# SEMICONDUCTORS

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① $\text{Force} = qE = eE$ (for electron)

② $I = I_e + I_h$
↓ electron ↳ holes

③ $n = p = n_i$ (for intrinsic semi)
↗ e density ↳ intrinsic concentration
↓ hole density

④ $n \times p = n_i^2$ (for extrinsic semi)

⑤ $I = neAv_d$ ← drift velo
$= eA(nv_e + pv_h)$
$\frac{V}{R} = eA(nv_e + pv_h)$

⑥ $\sigma = \frac{1}{\rho} = e(n\mu_e + p\mu_h)$
mobility

$\mu_e = \frac{v_e}{E}$, $\mu_h = \frac{v_h}{E}$

⑦ density of states $Z(E)dE = \frac{g(E)dE}{V} = \frac{8\sqrt{2}\pi m^{3/2}\sqrt{E}dE}{h^3}$

~~Energy of fermi level~~, Fermi energy

⑧ $E_F = \frac{E_c + E_v}{2}$ ← E of valence band; $E_c$ → E of conduction band
(for intrinsic)

⑨ $n = 2\left(\frac{2\pi m_e kT}{h^2}\right)^{3/2} e^{\frac{E_F - E_c}{2}}$
→ number of e per V in the conduction band

⑩ $p = 2\left(\frac{2\pi m_h kT}{h^2}\right)^{3/2} e^{\frac{E_v - E_F}{2}}$
→ density of holes

⑪ $\sigma = Ae^{-\frac{E_g}{2kT}}$

$\sigma = (\mu_e + \mu_h)2e\left(\frac{2\pi kT}{h^2}\right)^{3/2}(m_e m_h) e^{-\frac{E_g}{2kT}}$

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(12) $D_n = \frac{\mu_n KT}{e}$, $D_p = \frac{\mu_p KT}{e}$ } Einstein relation

Diffusion constant

mobility

(13) $E_H = Bv$
$= \frac{BJ}{ne}$

(14) $R_H = 1/ne \Rightarrow E_H = R_H BJ$

Hall coeff. $\boxed{R_H = \frac{-1}{ne} \text{ \& or } R_H = \frac{1}{pe}}$

(15) $V_H = R_H BJt$
$= R_H \frac{BI}{b}$

Hall voltage

(16) $F(E) = \frac{1}{e^{(E-E_F/KT)} + 1}$

Probability that an energy state is occupied.

(1~~3~~ ~~n=N~~ c

# DIFFERENTIATE

| Intrinsic | Extrinsic |
| --- | --- |
| > No impurities | Added impurities |
| > Electrical conductivity is Low | High |
| > No classification | classified to ~~[illegible]~~ n type, p type |
| > Rarely used in devices | Widely used |
| > e=h | e>h in n type<br>h>e in p type |
| > Ex: Si & Ge | Ex: As doped Si for n type, Al doped Si (or Ge) for p-type |

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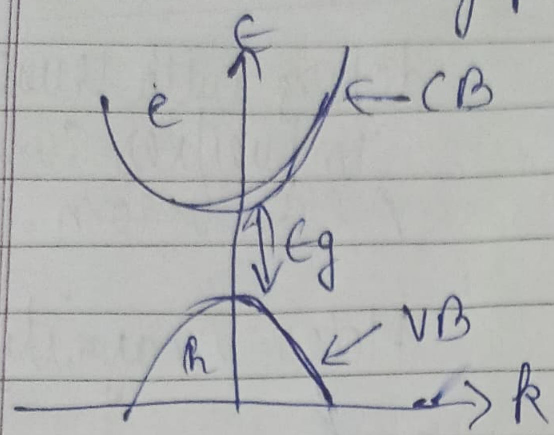
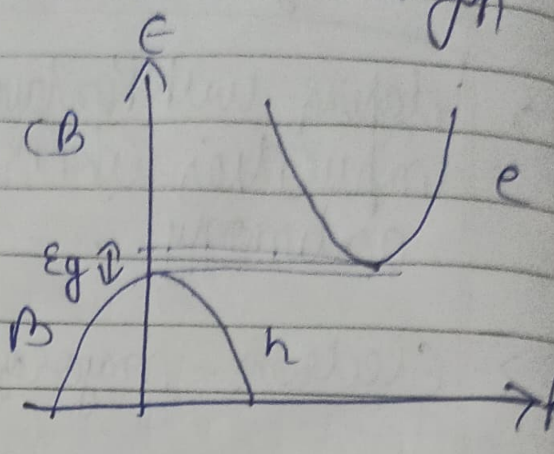
| N type | P type |
| --- | --- |
| > doping with Pentavalent impurities like As or antimony. | doping with trivalent impurities such as Al or boron. |
| > Electrons - majority carriers | Holes - majority carriers |
| > Added impurities are called donor atoms they donate one ē per added ~~atom~~ atom | called acceptor atoms, accept one ē ∴ atom |
| > Donor E level is just below CB | Acceptor E level is ~~above~~ above VB |
| > higher ~~[illegible]~~ electrical conductivity | lower |

Imp PYQ

| Direct Band Gap | Indirect Band Gap |
|---|---|
|   |   |
| Max of VB & Min of CB occur at same momentum values | Max of VB & Min of CB occur at 2 diff momenta values. |
| Electron making a transition from VB to CB need not undergo any change in its momentum | Electron requires energy for the change in momentum in addition to the energy gap, Eg. |
| Compound GaAs are Direct BG semi. | ~~Comp~~ Elemental Si, Ge, are indirect BG semi. |
| These DBG are used in LED & semi. lasers | ~~They~~ Not useful for LEDs & Semi. lasers. |

Deri

# DERIVATIONS

## CARRIER CONCENTRATION

$dn = Z(E) F(E) dE$

number of ~~free~~ electrons in $E \to E+dE$ in CB

$$n = \int_{E_c}^{\infty} Z(E) F(E) dE \quad - (1)$$

$$Z(E) dE = \frac{g(E) dE}{V} = \frac{8\sqrt{2}\pi m^{3/2} \sqrt{E} dE}{h^3}$$

$$F(E) dE = \frac{1}{1+e^{\frac{E-E_f}{KT}}} = \left(1+e^{\frac{E-E_f}{KT}}\right)^{-1}$$

$$E - E_f >> KT \Rightarrow F(E) dE = e^{\frac{E_F - E}{KT}}$$

(1) becomes $n = \int_{E_c}^{\infty} \frac{8\sqrt{2}\pi m_e^{*3/2}}{h^3} \sqrt{E-E_c}\, e^{\frac{E_f-E}{KT}} dE$

$$= \frac{8\sqrt{2}\pi m_e^*}{h^3} \int_{E_c}^{\infty} \sqrt{E-E_c}\, e^{E_f - E/KT} dE$$

$E - E_c = x$

$E = E_c + x$

$dE = dx$

$$\Rightarrow C e^{\frac{E_f}{KT}} \int_{E_c}^{\infty} \sqrt{x}\, e^{-\frac{E_c+x}{KT}} dx$$

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$$= \frac{8\sqrt{2}\pi m_e^{*3/2}}{h^3} e^{\frac{E_f - E_c}{KT}} \int_0^\infty \sqrt{x}\, e^{-\frac{x}{KT}} dx$$

$$n = \frac{8\sqrt{2}\pi m_e^{*3/2}}{h^3} e^{\frac{E_f - E_c}{KT}} \frac{(KT)^{3/2}\sqrt{\pi}}{2}$$

$$\boxed{n = 2\left(\frac{2\pi m_e^* KT}{h^2}\right)^{3/2} e^{\frac{E_f - E_c}{KT}}}$$

$$\boxed{n = N_c e^{E_f - E_c/KT}} \quad -(2)$$

~~election concentration~~

election concentration in CB

Similarly $\boxed{p = N_v e^{(E_v - E_f)/KT}}$ $-(3)$

$$\boxed{N_v = 2\left(\frac{2\pi m_p^* KT}{h^2}\right)^{3/2}}$$

$$n \cdot p = n_i^2$$

$$n \cdot p = N_c e^{E_f - E_c/KT} \cdot N_v e^{E_v - E_f/KT}$$

$$\boxed{np = N_c N_v e^{E_v - E_c/KT}} \quad -(4)$$

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For intrinsic semi conductor,

$h_i = p_i$

$$\boxed{n_i^2 = N_c N_v e^{-E_g/KT}} \quad -(5)$$

$-E_g = -(E_c - E_v)$ ← we know ~~that~~ this

⇒ from (4) & (5), $\boxed{np = n_i^2}$

# FERMI LEVEL IN INTRINSIC

$$n_c = N_c e^{-(E_c - E_f)/KT} \quad -(1)$$

$$n_v = N_v e^{-(E_f - E_v)/KT} \quad -(2)$$

$N_c = N_v$, $n_c = n_v$ for intrinsic

(1)/(2) ⇒ $E_c - E_f = E_f - E_v$

$$\Rightarrow E_f = \frac{E_c + E_v}{2}$$

⇒ Fermi level lies in the middle of CB & VB

# EINSTEIN EQN

At $\rightleftharpoons$, with no applied E field, the free e distribution is uniform & there is no net current flow.

Any change in $\rightleftharpoons$, which would lead to a diffusion current, creates an internal electric field and a drift current balancing the diffusion current component.

Thus:

$$\Delta n \, e E \mu_n = e D_n \frac{\partial \Delta n}{\partial x}$$

$$F = (\Delta n) e E = \frac{e D_n}{\mu_n} \frac{\partial \Delta n}{\partial x}$$

$F = KT \frac{\partial \Delta n}{\partial x}$ by corresponding to pressure gradient from kinetic theory of gases.

$$\Rightarrow KT = \frac{e D_n}{\mu_n} \quad \Rightarrow \boxed{D_n = \frac{\mu_n KT}{e}}$$

$$\Rightarrow \frac{D_n}{\mu_n} = \frac{KT}{e}$$