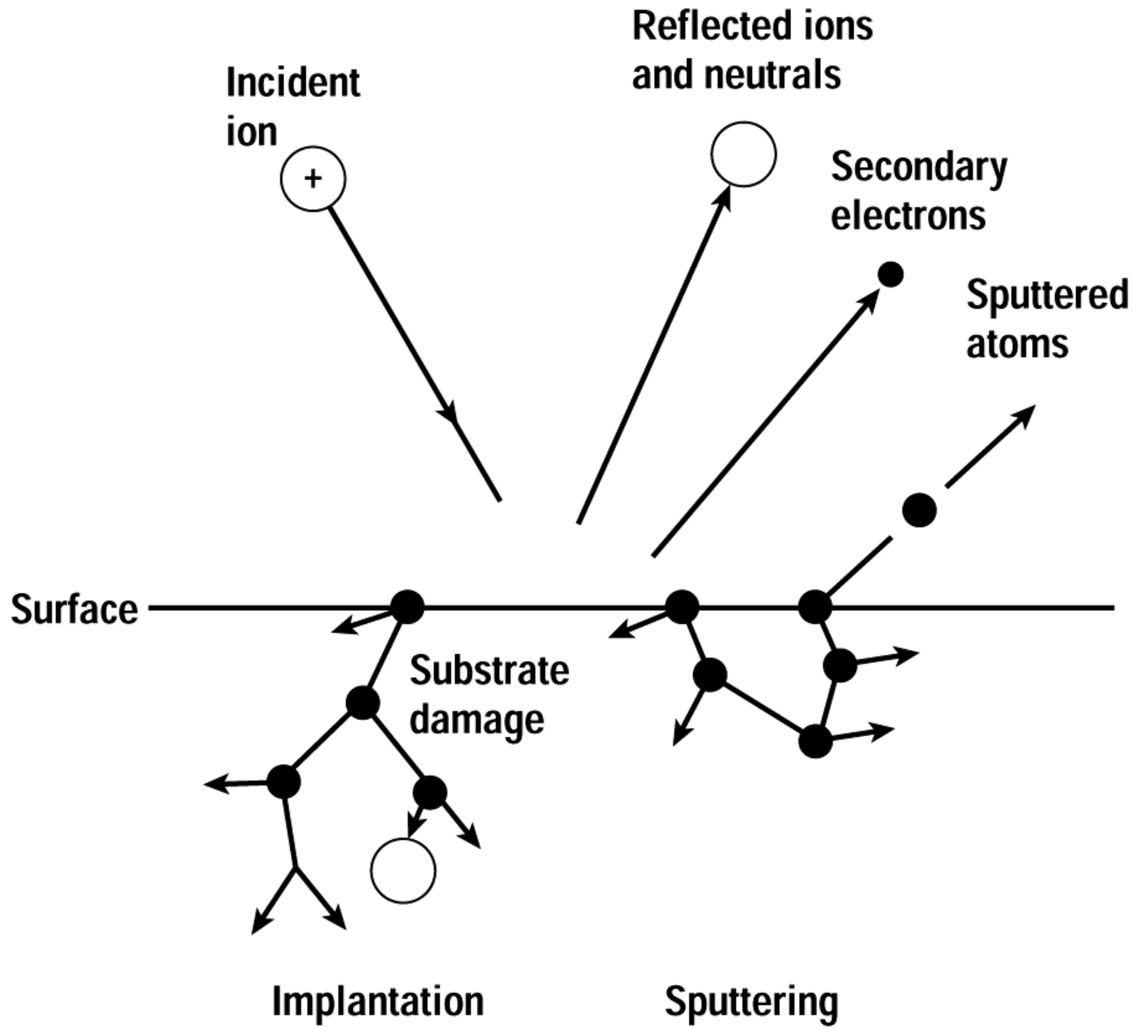
Plasma Basics



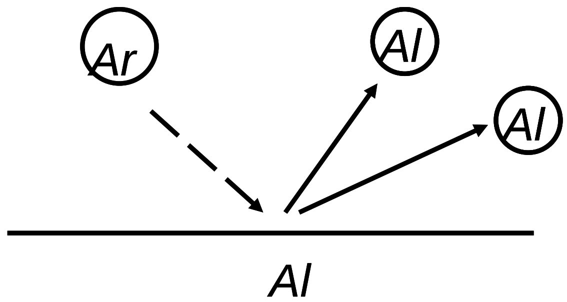
Basic Properties of Plasma

- The bulk of plasma contains equal concentrations of ions and electrons.
- Electric potential is ≈ constant inside bulk of plasma. The voltage drop is mostly across the sheath regions.
- Plasma used in IC processing is a "weak" plasma, containing mostly neutral atoms/molecules. Degree of ionization is ≈ 10^{-3} to 10^{-6}.

Outcomes of Plasma bombardment



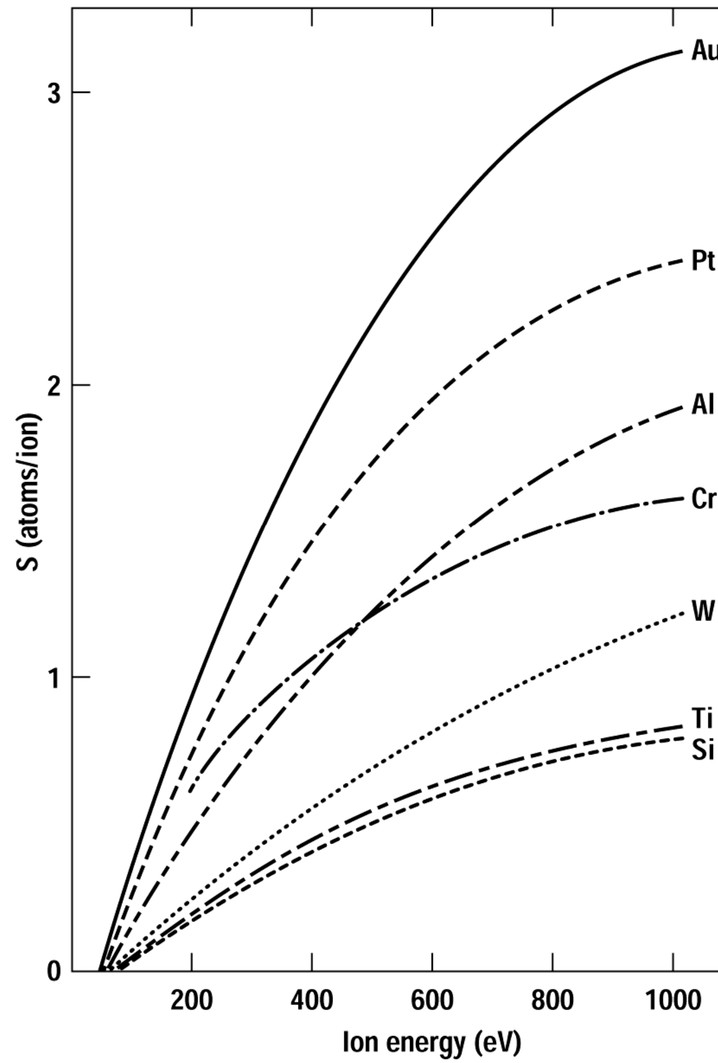
Sputtering Yield



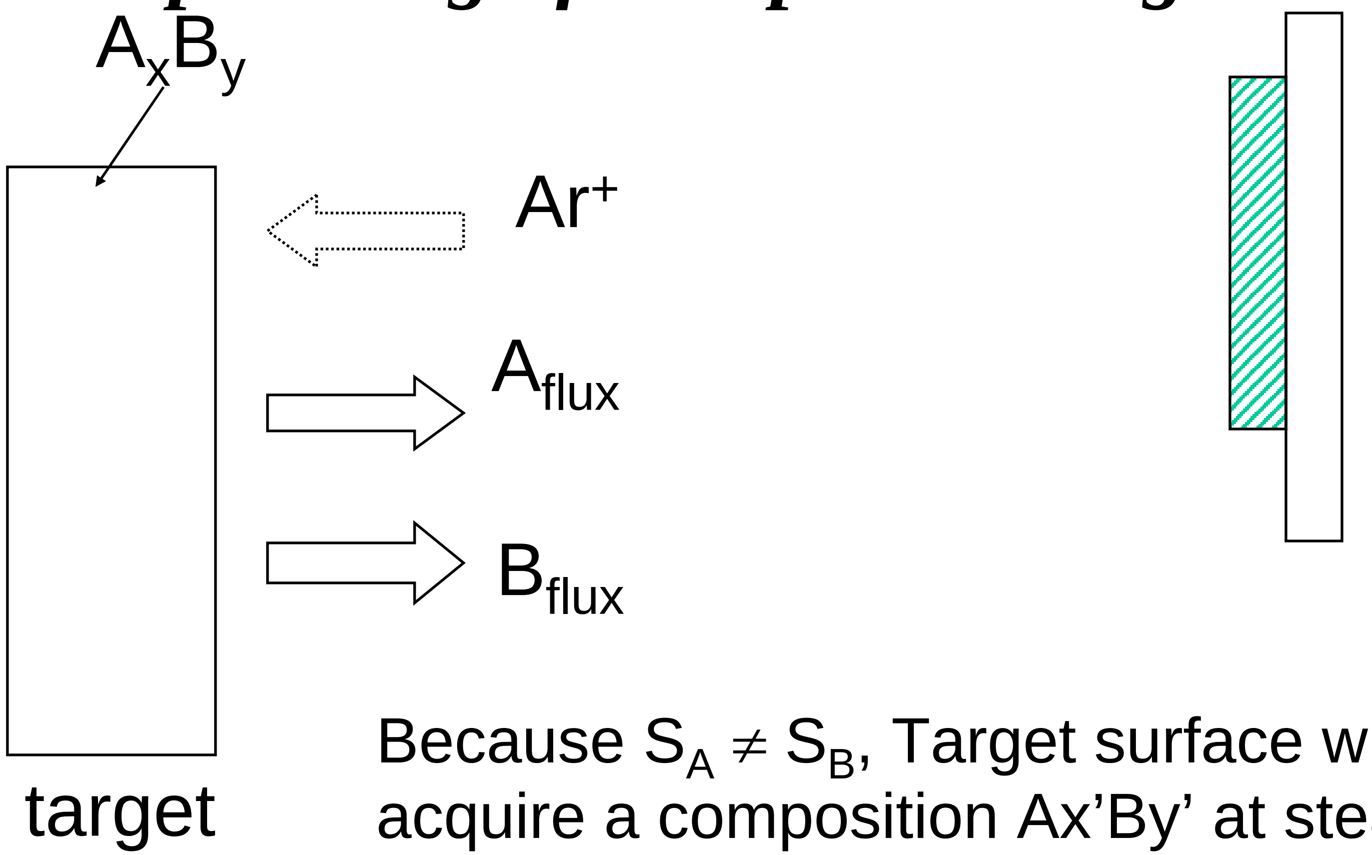
Sputtering Yield S

$$S \equiv \frac{\text{\# of ejected target atoms}}{\text{incoming ion.}}$$

0.1 < S < 30



Sputtering of Compound Targets

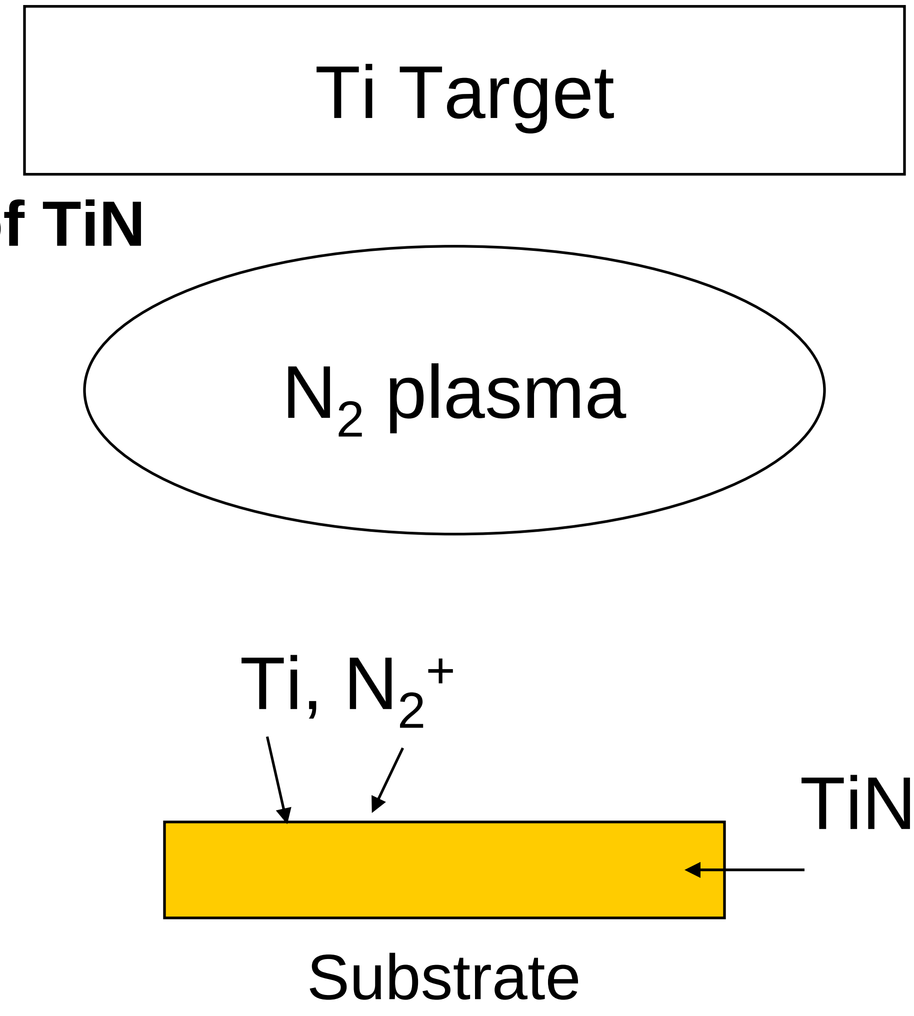


Because $S_A \neq S_B$, Target surface will acquire a composition Ax'By' at steady state.

Reactive Sputtering

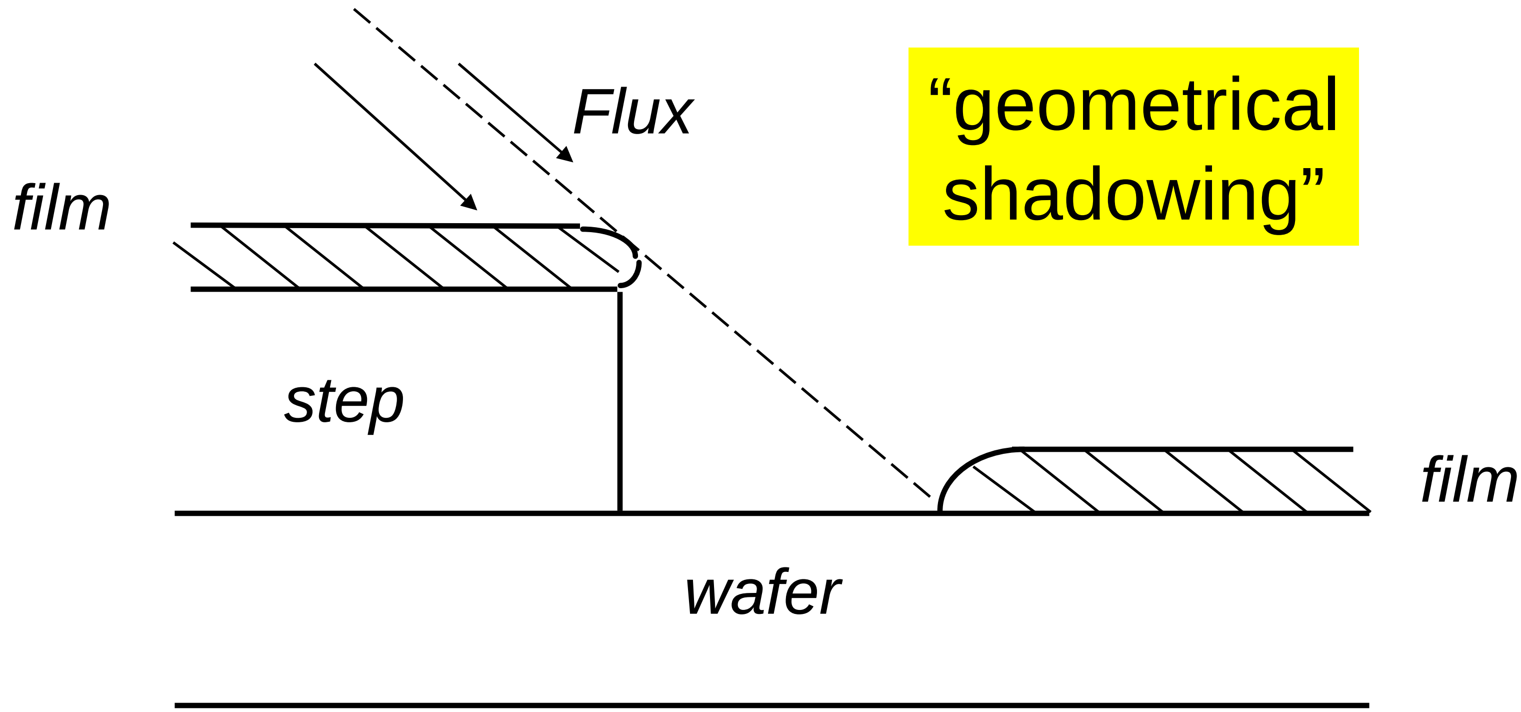
Example: Formation of TiN

- Sputter a Ti target with a nitrogen plasma

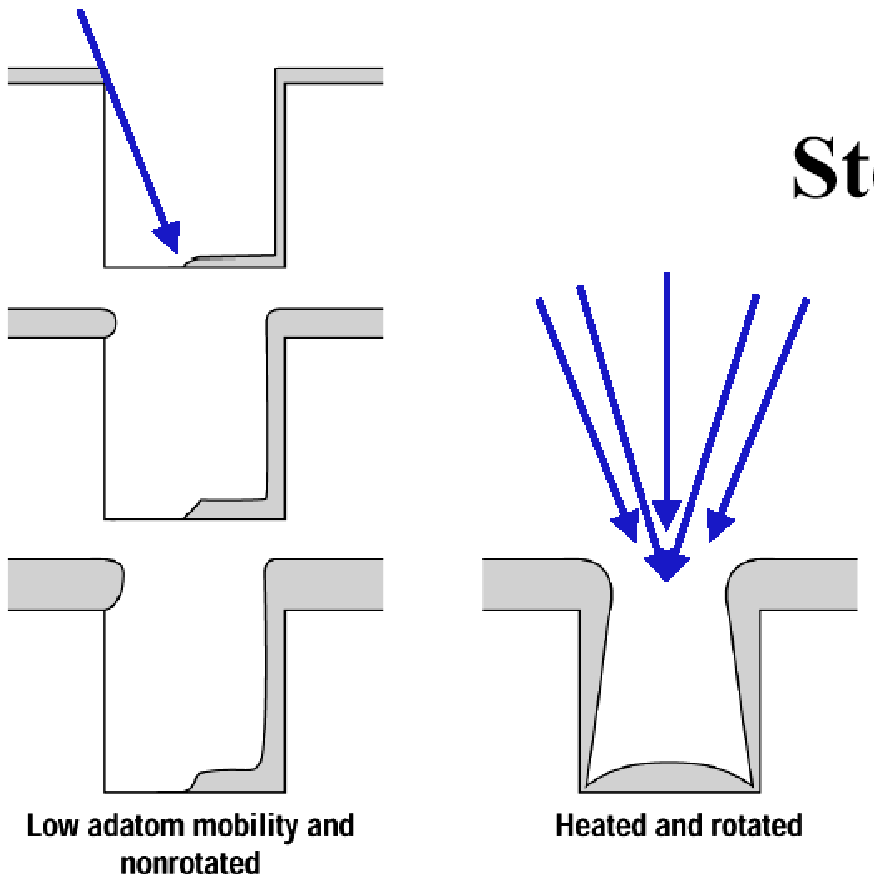


Step Coverage Problem with PVD

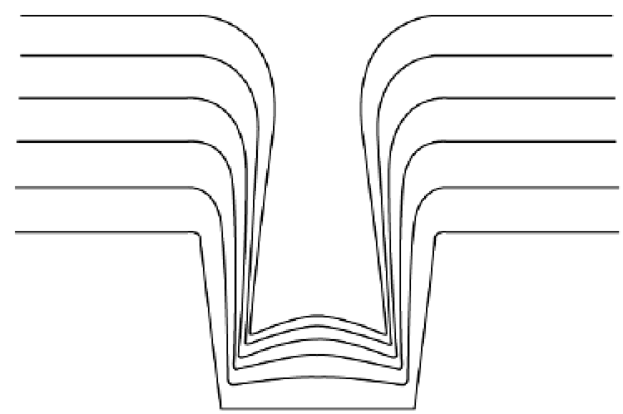
- Both evaporation and sputtering have directional fluxes.



Step Coverage concerns in contacts

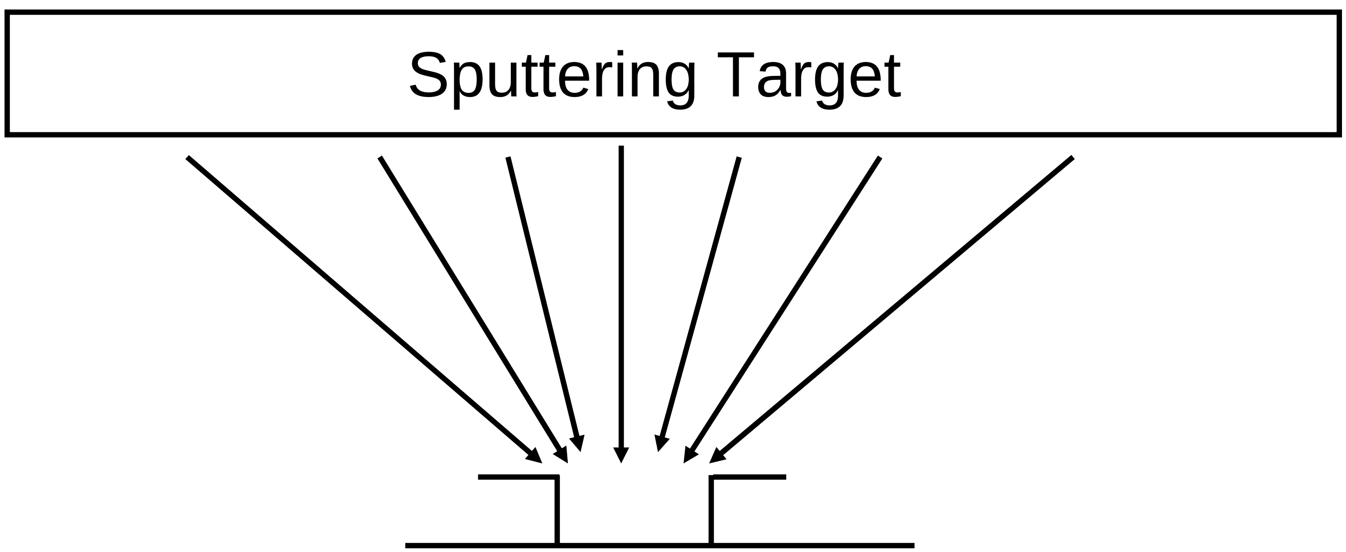


Step Coverage



Methods to Minimize Step Coverage Problems

- Rotate + Tilt substrate during deposition
- Elevate substrate temperature (why?)
- Use large-area deposition source



Advantages of Sputtering over Evaporation

•For multi-component thin films, sputtering gives **better composition control** using compound targets. Evaporation depends on vapor pressure of various vapor components and is difficult to control.

•**Better lateral thickness uniformity –** superposition of multiple point sources