Lecture#9:

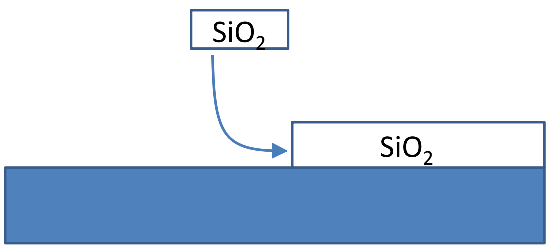
Deposition (1)

:Physical Vapor Deposition (PVD)

Vapor Deposition

Deposition (1): Physical Vapor Deposition (PVD)

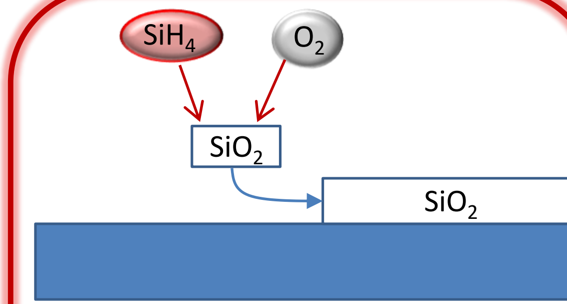
- **Physical vapor deposition (PVD)**



Evaporation
Sputtering
Molecular beam Epitaxy (MBE)

- At low/moderate temperature
- Energetic particle
- Physical adhesion

- **Chemical vapor deposition (CVD)**



Thermal oxidation
Atmospheric pressure CVD (APCVD)
Low pressure CVD (LPCVD)
Plasma enhanced CVD (PECVD)
Metal organic CVD (MOCVD)

- At high temperature
- Reactive substances
- Chemical reaction(Deposit)

PVD Evaporation

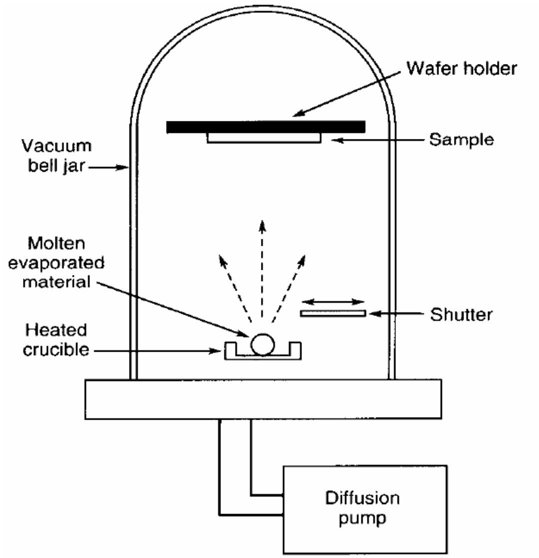
Deposition (1): Physical Vapor Deposition (PVD)

- **What is evaporation**

; Aluminum and gold are heated to the point of vaporization, and then evaporate to form a thin film covering the surface of the silicon wafer.

; In order to control the composition material, evaporation is performed under vacuum conditions.

- **Basic deposition system**

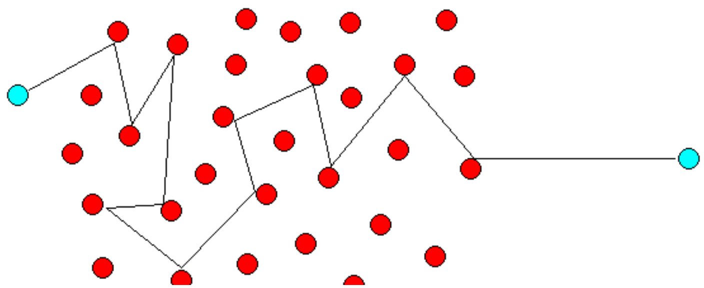


Main system
- Vacuum Chamber
- Gas & Gas line
- Pumping system (Rotary, Turbomolcular. Cryo, Ion pump)

Mean free path of gas molecule

; Pressure and temperature also determine an important film-deposition parameter called the mean free path.

; Average distance - the molecule travels before it collides with another molecule



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

d: the diameter of the gas molecule (2~5Å)

Evaporation is usually done at a background pressure near 10^{-4} Pa. At this pressure, a 4 Å molecule has a mean free path of approximately 60 m.

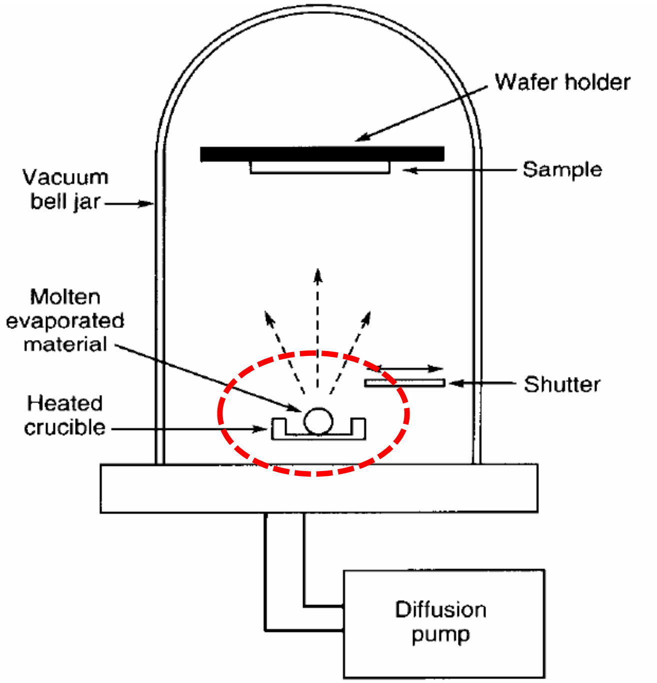
$\lambda = 60m$ (P= 10^{-4}Pa, d=4Å)

; Generally, there is no interact with the background gases and deposition materials

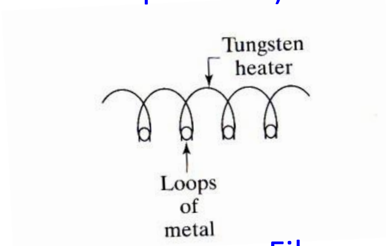
$cf)\ \lambda = 60um$ (P= 100Pa, d=4Å)

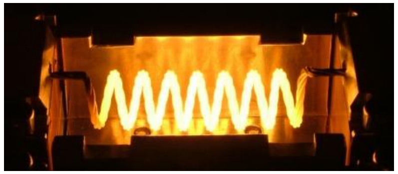
PVD Evaporation: Two Forms

Deposition (1): Physical Vapor Deposition (PVD)



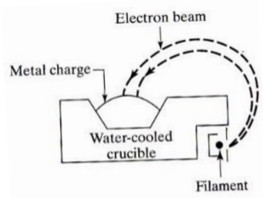
- **Thermal evaporator**
  : Easy
  : High contamination (from filament material)
  : not easy to control composite material (different evaporation temperature)

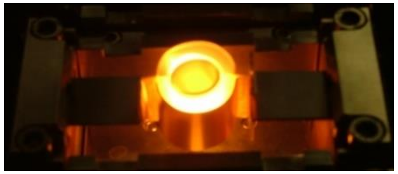




Filament temperature is raised to evaporate the target materials from the filament

- **e-Beam evaporator**
  : Low contamination
  : High T material





A high-intensity beam of electrons, 15 keV, is focused on a source target containing the material to be evaporated.

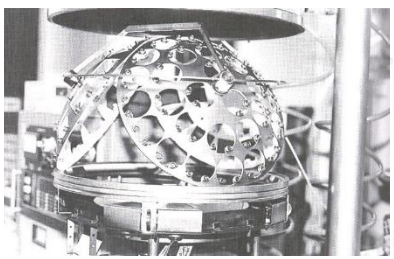
[Note] monitoring the deposition rates uses a quartz crystal which is covered by the evaporating material during deposition.
The resonant frequency of the crystal shifts in proportional to the thickness of the deposited film.

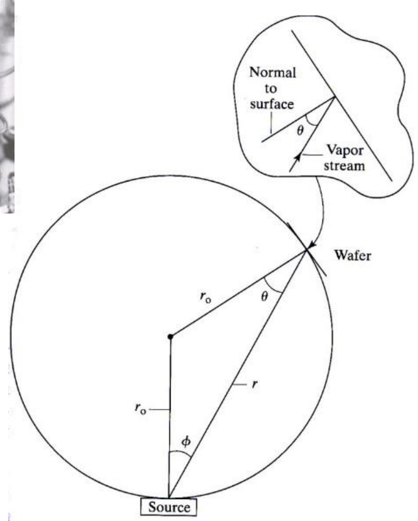
Deposition rate

$$R = \frac{m}{\pi \rho r^2} \cos\theta \cos\phi \text{ (cm/sec)}$$

m; mass evaporation rate (g/sec)
ρ : density

For batch deposition, a planetary substrate holder consisting of rotating section of a sphere is used. Each substrate is positioned tangential to the surface of the sphere with radius r_0.





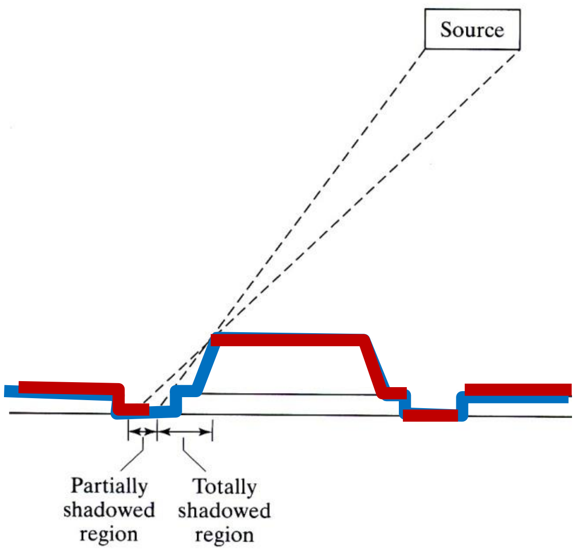
$$\cos\theta = \cos\phi = \frac{r}{2r_0}$$

$$R = \frac{m}{4\pi\rho r_0^2}$$

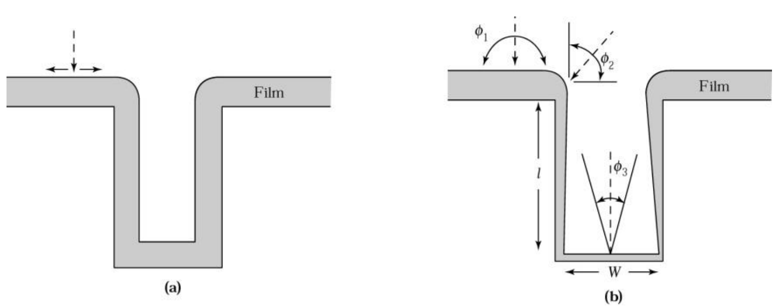
[Note] The wafers are mounted above the source and are typically rotated around the source during deposition to ensure uniform coverage.
Wafers are also often radiantly heated to improve adhesion and uniformity of the evaporated material.

PVD Evaporation: Shadowing & Step Coverage

Shadowing & Step coverage



- Because of large mean free paths of gas molecules at low pressure, evaporation tend to be directional in nature, and shadowing of pattern and poor step coverage can occur during deposition.



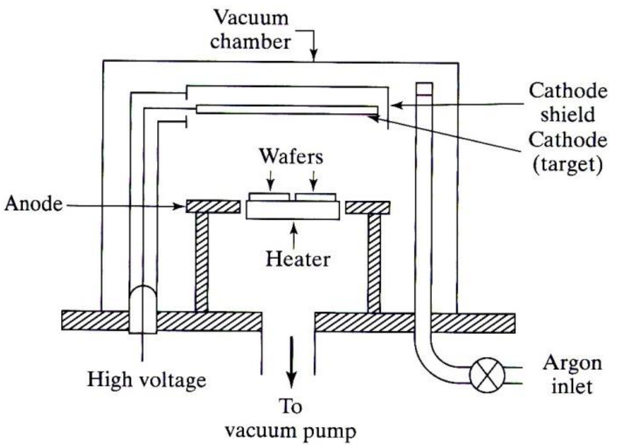
Good

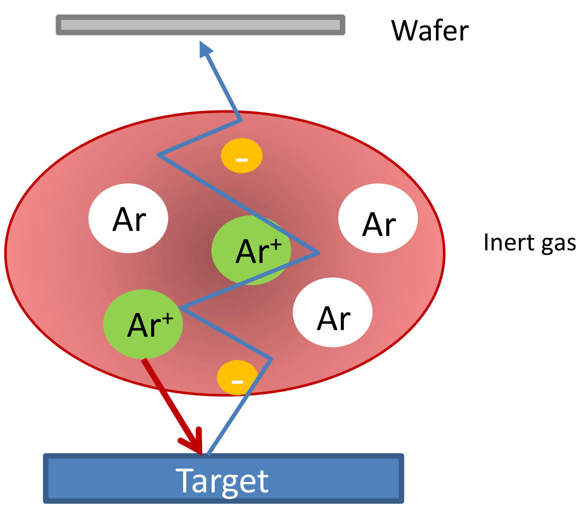
Poor

- To minimize these effects, the planetary substrate holder of the electron-beam system continuously rotates the wafers during the film deposition.

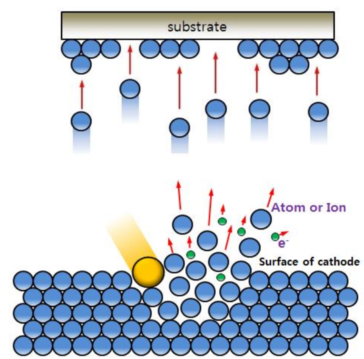
PVD Evaporation: Sputtering (1)

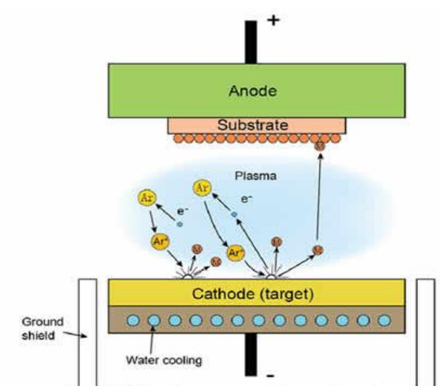
Sputtering





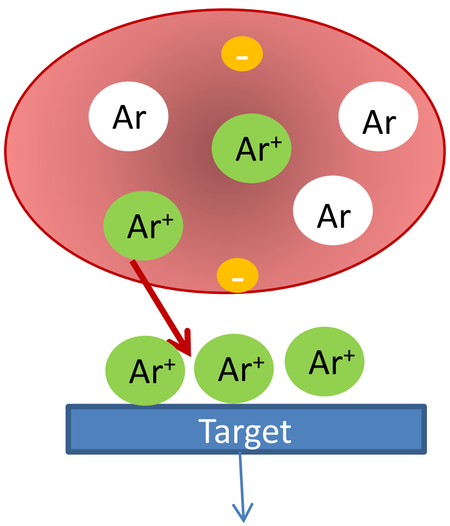
- Sputtering is achieved by bombarding a target with energetic ions, typically Ar+.
- Atoms at the surface of the target are knocked loose and transported to the substrate, where deposition occurs.
- In sputtering deposition, there is a threshold energy which must be exceeded before sputtering occurs.
- Sputtering can be used to deposit a broad range of materials; Alloy may be deposited in which the film has the same composition as the target.





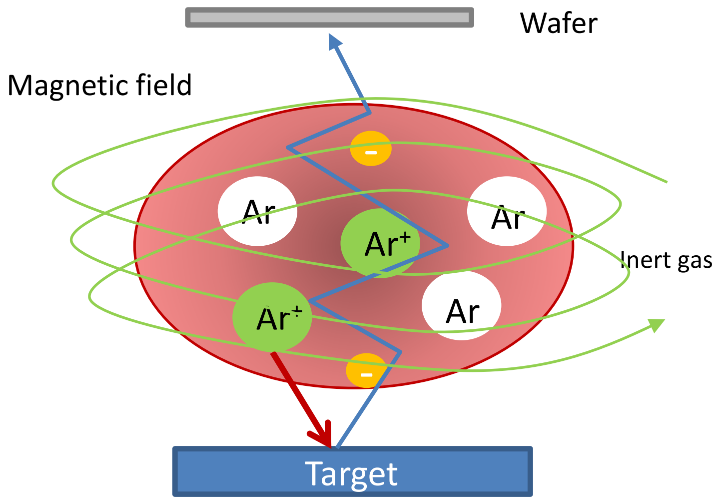
PVD Evaporation: Sputtering (2)

Charging issue



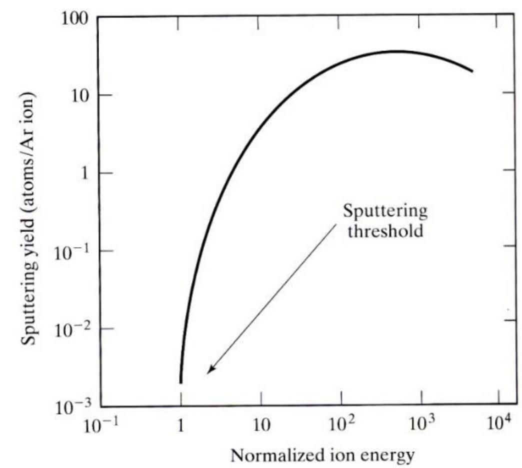
Metal :DC - sputtering
Insulator : RF- sputtering

Deposition rate



Magnetic field
→ capture & spiral electrons
→Increasing ionizing effect
→ Increasing deposition rate

Sputtering yield



- Above specific ion energy, ion implantation is main mechanism.

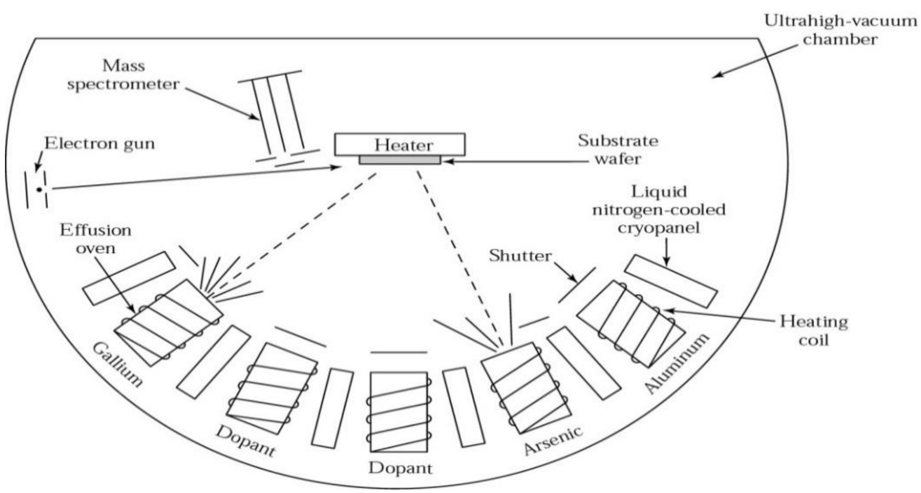
- During sputtering process, the substrate can be heated up 350℃ due to molecular bombardment.

- Process temperature
1. Low Temp Process : Metal deposition (<200°C)
2. High Temp Process: Semiconductor or oxide materials

PVD Evaporation: Molecular Beam Epitaxy (MBE)

Deposition (1): Physical Vapor Deposition (PVD)

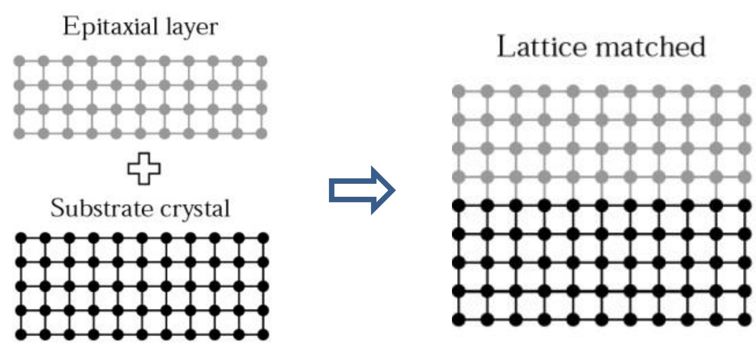
Molecular Beam Epitaxy (MBE)



- One of evaporation system
- General purpose is the growth epitaxial layer
- Growth rate is quite low
- Ultimate high vacuum state (~10^{-8} Pa)
- Monocrystalline film formation at low temperature (400℃ ~ 900℃)

- What is epitaxial layer?

“the method of depositing a monocrystalline film on a monocrystalline substrate”



Impingement rate

; how many molecules impinge on a unit area per unit time

$$\emptyset = \frac{P}{\sqrt{2\pi mkT}} = 2.64 \times 10^{20}\left(\frac{P}{\sqrt{MT}}\right)$$

- m ; the mass of a molecule M : the molecular weight
- k ; Boltzman’s constant = 1.38 x 10^{-23} J/K = 1.37 x 10^{-22} atm-cm^3/K