Lecture after midsem

$$n = \int_{E_{cmin}}^{\infty} D(E)\, f(E)\, dE \qquad e^- \text{ concentration}$$

$$p = \int_{-\infty}^{E_{vmax}} D(E)\,(1 - f(E))\, dE \qquad \text{hole concentration}$$

for an intrinsic semiconductor with effective mass of e^- = effective mass of holes

↳ $n = p$ because $f(E) = \frac{E_c + E_v}{2} = 1 - f(E)$

$$f(E) = \frac{1}{1 + e^{(E - E_f)/k_bT}}$$

$$\overset{n_i}{\overset{|||}{n_0}} = N_c f(E_c) \simeq N_c e^{-(E_c - E_f)/KT}$$

↳ equilibrium e^- carrier concentration

$N_c \rightarrow$ effective density of states for e^-

$$\underset{(cm^{-3}/m^{-3})}{N_c} = 2\left(\frac{2\pi m_n^* KT}{h^2}\right)^{3/2} \rightarrow \text{for 3d}$$

$$\overset{p_i}{\overset{|||}{p_0}} = N_v f(E_v) \simeq e^{-(E_f - E_v)/KT}$$

↳ equilibrium hole carrier concentration

$$\underset{(cm^{-3}/m^{-3})}{N_v} = 2\left(\frac{2\pi m_p^* KT}{h^2}\right)^{3/2} \rightarrow \text{for 3d}$$

m_n^* / m_p^*

$$m^*_{DOS} = (g_v^2 \, m_x \, m_y \, m_z)^{1/3}$$

$g_v \rightarrow$ valley degeneracy

$$g_{0d}(E) = g_v \, 2\delta(E - E_c)$$

$$g_{1d}(E) = g_v \frac{1}{\pi\hbar} \sqrt{\frac{m^*}{2(E-E_c)}}$$

$$g_{2d}(E) = g_v \frac{m^*}{\pi\hbar^2}$$

$$g_{3d}(E) = g_v \frac{(2m^*)^{2/3}}{2\pi^2\hbar^3} \sqrt{E - E_c}$$

Si, Ge : Electric and Anisotropic in nature

for Si $\rightarrow$ $m_x = m_l$

$m_y = m_z = m_t$

$g_v = 6$

So, $m^*_{DOS} = (6 m_l m_t^2)^{1/3}$

$$m^*_{transport} = \frac{3}{\frac{1}{m_x} + \frac{1}{m_y} + \frac{1}{m_z}}$$

↓

transport effective mass

if $m_x = m_y = m_z \rightarrow m^*_{transport} = m_x$

↳ isotropic case like GaAs

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	Si	Ge	GaAs
N_c	2.8×10^{19}	1.04×10^{19}	4.7×10^{17}
N_v	1.04×10^{19}	6×10^{18}	7×10^{18}

off state current ≡ leakage current

Silicon's off state I is less than that of Ge

for intrinsic semiconductor → $n_o = p_o = n_i = p_i$ →

$$n_i^2 = n_o p_o = N_C N_V e^{-(E_c - E_v)kT}$$

$$= N_C N_V e^{-E_g/kT}$$ law of mass Action

$$\boxed{n_i = \sqrt{N_C N_V}\, e^{-E_g/2kT}}$$

→ exponentially decreasing with factor of band gap$/2kT$

if $E_g \gg$ → $n_i \lll$ very rapidly

equilibrium → thermodynamically static / stable system

extrinsic ≡ doped / impurity

now, intrinsic → extrinsic : how?

trivalent : p type doping | pentavalent : n type doping

$p > n$ $\qquad$ $n > p$

Charge Neutrality condition (for any system)

$$\underbrace{\underset{\text{hole concen.}}{p} - \underset{e^- \text{ concn.}}{n}}_{\#\text{ of carriers}} + \underbrace{\underset{\text{(donor) pentavalent}}{N_D^+} - \underset{\text{(acceptor) trivalent}}{N_A^-}}_{\#\text{ of ions}} = 0$$

$\rightarrow p + N_D = n + N_A$

Total charge = 0

Electrically Neutral

Intrinsic : $n_i p_i = n_i^2$

Extrinsic : $np = n_i^2$

Amphoteric Dopant : element which can act either as a donor or an acceptor

eg: Silicon for GaAs

acts as donor on Ga site

acts as acceptor on As site

for n type system $\rightarrow$ $n >> p$

if $N_D >> N_A$ $\rightarrow$ $N_D + p = N_A + n$

$$N_D = n$$

$$n = N_c e^{-(E_c - E_f)/KT} = N_D$$

$$\frac{-(E_c - E_f)}{KT} = \ln\left(\frac{N_D}{N_c}\right)$$

$$\ln\left(\frac{N_c}{N_D}\right) = \frac{E_c - E_F}{KT}$$

$$E_c - E_F = KT \ln\left(\frac{N_c}{N_D}\right)$$

for higher donor conc, smaller the energy difference $(E_c - E_F)$, fermi level moves closer to the bottom of conduction band

for a p type system, if $N_A >> N_D$,

$N_A = p$ and similar like before,

$$E_v - E_f = KT \ln\left(\frac{N_A}{N_v}\right)$$