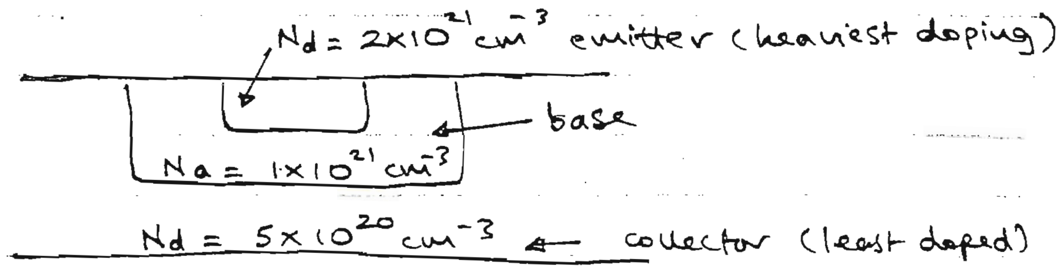
EEE 207 2007 – 2008 (S2) Worked examples

1
a)



This is a n-p-n transistor.

b) Charge neutrality gives: $n + N_a = p + N_d$

also $np = n_i^2$

so $n + N_a = \dfrac{n_i^2}{n} + N_d$

$$n^2 + n(N_a - N_d) - n_i^2 = 0$$

so, $$n = \left(\frac{N_d - N_a}{2}\right) \pm \frac{\sqrt{(N_d-N_a)^2 + 4n_i^2}}{2}$$

$$= \left(\frac{N_d - N_a}{2}\right)\left(1 \pm \sqrt{1 + \left(\frac{2n_i}{N_d - N_a}\right)^2}\right)$$

In this case, $n_i \ll |N_d - N_a|$

so $n_{coll.} = 5\times10^{20}\,cm^{-3}$

$p_{base} = 10^{21} - 5\times10^{20} = 5\times10^{20}\,cm^{-3}$

$n_{emitt.} = 2\times10^{21} + \underset{\substack{\uparrow \\ \text{(original doping in wafer)}}}{5\times10^{20}} - 1\times10^{21} = 1.5\times10^{21}\,m^{-3}$

:) $n_i = 2\times10^{20}$ at 500 K, so cannot assume $n_i \ll |N_d - N_a|$ and must use full expression

$$n_{coll.} = \frac{N_d}{2}\left(1 \pm \sqrt{1 + \left(\frac{4\times10^{20}}{5\times10^{20}}\right)^2}\right) = 5.7\times10^{20}\ m^{-3}$$

$$p_{base} = \frac{N_a - N_d}{2}\left(1 \pm \sqrt{1 + \left(\frac{2n_i^2}{N_a - N_d}\right)^2}\right) = \frac{5\times10^{20}}{2}\left(1 \pm \sqrt{1 + \left(\frac{4\times10^{20}}{5\times10^{20}}\right)^2}\right)$$

$$= 5.7\times10^{20}\ m^{-3}$$

$$n_{emitt} = \frac{N_d - N_a}{2}\left(1 \pm \sqrt{1 + \left(\frac{2n_i^2}{N_d - N_a}\right)^2}\right) = \frac{1.5\times10^{20}}{2}\left(1 \pm \sqrt{1 + \left(\frac{4\times10^{20}}{1.5\times10^{20}}\right)^2}\right)$$

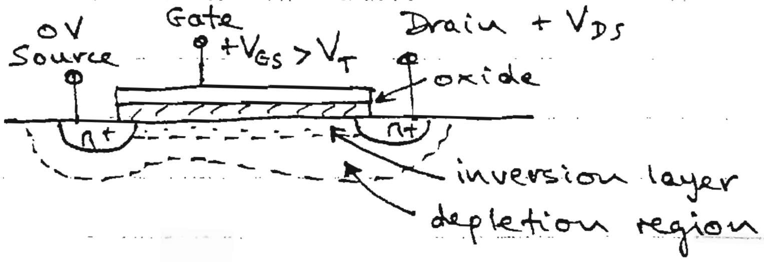
$$= 1.59\times10^{21}\ m^{-3}$$

The carrier levels are not significantly changed at this temperature, so the device still works.

(d) At 77K, $KT = 6.6$ meV. Although the donor levels will be ionised, acceptors will not be ionised to any significant extent. The base doping is effectively reduced, increasing its resistance, consequently affecting device performance such as freq. response.

Q2

(a)



(b) Formula in unsaturated region is:

$$I_d = \mu_e C_g \left(V_{gs} - V_T - \frac{V_{ds}}{2} \right) \frac{V_{ds}}{l^2}$$

Saturation occurs when I_d is maximum – this occurs when $\partial I_d / \partial V_{ds} = 0$

$$\therefore \quad \frac{\partial I_d}{\partial V_{ds}} = \frac{\mu_e C_g}{l^2} \left(V_{gs} - V_T - V_{ds} \right) = 0$$

$$V_{gs} - V_T - V_{ds} = 0$$

$\therefore$ Unsaturated when $V_{gs} - V_T - V_{ds} > 0$

(c) If $V_{gs} - V_T - V_{ds} < 0$, device is in saturated region and this value is given when $\partial I_d / \partial V_{ds} = 0$ above.

i.e. when $V_{gs} - V_T = V_{ds}$

$$\therefore \quad I_d = \frac{\mu_e C_g}{l^2} \left(V_{gs} - V_T - \frac{V_{gs} - V_T}{2} \right) . (V_{gs} - V_T)$$

$$= \frac{\mu_e C_g}{2 l^2} (V_{gs} - V_T)^2$$

2.2. cont

(d) When drain and gate are shorted, $V_{gs} = V_{ds}$.

from part (c)

$$I_d = \frac{\mu_e C_g}{2l^2}\left(V_{ds} - V_T\right)^2$$ is the saturated current provided $V_{ds} > V_T$.

If $V_{ds} < V_T$, $I_d = 0$

(e) When $V_{ds} = 2V$, $V_{ds} < V_T$ so $I_d = 0$

$V_d = 3V$, $V_{ds} = V_T$ so $I_d = 0$ (conducting channel just formed)

$V_d = 4V$, $I_d = \frac{6\times10^{-4}}{2} = 0.3mA$

It can be used as a non-linear resistor

3 (a) $E = hf$, $c = f\lambda$

$= \frac{hc}{\lambda}$

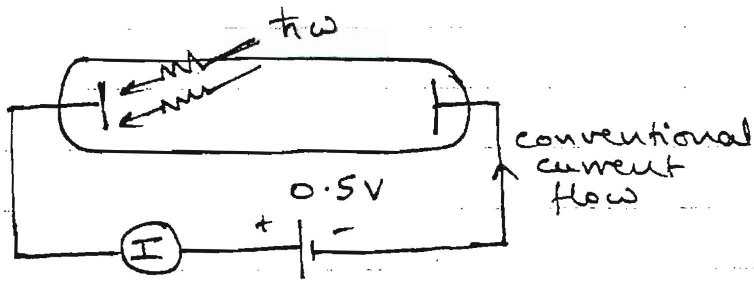
$\therefore \lambda = \frac{hc}{E}$ where E is in joules

To get E in electron-volts, multiply the electron charge,

$\therefore L = \frac{hc}{e} = \frac{6.62\times10^{-34} \times 3\times10^{8}}{1.6\times10^{-19}} = 1.24\ \mu m\ eV$

b) de Broglie : $mv = h/\lambda$ where m = mass, v = velocity,
h = Planck's const.
λ = de Broglie wavelength

c)
(i)



External voltage opposes the conventional current flow.

(ii) Work function energy = minimum energy required to eject an electron from the bulk of the material into a vacuum.

(iii) Energy of photon $= \hbar\omega = \phi_w + K.E. = \phi_w + eV$

$\therefore \phi_w = \hbar\omega - eV = \frac{1.24}{0.633} - 0.5$

$= 1.96\,eV - 0.5\,eV$

$= 1.46\,eV$

3 cont. (iv) Experiment shows that light exists in quanta and that each 'photon' gives rise to one excited electron only.

(v) Power $P = \hbar\omega n$, where n = no. of photons/unit time

Current $I = en\eta = e\eta \cdot \frac{P}{\hbar\omega}$, where η = Q.E.

$$\therefore \eta = \frac{I\hbar\omega}{Pe} = \frac{2\times10^{-3} \times 1.24 \times e}{10\times10^{-3} \times e \times 0.633} = 0.39 \text{ or } 39\%$$

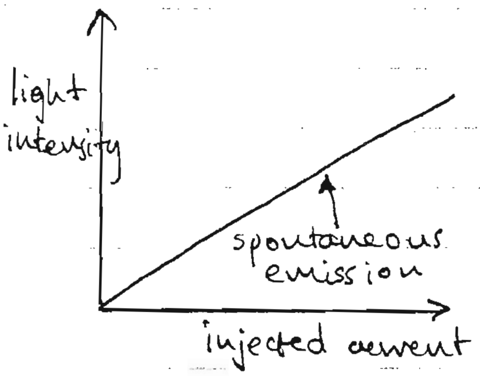
(vi) Double laser $\lambda = 1266\,\text{nm}$

Light energy $= \frac{1.24}{1.266} = 0.98\,\text{eV} < \phi_w$ of metal

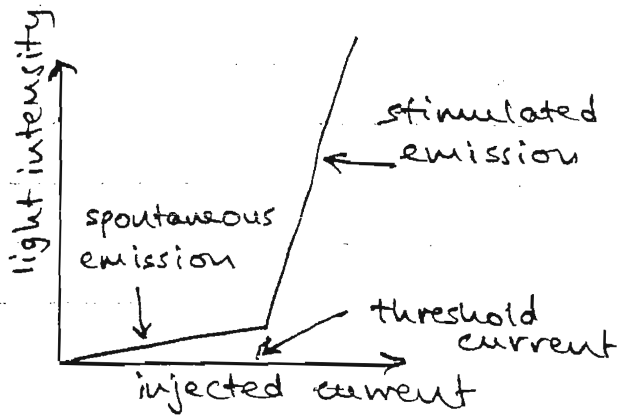
No current can flow regardless of laser power.

Q4

(a)

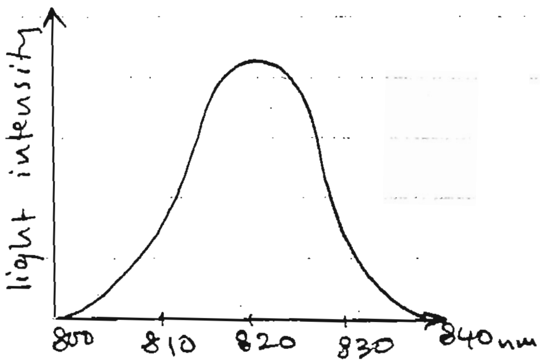


LED

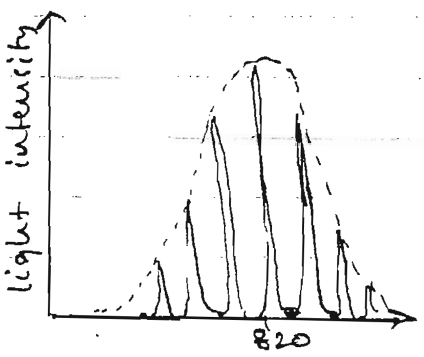


Laser

(b)



LED



Laser

(c) Choose the InGaAs and InAlAs pair. Other two will give wavelenghts that are too short for 1·55 μm operation, no matter what QW dimension is used.

(d) Energy corresponding to 1·55 μm $= \frac{1\cdot 24}{1\cdot 55\,\mu m} = 0\cdot 8\,eV$

Bulk (thick) band-gap of InGaAs = 0·75 eV, so quantisation should increase the band gap by 50 meV.

4(d) Using expression for 1st bound energy levels for electron and holes :

$$\frac{h^2}{8m_e^* m_o L^2} + \frac{h^2}{8m_h^* m_o L^2} = 50\,meV$$

$$\frac{h^2}{8m_o L^2}\left(\frac{1}{m_e^*} + \frac{1}{m_h^*}\right) = 50\,meV$$

$$L^2 = \frac{h^2}{8m_o} \cdot \frac{1}{50\times10^{-3}\times1.6\times10^{-19}} \cdot \left(\frac{1}{m_e^*} + \frac{1}{m_h^*}\right)$$

$$= 2.05\times10^{-16}$$

$$L = 14.3\,nm$$

e) As the wavelength becomes shorter, carriers would start to escape thermionically due to temperature effects. As the bound levels rise in energy, they will start to tunnel through the InAlAs barrier.