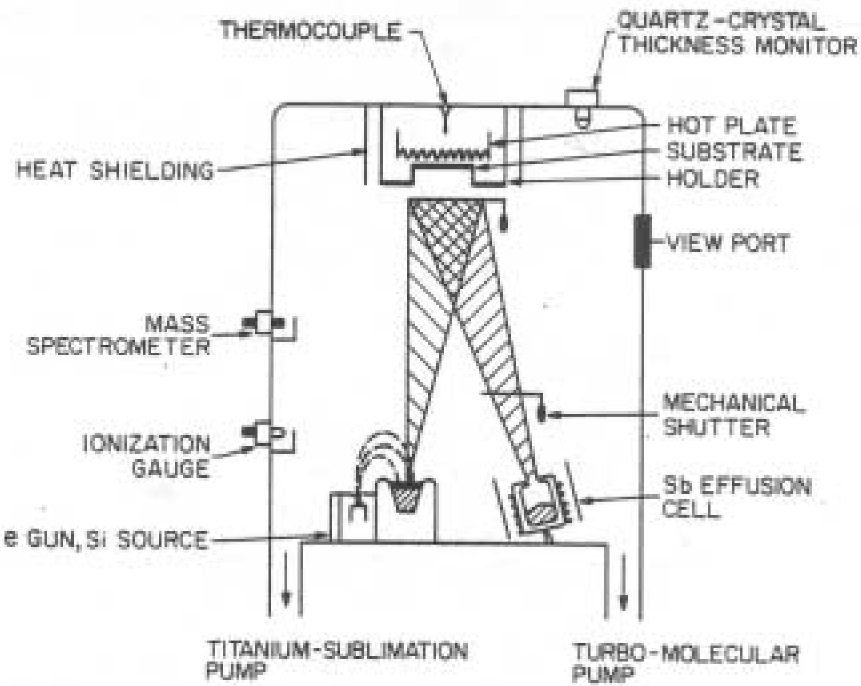
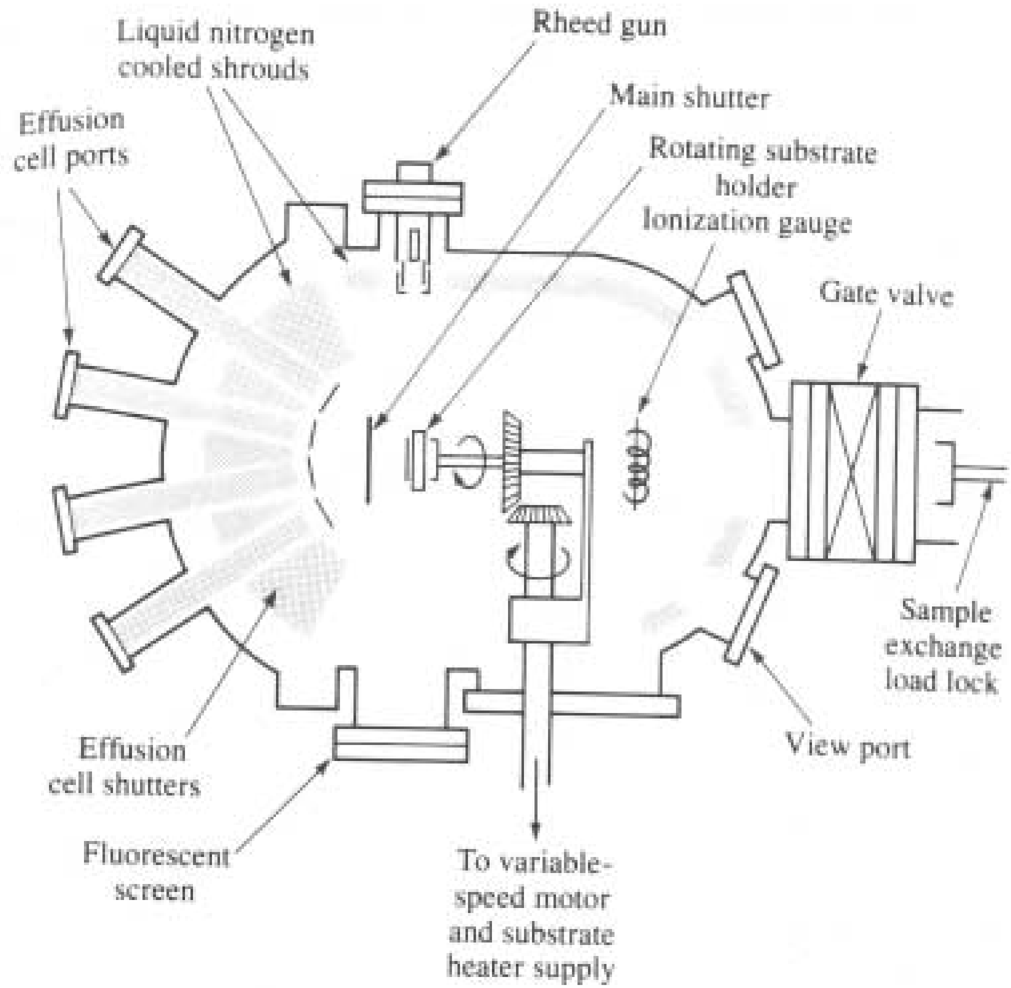
Molecular Beam Epitaxy (MBE)

- An evaporation method to bring the atoms to the surface one by one (almost like laying bricks) at very low pressures such that $\lambda_{mf} >> L$
- Advantages:
  - Precise layer by layer control of epitaxial films and doping
  - Not complicated by transport effects
  - No gas phase reactions
- Important Issues
  - How quickly does the source evaporate?
  - What is the deposition rate on the substrate?
  - What determines uniformity?
  - Growth mode and surface diffusion
  - Defects

Typical MBE Apparatus

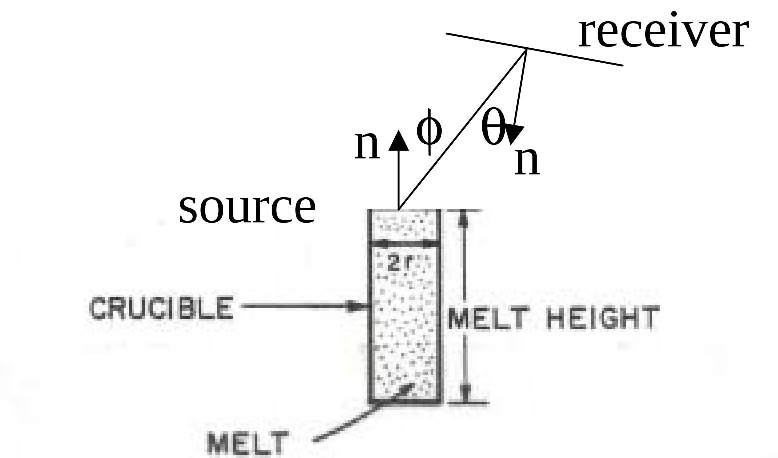




Evaporation from a source, Knudsen Cell

Hertz-Knudsen Equation

$$F_e = \frac{N < v >}{4} = \frac{1}{4}\frac{P_v}{kT}\sqrt{\frac{8kT}{\pi m}} = \frac{P_v}{\sqrt{2\pi mkT}}$$



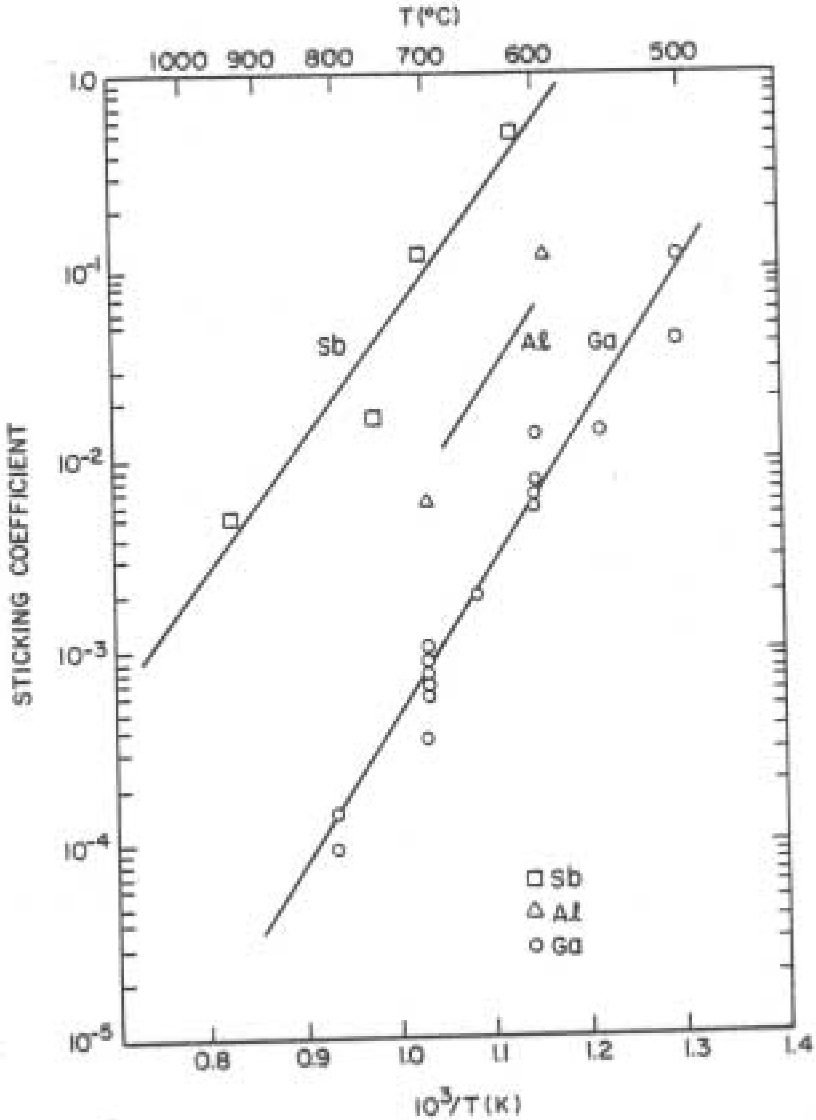
P_v = vapor pressure at source T

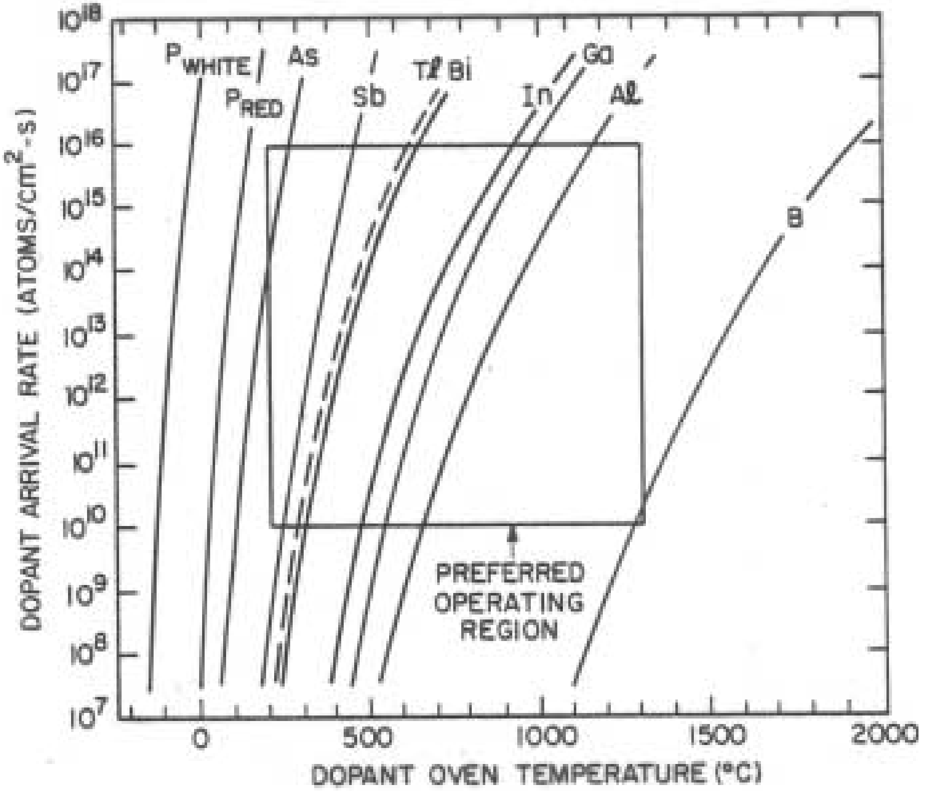
$$F_{eT} = \int_{A_s} F_e dA_s$$

Sticking probability

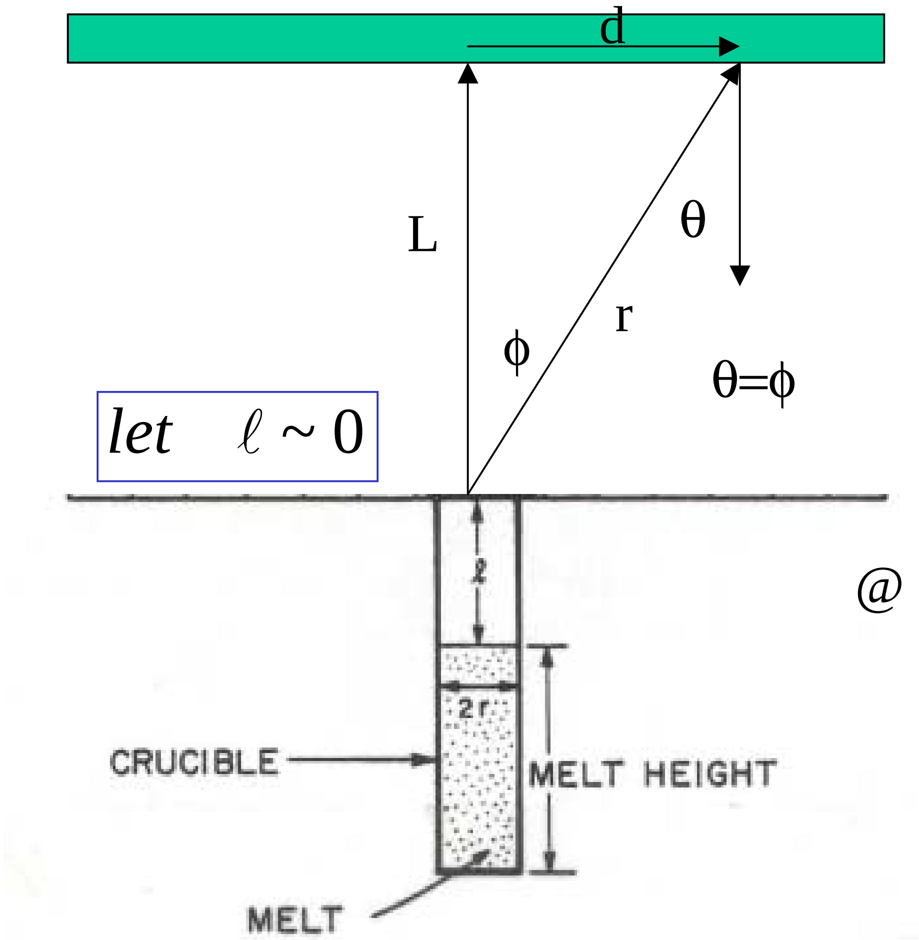
$$r_D = \frac{F_{eT} S}{\pi r^2} \cos\phi \cos\theta$$

T dependence of P_v and S for common MBE materials





Deposition Uniformity



Centerline deposition rate

$$r_{Do} = \frac{F_{eT} S}{\pi L^2}$$

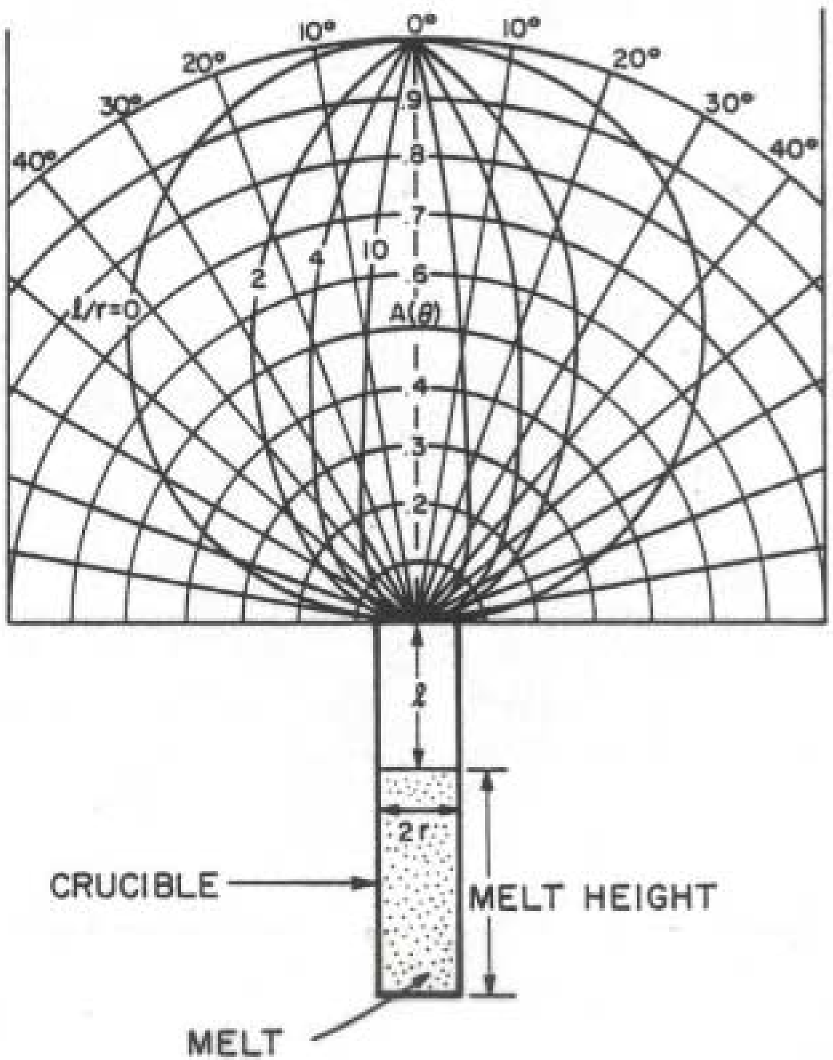
$$\cos\phi = \frac{L}{\sqrt{L^2 + d^2}} \quad and \quad r^2 = L^2 + d^2$$

@ d

$$r_D(d) = \frac{F_{eT} S}{\pi (L^2 + d^2)} \left(\frac{L}{\sqrt{L^2 + d^2}} \right)^2$$

$$r_D(d) = \frac{F_{eT} S}{\pi} \left(\frac{L}{L^2 + d^2} \right)^2$$

Deposition Uniformity

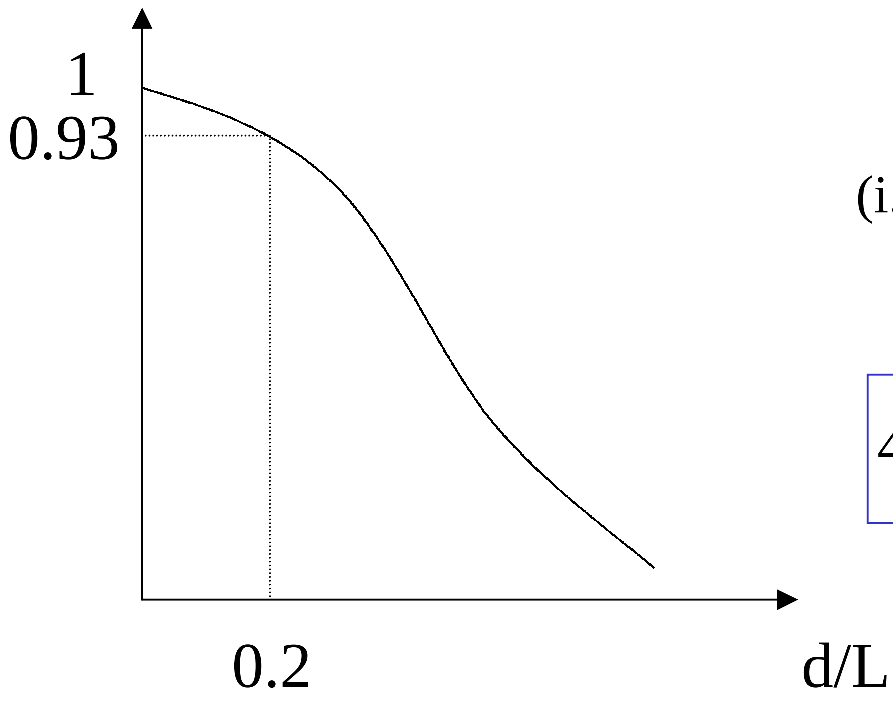


$$U = \frac{r_D}{r_{Do}} = \frac{F_{eT} S / \pi}{F_{eT} S / \pi} \frac{\frac{L^2}{(L^2 + d^2)^2}}{\frac{1}{L^2}}$$

$$U = \frac{r_D}{r_{Do}} = \frac{L^4}{(L^2 + d^2)^2}$$

$$U = \frac{r_D}{r_{Do}} = \frac{1}{(1 + (d / L)^2)^2}$$

Deposition Uniformity



$$as\ d/L \rightarrow 0 \quad U = \frac{r_D}{r_{Do}} \rightarrow 1$$

(i.e., as L gets large but also r_D decreases

$$4'' \quad wafer \Rightarrow d = 2'' \quad L = \frac{2''}{0.2} = 10''$$