~~Q1>~~ Q 3>

$$n_i^2 = N_c N_v \, Exp\left(\frac{-E_g}{KT}\right) \sim T^3 \, Exp\left(\frac{-E_g}{KT}\right)$$

$$n_i(T_2) = n_i(T_1)\left(\frac{T_2}{T_1}\right)^{3/2} Exp\left(-\frac{E_g(\cancel{K}T_2)}{2KT_2} + \frac{E_g(T_1)}{2KT_1}\right) \quad \text{— (A)}$$

where $E_g(T) = 1.17\,eV - 4.73 \times 10^{-4}\left(\frac{T^2}{T+636}\right)$

Putting appropriate values in (A) we obtain the value for $n_i(77K)$.

Q9) $E = ak^2 + \text{Constant}$

Effective mass of electron in conduction Band = m^*

then $\frac{1}{m^*} = \frac{1}{\hbar}\frac{d^2E}{dk^2} = \frac{2a}{\hbar^2}$ —①

$\omega_c = \frac{eB}{m^*}$

$\Rightarrow a = \frac{\hbar^2 \omega_c}{2eB} = \frac{(1.05\times10^{-34})^2 \times 1.8\times10^{11}}{2\times1.6\times10^{-19}\times0.1}$

$$\boxed{a = 6.2\times10^{-38}\ Jm^2}$$

~~Q5)~~ Q1) ~~Q3)~~ $E_g = 0.7eV$

$T = 300K$

$E_F = \frac{E_g}{2} + \frac{3KT}{4}\log\left[\frac{m_h^*}{m_e^*}\right]$

$= \left(\frac{0.7\times1.6\times10^{-19}}{2}\right) + \frac{3\times1.38\times10^{-23}}{4}\times300\ \log_e(5)$

$E_F = 5.6\times10^{-20} + 3.105\times10^{-21}\log_e(5)$ Joules

$E_F = 6.099\times10^{-20}\ J$

OR $\boxed{E_F \approx 0.38\ eV}$

Model Sol^n of Practice Problems

(4.) $I = I_0 \exp(eV/k_B T)$

$$\Rightarrow \frac{eV}{k_B T} = \ln\left(\frac{I}{I_0}\right)$$

$$\Rightarrow V = \frac{k_B T}{e} \ln\left(\frac{I}{I_0}\right)$$

$$\therefore \frac{dV}{dI} = \lim_{\Delta I \to 0} \frac{\Delta V}{\Delta I} = \frac{k_B T}{e} \cdot \frac{1}{(I/I_0)} \left(\frac{1}{I_0}\right)$$

$$= \frac{k_B T}{e} \frac{1}{I}$$

$$\boxed{\therefore \frac{\Delta V}{\Delta I} \propto \frac{1}{I}}$$

(5.) The equilibrium hole density is given by,

$$P(E) = g_v(E) F(E)$$

where $g_v(E) = \dfrac{m_p^* \sqrt{2 m_p^* (E_v - E)}}{\pi^2 \hbar^3}$; $E \leq E_v$

and $F(E) = \dfrac{1}{\exp (E - E_f)/k_B T + 1}$

$$\cong \exp\left(-(E - E_f)/k_B T\right)$$; when

$E - E_f \gg k_B T$, the Fermi-Dirac distribution becomes Maxwell-Boltzmann distribution.

Hence,

$$P(E) = g_v(E)\, F(E)$$

$$\Rightarrow P(x) = \text{constant} \cdot \sqrt{x} \cdot \exp(-x) = c\sqrt{x}\exp(-x)$$

Where $x = (E_v - E)/k_B T$

To find the maxima,

$$\frac{dP(x)}{dx} = c \times \left(\frac{1}{2\sqrt{x}} - \sqrt{x}\right)\exp(-x) = 0$$

$$\Rightarrow x = \frac{1}{2}$$

$$\Rightarrow \boxed{E_v - E = \frac{k_B T}{2}}$$

Q:-6 The mobilities of electrons and holes in intrinsic Ge are 0.39 and 0.19 $m^2/V\text{-}s$ respectively. Determine the intrinsic carrier concentration and conductivity of Ge at 300K if the band gap of Ge is 0.67 eV and the effective masses of electrons and holes are 0.55 m_0 and 0.37 m_0 respectively, m_0 being the electronic rest mass. How many dopants must be added per cubic metre of Ge to increase its conductivity by a factor of 10^4?

Ans:-

$$\mu_n = 0.39 \ m^2/V\text{-}s$$
$$\mu_p = 0.19 \ m^2/V\text{-}s$$
$$m_n^* = 0.55 \ m_0$$
$$m_p^* = 0.37 \ m_0$$
$$E_g = 0.67 \ eV$$
$$T = 300K$$

The intrinsic carrier concentration can be calculated by using the formula

$$n_i = 2\left[\frac{2\pi kT}{h^2}\right]^{3/2} \cdot (m_n^* \cdot m_p^*)^{3/4} \cdot \exp\left[-E_g/2kT\right]$$

$$\boxed{n_i = 1.81 \times 10^{19} \ m^{-3}}$$

The conductivity can be calculated by

$$\sigma = e n_i [\mu_n + \mu_p]$$
$$\sigma = 1.68 \ \Omega^{-1} m^{-1}$$

To increase the conductivity by a factor of 10^4,

$$\rightarrow \quad n_d \cdot e \cdot \mu_n = 1.68 \times 10^4$$

$$n_d = \frac{1.68 \times 10^4}{1.6 \times 10^{-19} \times 0.39} = 2.69 \times 10^{23} \ m^{-3}$$

for n type

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Q:-7 Show that the product of electron and hole concentration in a semiconductor is constant at a given temperature?

Ans:- As we know, for an intrinsic semiconductor

$$n = p = n_i \quad \text{--- (1)}$$

where n = concentration of $\bar{e}$s

p = concentration of holes.

n_i = intrinsic carrier concentration.

Further, $$n = N_c \exp.\left[-\left(\frac{E_C - E_F}{kT}\right)\right] \quad \text{--- (2)}$$

where N_c is the effective density of states of $\bar{e}$s at the conduction band edge

and $$N_c = 2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2}$$

Similarly, $$p = N_v \exp\left[-\left(\frac{E_F - E_v}{kT}\right)\right] \quad \text{--- (3)}$$

where N_v is the effective density of holes at the valence band edge

and $$N_v = 2\left[\frac{2\pi m_p^* kT}{h^2}\right]^{3/2}$$

By using eq. (2) and (3) and eq. (1), we get

$$np = n_i^2 = N_c N_v \exp\left[-\frac{E_C - E_V}{kT}\right]$$

$$n p = n_i^2 = N_c N_v \exp\left[-E_g/kT\right]$$

$$\boxed{n \cdot p = n_i^2 = 4\left[\frac{2\pi kT}{h^2}\right]^3 (m_n^* m_p^*)^{3/2} \cdot \exp\left[-E_g/kT\right]} \quad \text{--- (4)}$$

Hence, at a particular temperature, the product $(n \cdot p)$ is constant as all quantities are constant one. [Law of mass action]

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Q:- 7 How is the energy gap determined from the measurement of electrical conductivity of a semiconductor?

Ans:- The conductivity of a semiconductor, in general, is given by the expression:

$$\sigma = e\,(n\mu_n + p\mu_p) \quad \text{—— (5)}$$

As for intrinsic semiconductor, $n = p = n_i$

Hence,
$$\sigma = e\,(n_i\mu_n + n_i\mu_p)$$
$$\Rightarrow \sigma = e\,n_i\,(\mu_n + \mu_p)$$
$$\Rightarrow \sigma = e.n_i.\mu \quad \text{—— (6)}$$

From eq. (4), we get

$$n.p = n_i^2 = 4\left[\frac{2\pi kT}{h^2}\right]^3 (m_n^* . m_p^*)^{3/2} . \exp\left[-E_g/kT\right]$$

$$\Rightarrow n_i = 2.\left(\frac{2\pi kT}{h^2}\right)^{3/2} . (m_n^* . m_p^*)^{3/4} . \exp\left[-E_g/2kT\right] \quad \text{—— (7)}$$

By using eq. (7) in eq. (6), we get the relation between σ and E_g as.

$$\sigma = e.n_i.\mu$$
$$\sigma = e.\mu\left[2.\left(\frac{2\pi kT}{h^2}\right)^{3/2} (m_n^* . m_p^*)^{3/4} . \exp\left[-E_g/kT\right]\right]$$

$$\Rightarrow \boxed{E_g = -2kT\ln\left[\frac{\sigma}{e.\mu.2\left(\frac{2\pi kT}{h^2}\right)^{3/2} . (m_n^* . m_p^*)^{3/4}}\right]}$$

The plot of $\ln\sigma$ versus $1/T$ is a straight line and can be used to determine the band gap.

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Q:-8 The conductivity of a semiconductor changes when the concentration of electrons is varied by changing the position of impurity level? Show that it passes through a minimum when the concentration of electrons becomes $n_i\sqrt{\mu_p/\mu_n}$ where n_i is the intrinsic carrier concentration, μ_n and μ_p represent the mobilities of electrons and holes respectively. Determine the minimum value of conductivity?

Answer The conductivity of a semiconductor is given by

$$\sigma = e\left[n\mu_n + p\mu_p\right] \quad \text{—} \quad (A)$$

By using law of mass action, $n_i^2 = n \cdot p$, we can write as

$$\sigma_n = e\left[n \cdot \mu_n + \frac{n_i^2}{n} \cdot \mu_p\right] \quad \text{—} \quad (A)'$$

Let as assume that at $n = n_0 \Rightarrow \sigma = \sigma_{min}$.

$$\therefore \quad \frac{\partial \sigma_n}{\partial n} = 0$$

$$\Rightarrow \quad e\mu_n + e\, n_i^2 \cdot \mu_p\left[-\frac{1}{n^2}\right] = 0$$

Replacing n by n_0 for minimum conductivity

$$e\mu_n = e \cdot n_i^2 \cdot \frac{\mu_p}{n_0^2}$$

$$\Rightarrow \boxed{n_0 = n_i\sqrt{\mu_p/\mu_n}} \quad \text{—} \quad (B)$$

Hence, the minimum conductivity appears when concentration of electron becomes $n_i\sqrt{\mu_p/\mu_n}$.

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In the similar way, we can show that the minimum value of conductivity appears when concentration of holes becomes $p_0 = n_i\sqrt{\mu_n/\mu_p}$

i.e. $$p_0 = n_i\sqrt{\mu_n/\mu_p} \quad \text{—} \quad (C)$$

Now, minimum value of conductivity can be calculated by using eq. (B) in eq. (A)'.

$$\sigma_{min.} = e\left[n_i\sqrt{\mu_p/\mu_n}\cdot\mu_n + \frac{n_i^2}{n_i\sqrt{\frac{\mu_n}{\mu_p}}}\cdot\mu_p\right]$$

$$\Rightarrow \sigma_{min.} = e\left[n_i\sqrt{\mu_p\cdot\mu_n} + n_i\sqrt{\mu_p\cdot\mu_n}\right]$$

$$\sigma_{min.} = 2 e n_i\sqrt{\mu_p\cdot\mu_n}$$

8 – 9 of Practice problems

9) $n_i = \sqrt{N_C N_V} \exp\left(\frac{-E_g}{2KT}\right)$

$\sim a.T^{3/2} \exp\left(\frac{-E_g}{2KT}\right)$

$$N_C = 2\left[\frac{2\pi m_n^* KT}{h^2}\right]^{3/2}$$

$$N_V = 2\left[\frac{2\pi m_p^* KT}{h^2}\right]^{3/2}$$

or Take T dependance

After incorporating all the universal const. values =>

$$n_i = 5.5510^{66} \times \left[m_n^* m_p^*\right]^{3/4} \exp\left[\frac{-E_g}{2KT}\right]$$

(1) $\times T^{3/2}$

The p-n junction will loose it's identity when the intrinsic carrier concentration equalizes to the hole & electron ... concentration.

electron doping concentration.

So, solve eqn 1 for the T

when $n_i = N_a = N_d = 10^{14}\ cm^{-3}$ for a particular

p-n junction.

Use any method to solve the eqn =>

or enter T values manually & check for n_i

Temperature values are →

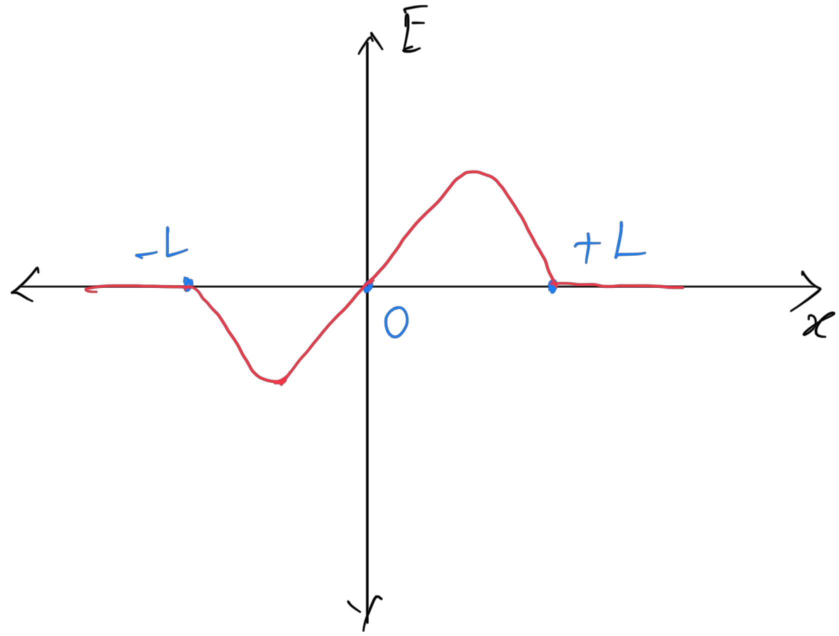
1) p-n junction with Si => ~500 K

2) " " Ge => ~335 K.

3) " " GaN => ~1500 K.
~1270 K.

Q-10 of practice problem

(i) Electric field with x →



(ii) For $x > L$ region,

$$E_i - E_F = E_g/4 = \frac{1.42}{4} = 0.355 \text{ eV}$$

so, $$p = N_A = n_i \exp\left[\frac{E_i - E_F}{KT}\right]$$

$$= 10^{10} \exp\left[\frac{0.355}{0.0259}\right]$$

$$= 8.96 \times 10^{15} \text{ cm}^{-3}$$

$\sigma = q N_A \mu_p$.

So, $\rho = \dfrac{1}{q p \mu_p}$

$$= \frac{1}{(1.6\times10^{-19})(8.96\times10^{15})(400)}$$

$$\boxed{\rho = 1.74 \ \Omega\,cm}$$

(iii) Semiconductor is under eq^m and there is no external force applied.

Since E_F is independent of x,

so that $\dfrac{dE_F}{dx} = 0$

(iv) At both $x = +L/2$ & $x = -L/2$

$J_n = 0$ & $J_p = 0$.

Note that net e & h currents are always zero everywhere under eq^m condition. Refer the discussion of diffusion in class under $\dfrac{dE_F}{dx} = 0$