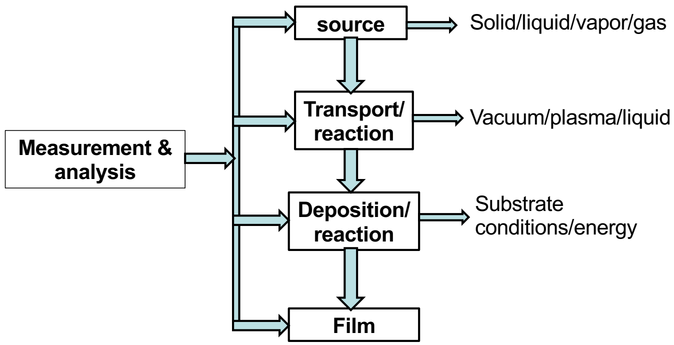
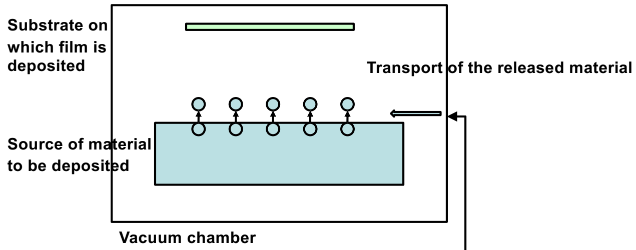
Basic thin film process



PVD – conceptual system



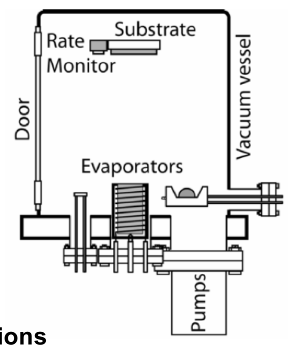
Measurements/ analysis:

- Vacuum measurements
- Film thickness, composition, interface,…..

Source of energy

- **Thermal (evaporation)**
  - Heating (thermal evaporation)
  - Electron beam (e-beam evaporation)
  - Laser (pulsed laser deposition)
- **High energy ions (sputtering)**
  - Ions from a plasma
  - Ion beams (Ion beam sputtering)

Typical Evaporation System



- **Typical applications**
  - **Deposition of metals and metallic compounds**
  - **Molecular beam epitaxy (MBE) of semiconductors**

Angus Rockett, "Material Science of Semiconductors", Springer Verlag, 2008

Pressure and mean free path

- **Mean free path is the average distance between collision events**

$$\lambda = \frac{k_B T}{\sqrt{2}\sigma P} = \frac{0.7}{P} cm$$

  - **Where, k_B is the Boltzman's constant (1.38×10^{-23} JK^{-1}), T is the temperature in Kelvin, P is pressure in Pascal, σ is the collision cross section in cm^2**
  - **$\sigma \sim 4 \times 10^{-15}$ cm^2 at 300K**
- **Mean free path at atmospheric pressure and room temperature is ~ 70nm.**
- **In an evaporation system, the mean free path >> chamber dimensions**
  - **Thermal evaporation, P = 10^{-3} to 10^{-6} Pa (7.5×10^{-3} mTorr to 7.5×10^{-6} m Torr). Mean free path in the range of 7 m to 7 km!**
  - **MBE, P < 10^{-9} Pa. Mean free path > 7000 km!**

Angus Rockett, "Material Science of Semiconductors", Springer Verlag, 2008

Why high vacuum?

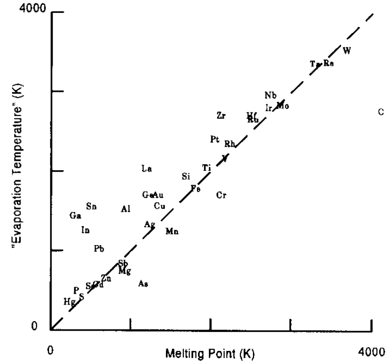
- **Flux of atoms striking a surface (e.g. substrate),**

$$F = 2.63 \times 10^{17} \frac{P}{\sqrt{mT}} cm^{-2} s^{-1}$$

  - **Where, T is the temperature in Kelvin, P is pressure in Pascal, m is the atomic mass in atomic mass units (AMU)**
- **For Nitrogen at 10^{-2} Pa, F = 3 x 10^{16} cm^{-2} s^{-1}**
- **If surface density of atoms is 5 x 10^{14} cm^{-2}, about 60 atoms strike one surface site per second! If the atoms stick to the surface, the surface would be covered in less than a second.**
- **For a pressure of 10^{-9} Pa, 60 atoms strike one surface site in 10^{7} seconds! (*or one atom strike in 46 hours!*)**
- **At such low pressure, the surface can be maintained clean for long durations and the surface and the growing film would have extremely low levels of contamination.**

Angus Rockett, "Material Science of Semiconductors", Springer Verlag, 2008

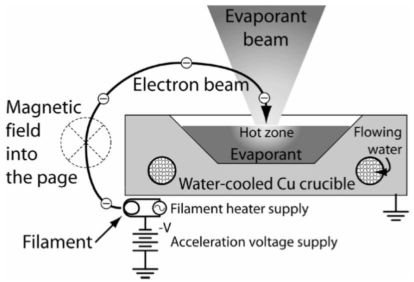
Evaporation Temperature



Temperature at which the vapor pressure of the material is 10^{-2} torr.

John E. Mahan, "Physical Vapor Deposition of Thin Films", John Wiley and Sons, 2000

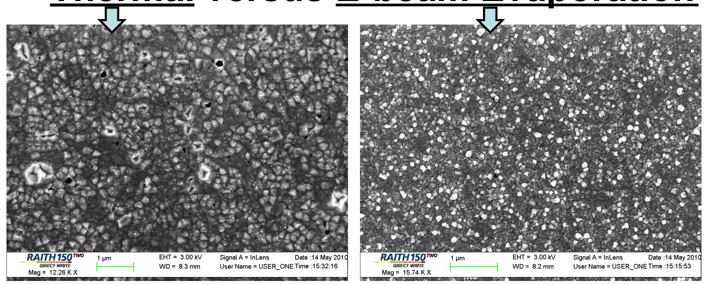
E-beam Evaporation



- **The power density at the hot spot can be several kilo watts => high melting point materials like Pt, Ir,…. can be evaporated**
- **Evaporant temperature at the hot zone can be much larger than the crucible temperature**
- **Low levels of contamination from the crucible**

Angus Rockett, "Material Science of Semiconductors", Springer Verlag, 2008

<u>Thermal</u> versus <u>E-beam Evaporation</u>



E-beam evaporation result in cleaner films.

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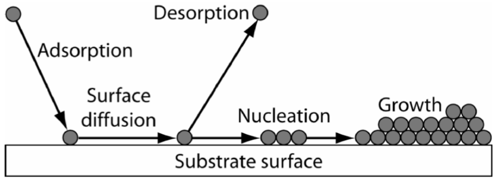
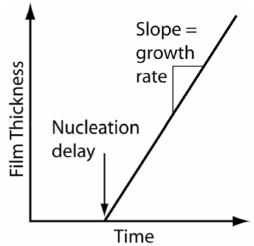
Film Growth Processes

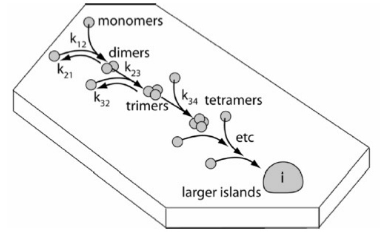


- Typical film growth processes on the substrate surface
- Adsorption and desorption may involve chemical reactions
- Desorption is generally undesirable in PVD processes
- Desorption of reaction byproducts is a critical process in CVD

Angus Rockett, "Material Science of Semiconductors", Springer Verlag, 2008

Film Growth Processes (nucleation)

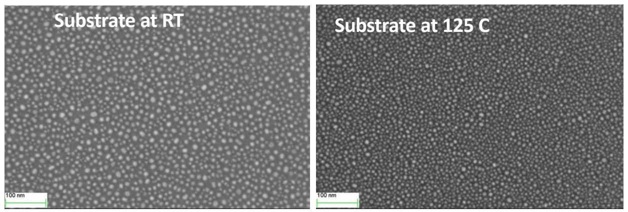




- Adsorbed particles form a lattice "gas" that diffuses on the surface
- Smaller particles diffuse faster than clusters.
- One consequence of this is nucleation and thus the film growth

Angus Rockett, "Material Science of Semiconductors", Springer Verlag, 2008

Nucleation: Example (1)



Pt nanocrystal formation by stopping the deposition (evaporation/sputtering) during nucleation.

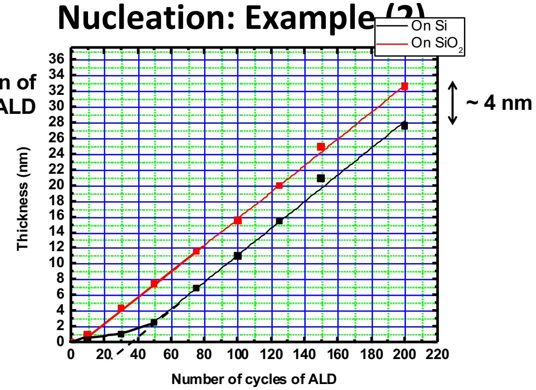
Deposition Time (Secs)	Average Diameter(nm)		Density*E11/cm^2		Area coverage (%)	
	Room temp	125^{0}C	Room temp	125^{0}C	Room temp	125^{0}C
45	6.2	5.48	6.34	10.6	22.38	30.55
60	7.35	6.03	4.37	9.05	22.98	31.63

Nanocrystal counting using ImageJ

Abhishek Misra, Sunny Sadana, IITBNF

Nucleation: Example (2)

Deposition of ZnO by ALD



Influence of the surface on nucleation

Exercise: Determine the nucleation delay in terms of the number of cycles in the two cases shown.

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