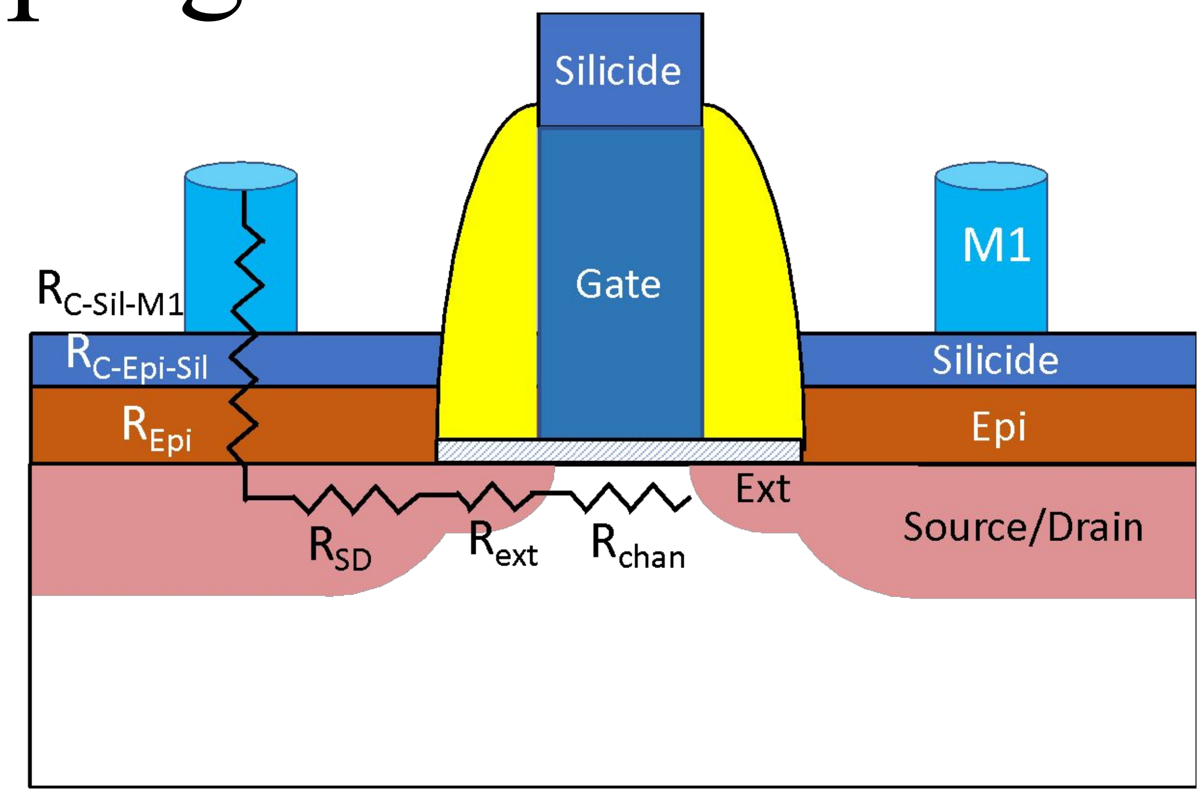
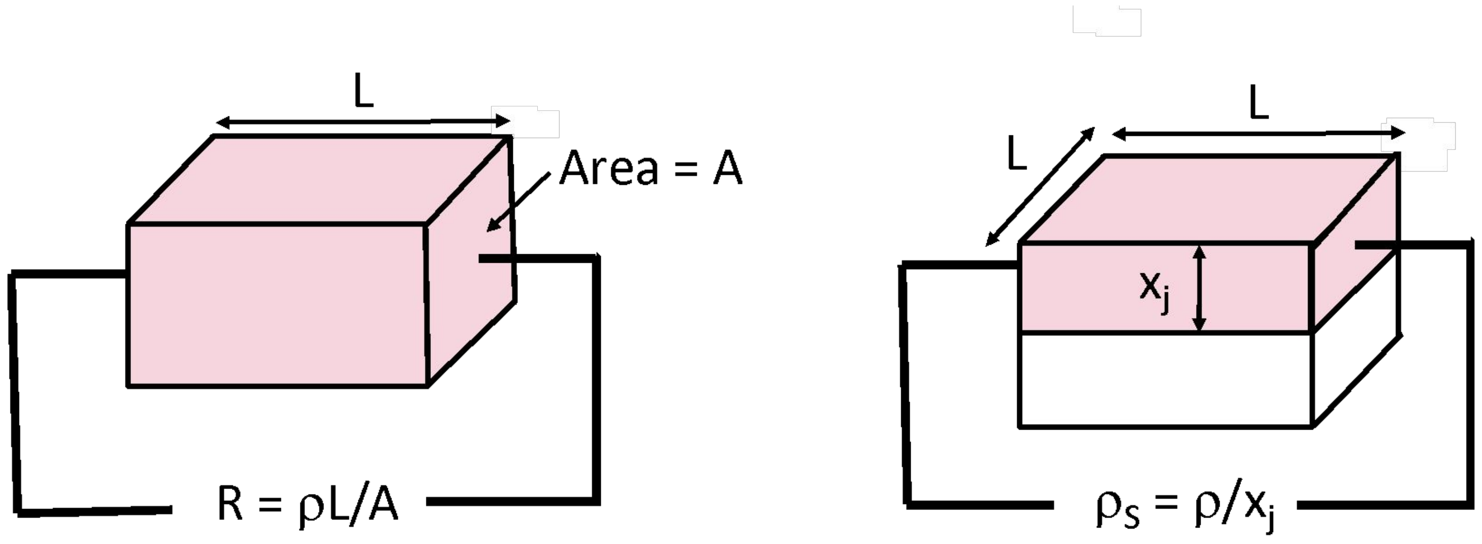
Diffusion

Doping



- All semiconductor devices depend on precision, local control of doping.
- Doping profiles are critical in all device characteristics.
- Resistance impacts drive current.
- Scaling implies all lateral and vertical dimensions scale by the same factor.
- Generally doping levels need to increase and x_J values need to decrease.

Sheet resistance

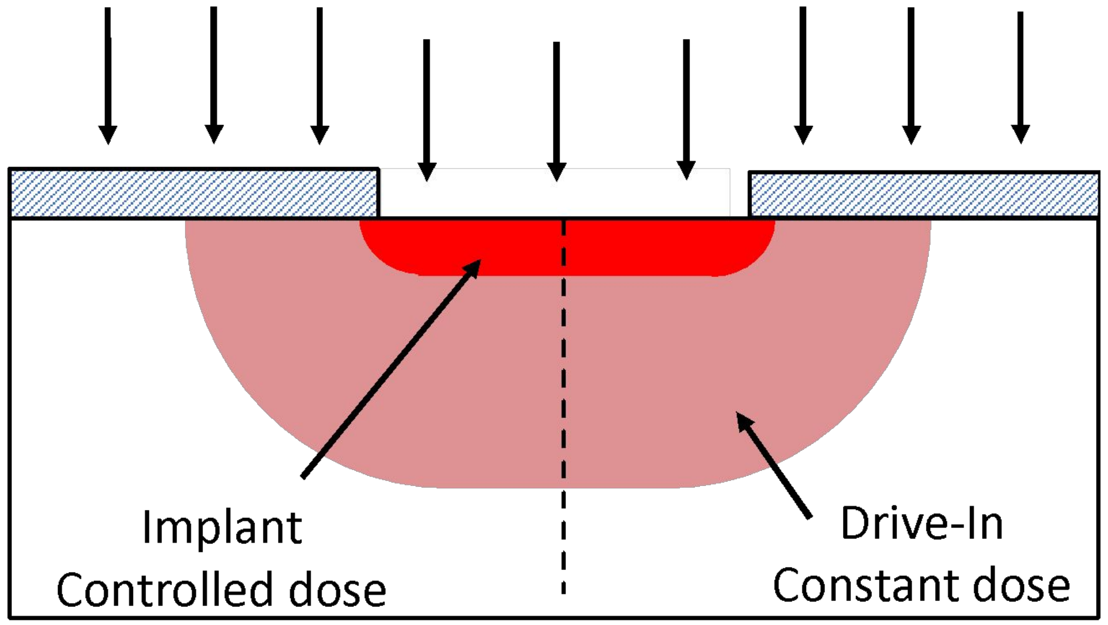


$$J = nq\upsilon = nq\mu\mathcal{E} = \sigma\mathcal{E} = \frac{1}{\rho}\,\mathcal{E}$$

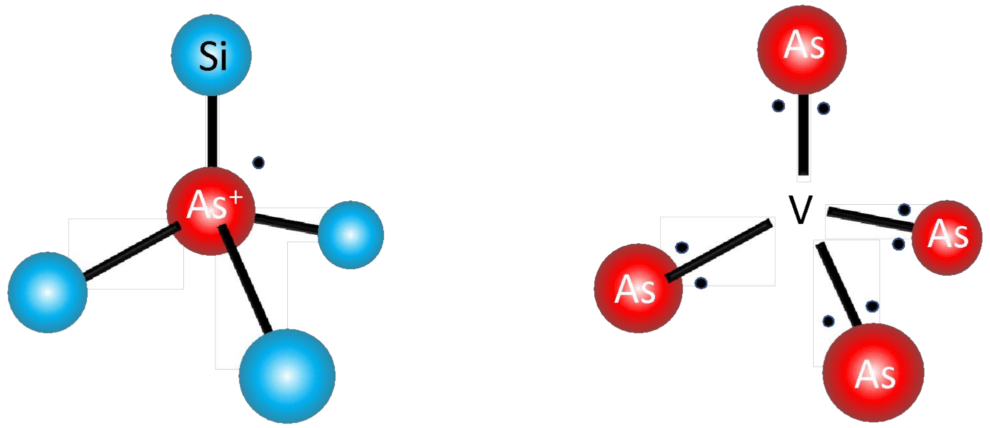
$$\rho = \frac{1}{nq\mu} = \frac{\mathcal{E}}{J}\ \Omega \cdot \mathrm{cm}$$

$$\rho_S \equiv \frac{\rho}{x_j}\Omega/\mathrm{square}$$

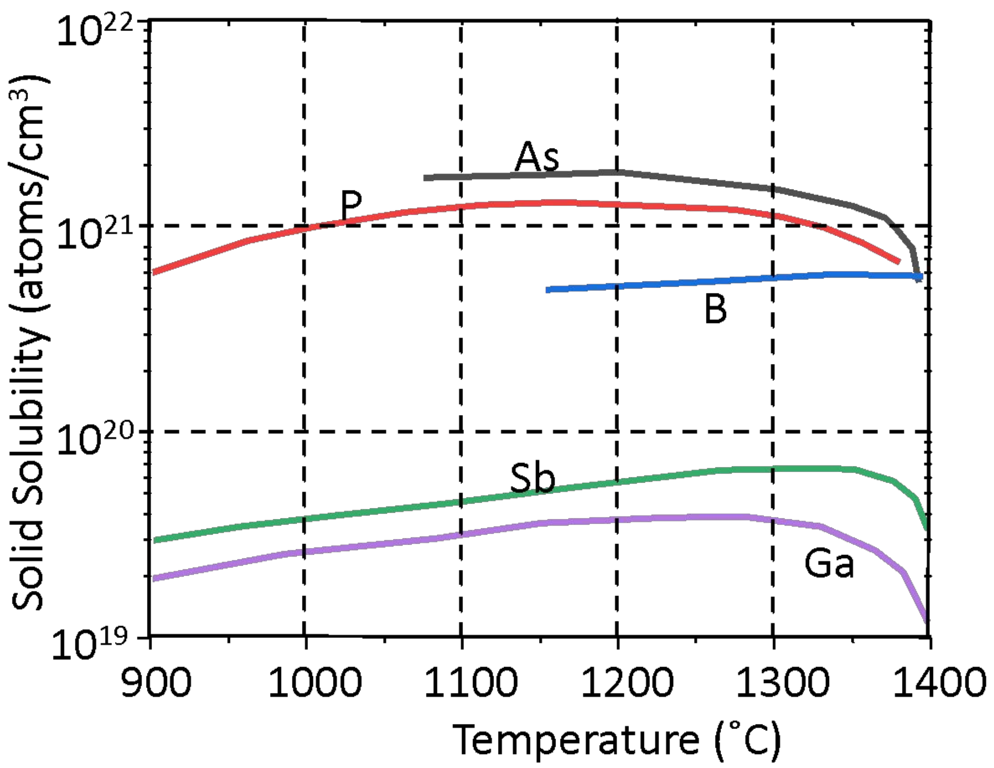
Diffusion Steps



- Predeposition: usually an ion implantation step is used to introduce the required dose of dopant into the substrate.
- Drive-In: a subsequent drive-in anneal then redistributes the dopant giving the required x_J and surface concentration.

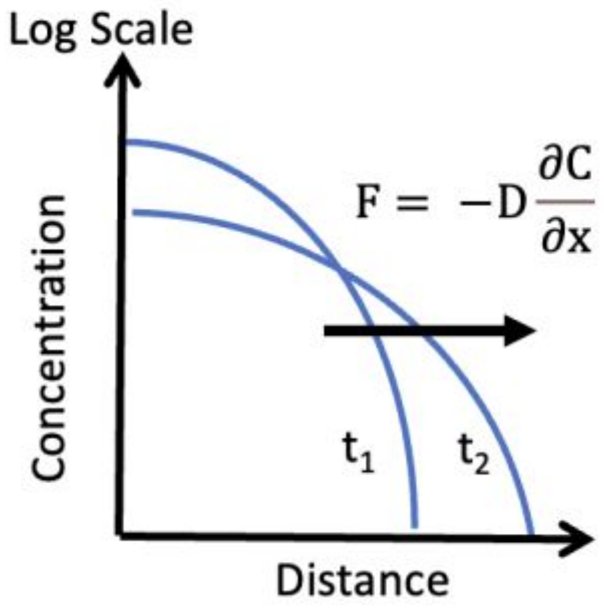


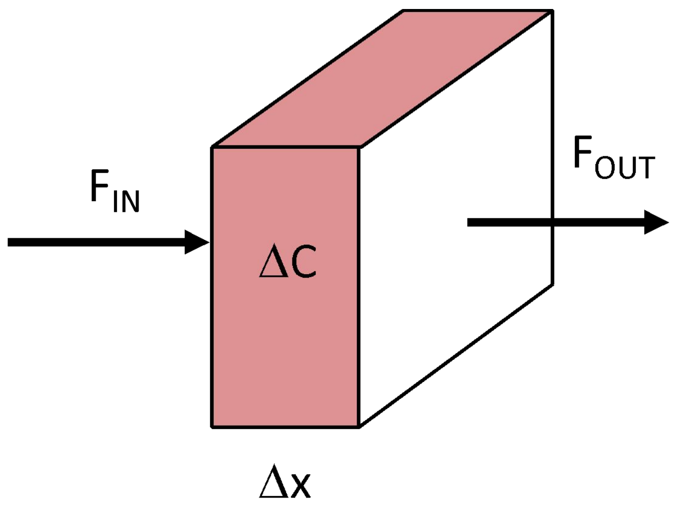
Electrically Active and Inactive Complexes

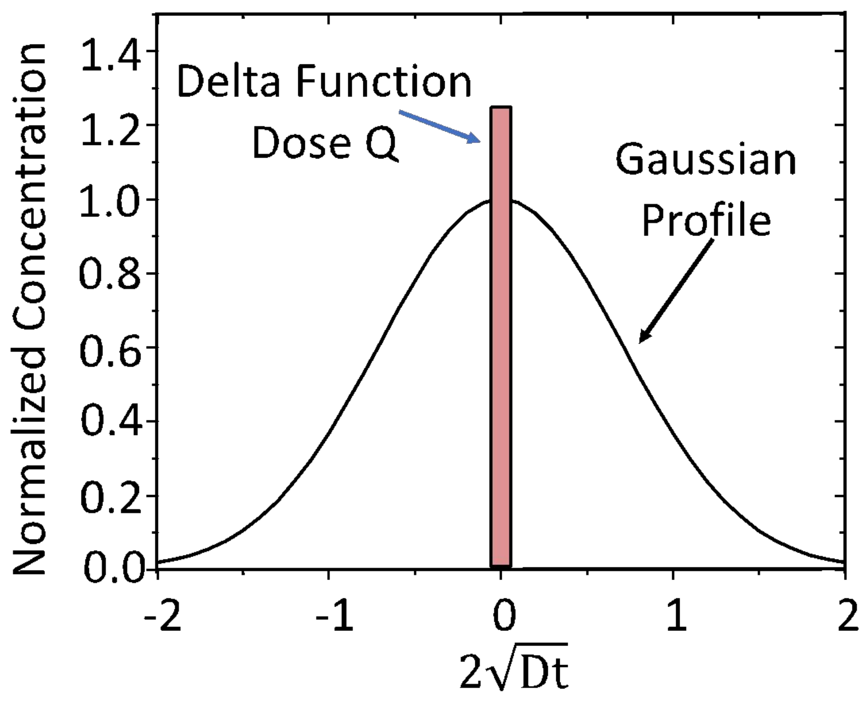


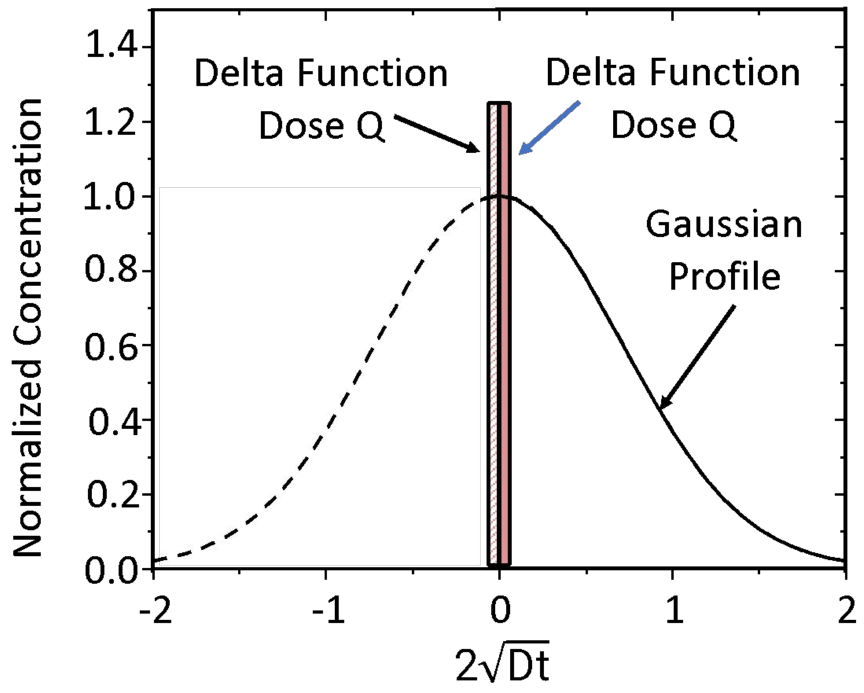
Solid Solubility Curves

Macroscopic View – Gaussian Profile



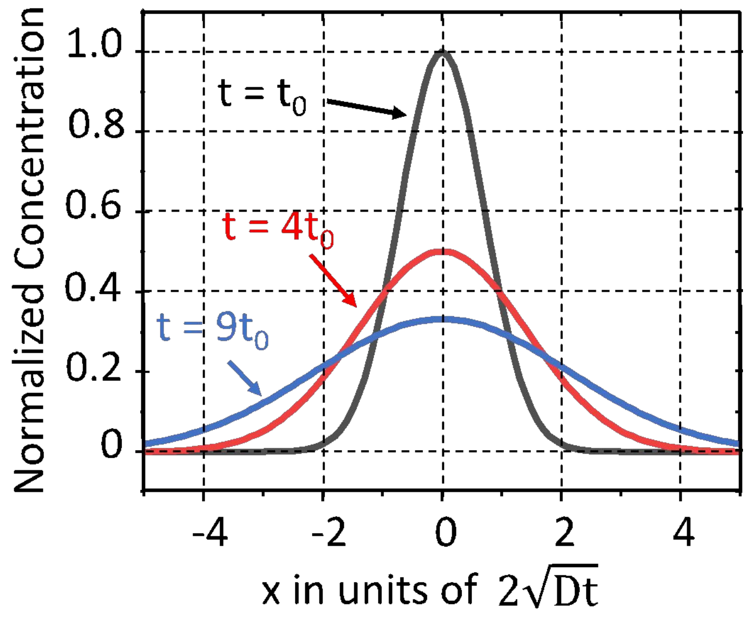


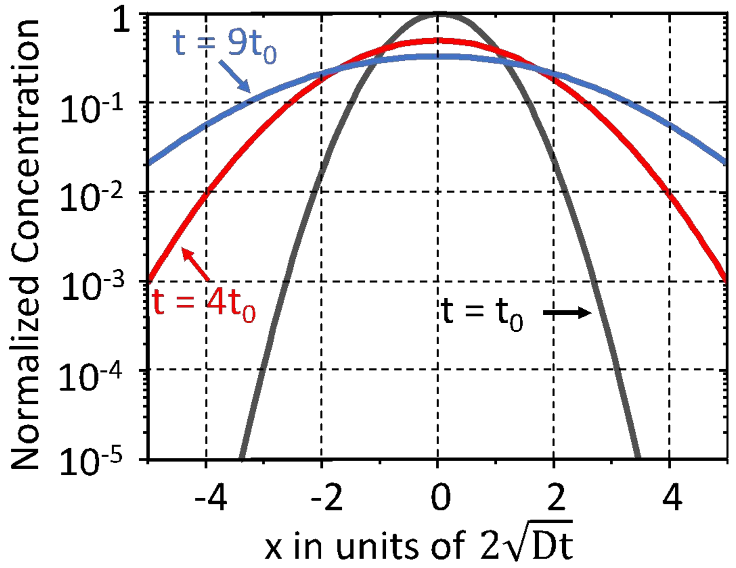




$$F = -D\frac{\partial C}{\partial x}$$ Fick's First Law

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial x^2}\right)$$ Fick's Second law



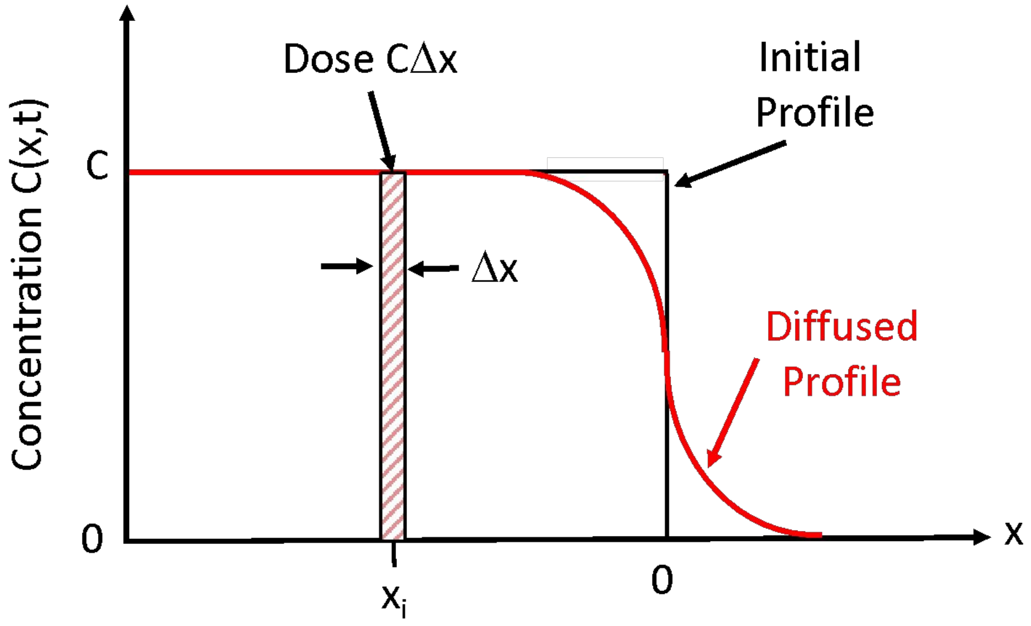


$$C(x,t) = \frac{Q}{2\sqrt{\pi D t}}\exp\left(-\frac{x^2}{4Dt}\right) = C(0,t)\exp\left(-\frac{x^2}{4Dt}\right)$$

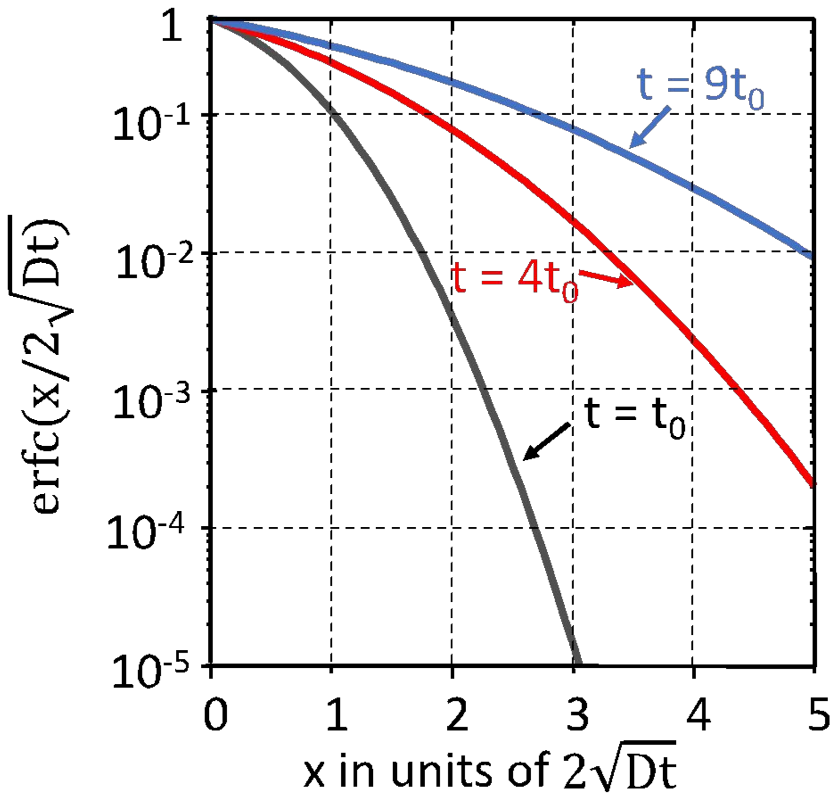
Important consequences:

1. Dose Q remains constant
2. Peak concentration decreases as $t^{-1/2}$
3. Diffusion distance increases as $2(Dt)^{1/2}$

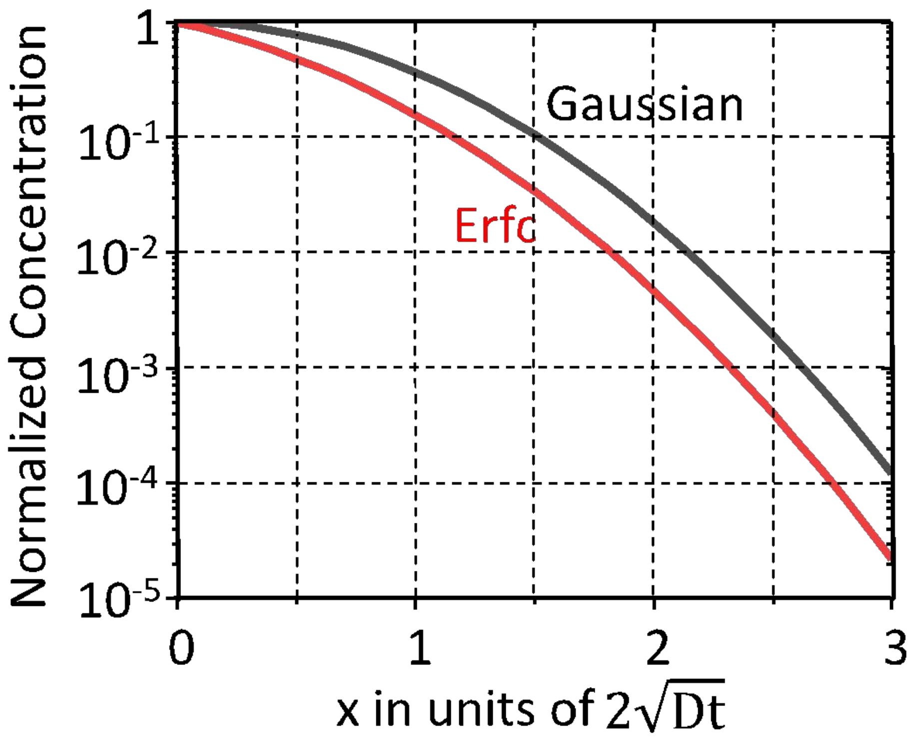
Macroscopic View – erfc Profile



$$C(x,t) = \frac{C}{2}\left[1 - \mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right)\right] = \frac{C}{2}\left[\mathrm{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)\right]$$

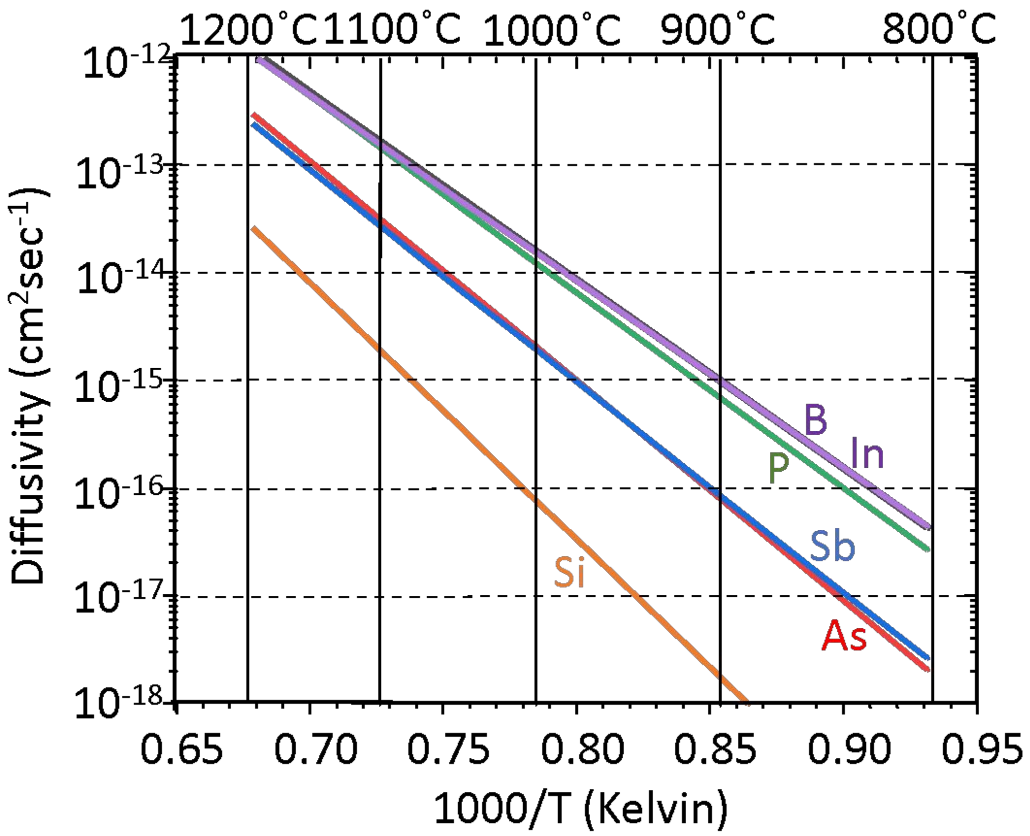


erfc profile



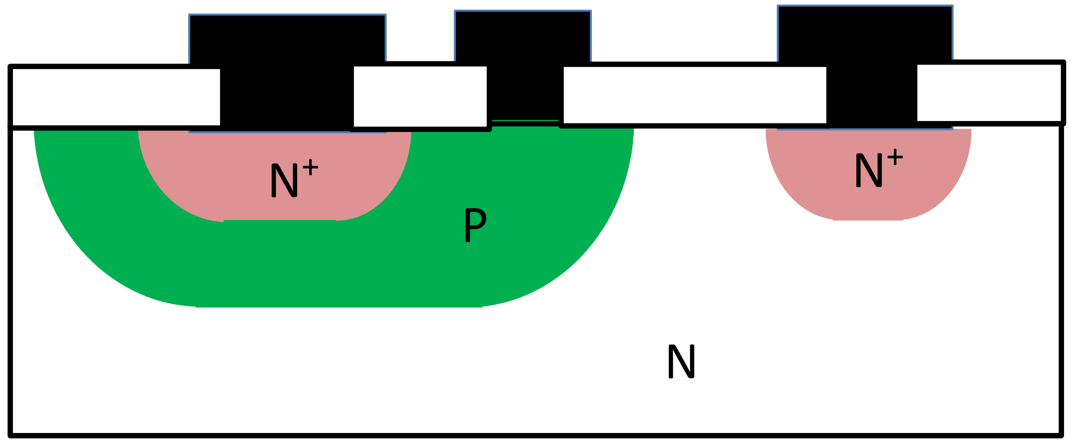
Comparison of Gaussian and erfc profile

Diffusion Coefficient

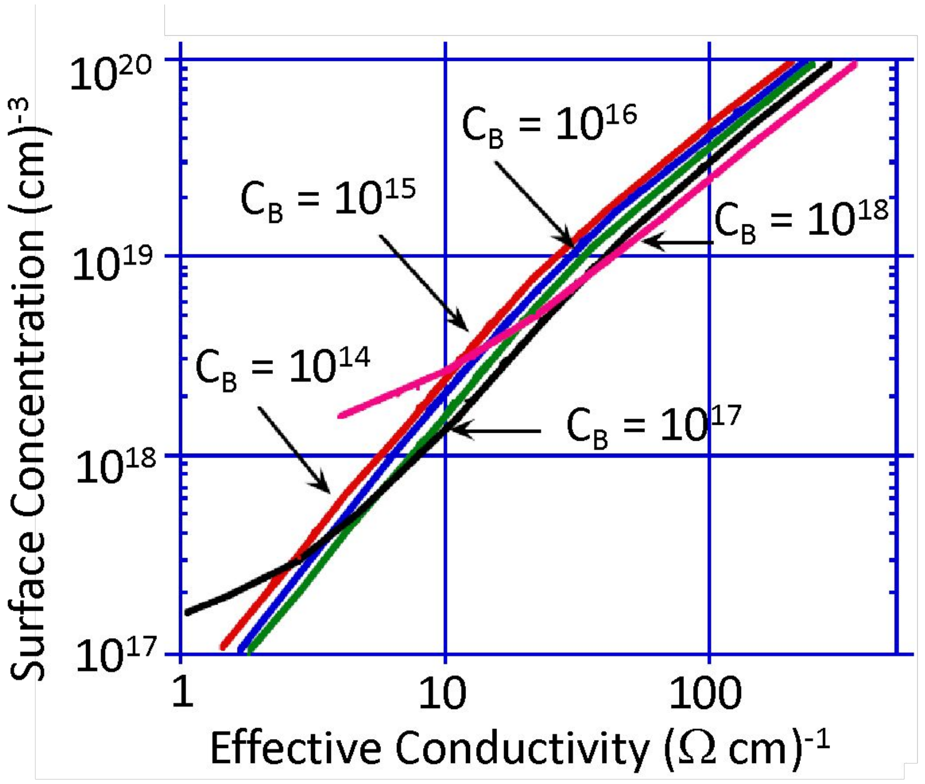


$$D = D^0 \exp\left(-\frac{E_A}{kT}\right)$$

Multiple Step diffusion

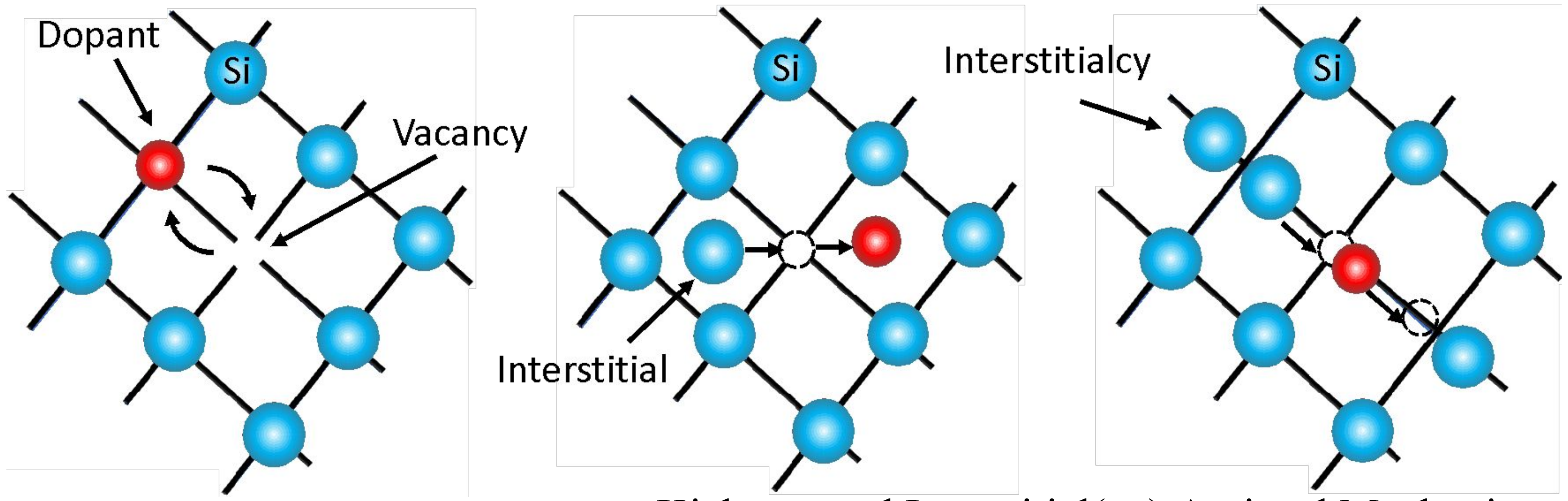


$$(Dt)_{eff} = D_1t_1 + D_2t_2 + \ldots$$



Irvin Curves

Diffusion at atomic scale



Vacancy Assisted Mechanism

Kick-out and Interstitial(cy) Assisted Mechanisms

- Vacancy
- Interstitial
- Interstitialcy
- Kick Out

THANK YOU