Carriers in Semiconductor

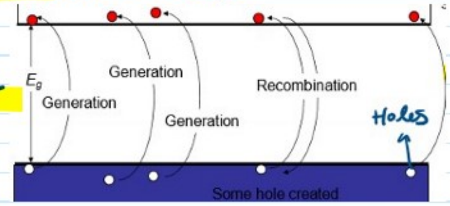
Thursday, November 5, 2020 12:01 AM

Electron & hole concentration

2.4.1 Intrinsic Case

- Properties of pure material → intrinsic to that material
- intrinsic concentration of e- in VB = intrinsic concentration of e- in CB

  $n_i = p_i$ → i = intrinsic, n = e⁻ concentration, p = hole concentration



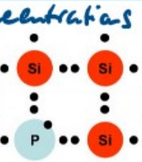
- holes in VB & e- in CB
- n_i, p_i depends on E needed to break band (E_B) & T

  $n_i = B(T)\exp\left(\frac{-E_g}{2kT}\right)$ → B(T) = material

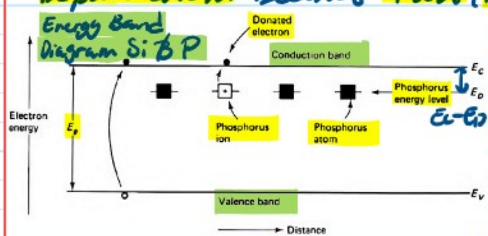
- Increase Conductivity: – Add carriers
  – Add elements that add e⁻ to CB or remove e⁻ from VB

2.4.2 Extrinsic Case

- Semiconductors doped w/ impurities can have n & p concentrations diff. than in pure materials
  ex. Doping P in Si: P → donor
  – extra e⁻ donated to CB of doped Si, can conduct

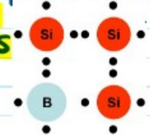


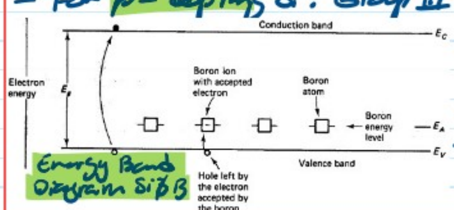
- Dopant atom becomes + ion (fixed in place)



- add P in Si lattice
  → E_D @ 0.044eV below CB → $E_C - E_D$ → E needed to donate e⁻
- $E_C - E_D$ – excitation of extra e⁻ → e⁻ in CB & P ion⁺
- ions = fixed & not conductive
- extra e⁻ ↑n → majority carrier
  ↳ ∴ carrier (-) charged, SC material doped = n-type (n-doping)
  ↳ P & As = group V & B = group III donors to dope Si
  ↳ creates e⁻

- For n-doping Si: group V → P & As → Donors
- For p-doping Si: Group III → B → Acceptors





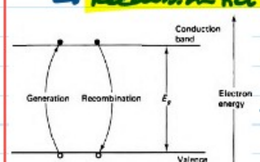
- 3 Ve⁻ B
  ↳ B → ion⁻
- creates holes
- extra holes ↑p → majority carrier

2.4.3 Charge Neutrality

- If no E field, charge density = 0 → electrically neutral
  ↳ Intrinsic: $n_i = p_i$
  ↳ Extrinsic: $\underbrace{n + N_A^-}_{(-)\text{ charge}} = \underbrace{p + N_D^+}_{(+)\text{ charge}}$ → N_D = conc. donor atom impurity, $N_D \neq N_D^+$
  N_A = conc. acceptor atom impurity, $N_A \neq N_A^-$
- If $N_D^+ = N_A^-$, $n = p$ → Intrinsic (compensated)

2.4.3 Dynamic Equilibrium

- Absorbed E → bonds break → Generate e⁻ & holes → Recombination = Thermal Equilibrium
- Recombination depends on T & n, p
  ↳ Recombination rate in extrinsic = intrinsic: $n_0 p_0 = n_i p_i$

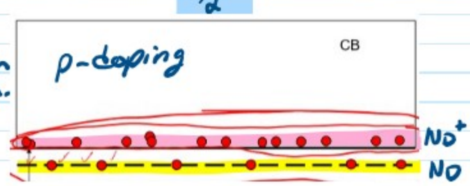


∵ $n_i = p_i$, $n_0 p_0 = n_i^2$ → n_i is known in Si @ 20°: $n_i = 10^{10}\ cm^{-3}$
- ↓p until recombination rate → equilibrium

- If doping lvl of a dopant >> other dopant or only 1 dopant used & its conc. >> n_i
  $n_0 = N_D^+$ for n-doped, $p_0 = N_A^-$ for p-doped
- If both n & p dopants used: $p_0 = \frac{(-N_D^+ + N_A^-) \pm \sqrt{(N_A^- - N_D^+)^2 + 4n_i^2}}{2}$

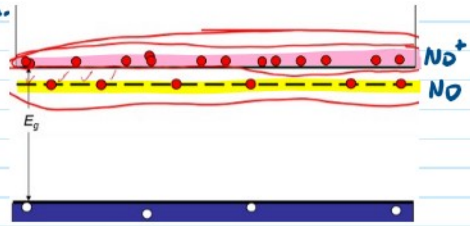
@ RT: $N_A = N_A^-$; $N_D = N_D^+ = n_0$

- Majority/Minority carriers
  $N_D^+ > N_A^-$: n-type material → e⁻ = maj, holes = min
  $N_A^- > N_D^+$: p-type material → holes = maj, e⁻ = min.

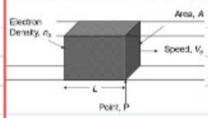


Current & Mobility

$N_A > N_D^+$: p-type material → holes = maj, e^- = min.



Current & Mobility



- time τ to move L
- avg speed e^- moves: $V_{drift} = \frac{L}{\tau}$
- charge in the box $= n_0 A L e$
  current $= \frac{-n_0 A L e}{\tau}$

Current Density $J = n_0 q_e v_e = -n_0 e v_e$

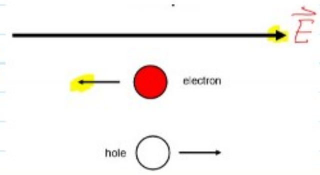
electron speed: $V_e = \mu \vec{E} \rightarrow \mu = \frac{e \tau_{collision}}{m^*}$ → eff. mass

electron density: $\vec{j} = -\frac{n_0 e^2 \tau_{coll}}{m^*} \vec{E}$

$= n_0 \mu_e e \vec{E}$

Conductivity: $\vec{j} = \sigma \vec{E} = n_0 e \mu E \rightarrow \sigma = n_0 e \mu$

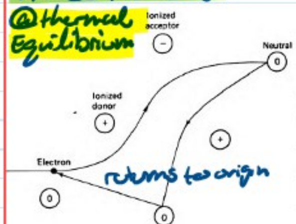
Ohm's law



- $V = IR$
- $JA = I = \sigma E A \rightarrow E = -\frac{\Delta V}{\Delta L}$
  $= \sigma A \frac{\Delta V}{\Delta L}$
- $R = \frac{\Delta L}{\sigma A}$
- E Field: $F = q\vec{E}$

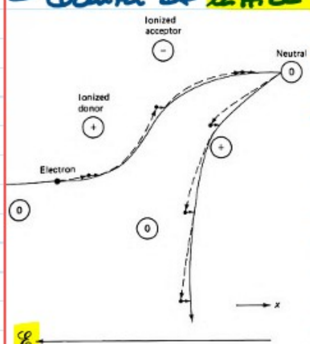
Drude Model

@thermal Equilibrium



- Conductivity $\propto$ to p in VB & n in CB,
  $\sigma = (\mu_e n_0 + \mu_h p_0)$
- ↑eff mass → ↓ v_{avg}
- ↑ doping level ↓ mobility, ↓T ↓ mobility
- ↑carriers ↑T
- Drude Model Fails at high fields → V_{drift} saturates or ↓ w/ ↑$\vec{E}$

- Collisions b/w e^- & ions & atoms @ lattice
- e^- motion randomized by collisions, random motion → no current
- when atoms in material absorb thermal E & vibrate in lattice
  atom spacing → perturbed
- Quanta of lattice vibrational E = phonon



- e^- drift, path of e^- displaced to right → e^- drift due to field $\mathcal{E}$
- e^- does not return to origin like @ equilibrium