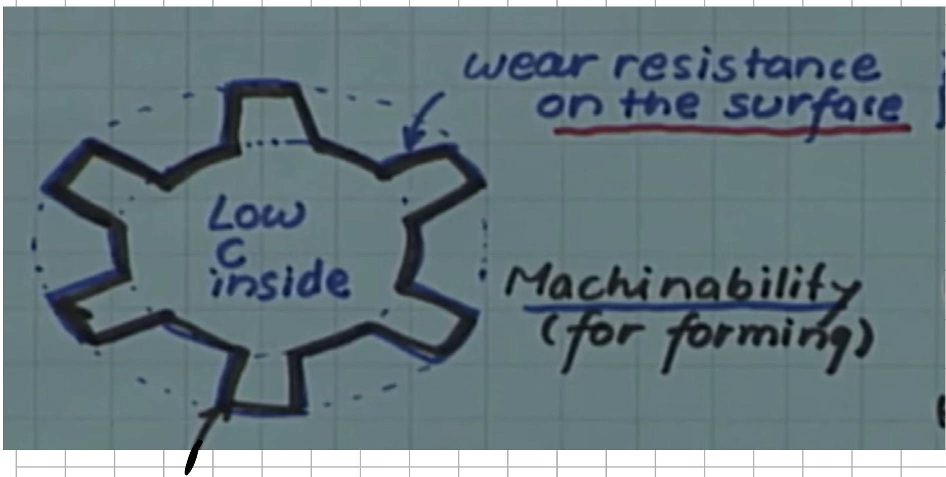
For gears,

we have lower carbon amount interior. This gives us machinability. Then through carburization, Carbon on surface can be increased & increase resistance wear.



Surface hardens due to increased amount of Carbon content.

How does C from atmosphere enter steel? Diffusion.

Mechanism for diffusion:

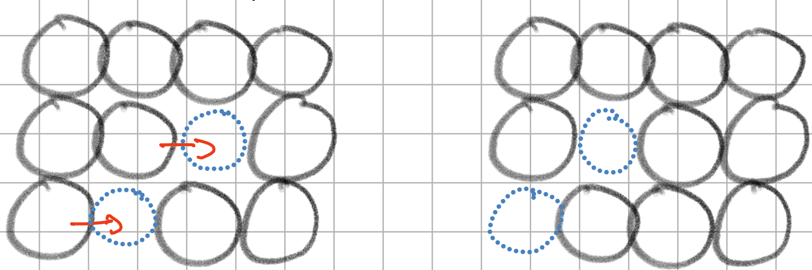
For gases & liquids: Brownian motion

For solids: Vacancy & interstitial diffusion

Diffusion in Solids:

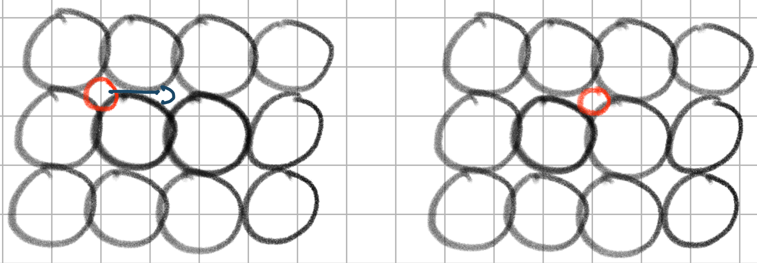
- Interstitial sites
- Vacancy

- Heat = KJ
- Concentration gradient



Vacancy/Substitutional diffusion

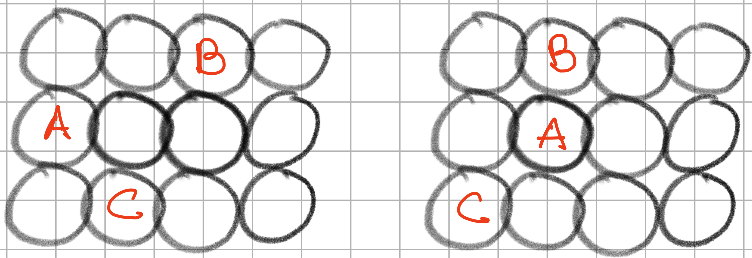
For different atoms, ↑ rate $\propto \dfrac{\text{no. of vancies} \uparrow}{\text{Activation energy to exchange} \downarrow}$



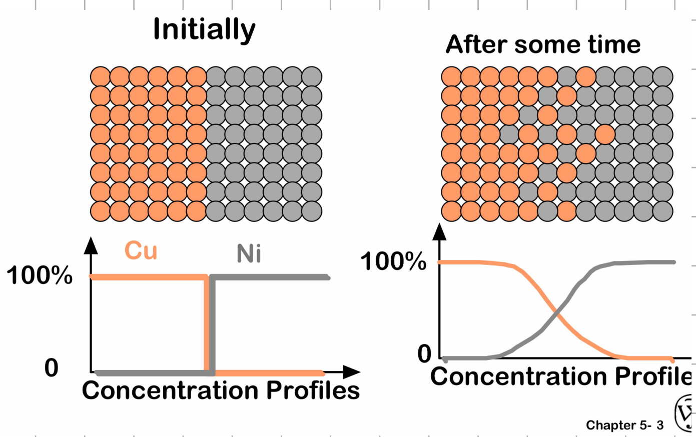
Interstitial diffusion

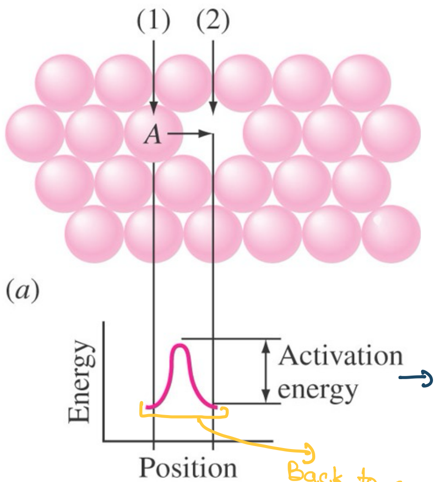
- Faster than vacancy because atoms move in already vacant sites

Diffusion rate $\propto$ Alloy formation



Self diffusion



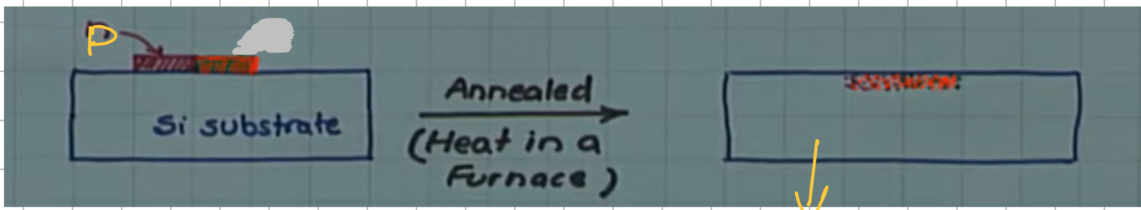


→ Energy required to move

Back to same level after moving

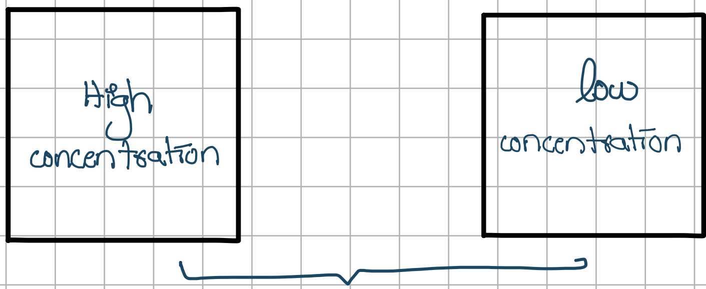
Process Using diffusing

Doping Si with P for n-type semi-conductor



Doped semi-conductor

Concentration gradient:



Steep concentration gradient

Steeper the concentration gradient, higher the diffusion rate

Fick's first law: (Diffusion independent of time)

Steady state

$$J = \frac{\text{moles/mass diffusing}}{\text{surface area} \times \text{time}}$$

$$= \frac{M}{A \times t}$$

Unit: $kg\, m^{-2} s^{-1}$ / $mol\, cm^{-2} s^{-1}$

Concentration gradient $= \dfrac{\Delta C}{L}$

unit: $kg\, m^{-4}$

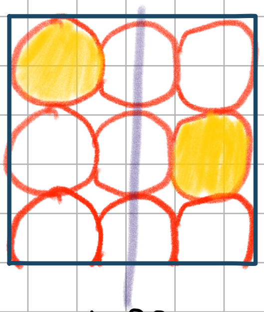
Direction of diffusion. -ev means high to low

$$J = -D \frac{dC}{dt}$$

Diffusion coeffient

C_A

J_x (Right)



J_x (left)

C_B

Net diffusion = 0, i.e concentration independent of time

$$J \propto \frac{dC}{dx}$$

$$J = -D \frac{dC}{dx}$$

$$\frac{dC}{dx} \approx \frac{\Delta C}{\Delta x} = \frac{C_B - C_A}{x_B - x_A}$$

Diffusivity D:

Highly temp dependent

$$D = D_0 \, e^{\frac{-Q}{RT}}$$

Activation energy

pre exponential facto

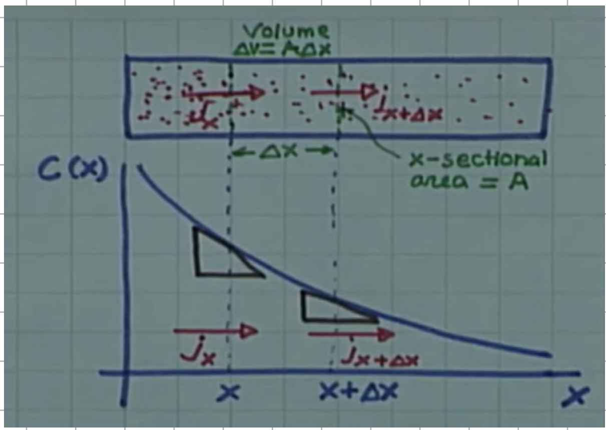
has const

Absolute tem

Diffusion constant D depends on:

- Temperature
- Diffusion mechanism. Substitutional vs Interstitial
- Type of crystal structure of host
  Easier in BCC than FCC
- Types of crystal imperfections:
  - Faster along grain boundaries
  - Faster along dislocation line
  - Excess vacanies will enchance diffusion

Fick's Second law (Concentration changes with time)
Non-steady state



mass entering ΔV at x in time interval Δt:

$$m_x = j_x A \Delta t$$

mass entering ΔV at $x+\Delta x$ in time interval Δt:

$$m_{x+\Delta x} = j_{x+\Delta x} A \Delta t$$

Mass accumulating in ΔV in time Δt:

$$\Delta m = m_x - m_{x+\Delta x}$$

$$= j_x A \Delta t - j_{x+\Delta x} A \Delta t$$

$$= (j_x - j_{x+\Delta x}) A \Delta t$$

$$= -(j_{x+\Delta x} - j_x) A \Delta t$$

$$= -\Delta j \, A \Delta t$$

Concentration change in ΔV in time interval Δt:

$$\Delta C = \frac{\Delta m}{\Delta V}$$

$$= \frac{-j A \Delta t}{A \Delta x}$$

$$= -\frac{\Delta j}{\Delta x}\Delta t$$

$$\frac{\Delta C}{\Delta t} = -\frac{\Delta j}{\Delta x}$$

$$\lim_{\Delta t \to 0}\frac{\Delta C}{\Delta t} = -\lim_{\Delta x \to 0}\frac{\Delta j}{\Delta x}$$

$$\boxed{\frac{\partial c}{\partial t} = -\frac{\partial j}{\partial x}}$$

$$\frac{\partial c}{\partial t} = -\frac{\partial}{\partial x}\left(-D\frac{\partial c}{\partial x}\right)$$

$$\boxed{\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2}}$$

$t=0$, $C=C_0$, at $0 \leq x \leq \infty$

$t>0$, $C=C_s$, at $x=0$

$C=C_0$, at $x=\infty$

Error function:

$$\frac{C(x,t)-C_0}{C_s-C_0} = 1-\mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$= 1-\mathrm{erf}(z)$$

$$\mathrm{erf}(z) = \frac{2}{\sqrt{\pi}}\int_0^z e^{-y^2}\,dy$$

$$\underbrace{\mathrm{erf}(z)}_{\text{check in table range}} = 1-\frac{C(x,t)-C_0}{C_s-C_0}$$

R_1	V_1
z	value
R_2	V_2

$$\frac{z - R_1}{R_2 - R_1} = \frac{\text{value} - V_1}{V_2 - V_1}$$

$$z = ?$$

put in $z = \dfrac{x}{2\sqrt{Dt}}$

to find D, t or x