Answers EE2 Semiconductor Devices (2008)

1 a) Holes

b) $n_n = 5\ 10^{17}\ cm^{-3}$ majority carrier concentration

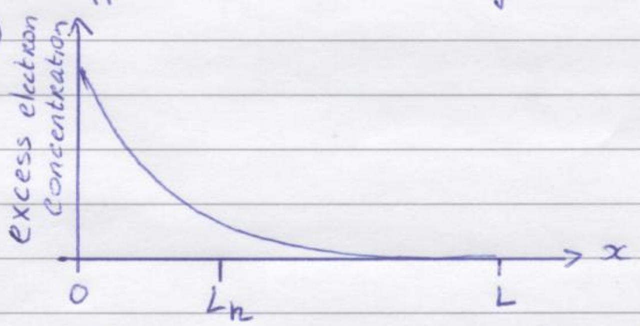
$$p_n = \frac{n_i^2}{N_D} = \frac{(1.45\ 10^{10}\ cm^{-3})^2}{5\ 10^{17}\ cm^{-3}} = 420.5\ cm^{-3}$$

= minority carrier concentration.

c) Drift is caused by an electric field

Diffusion is a result of carrier gradients

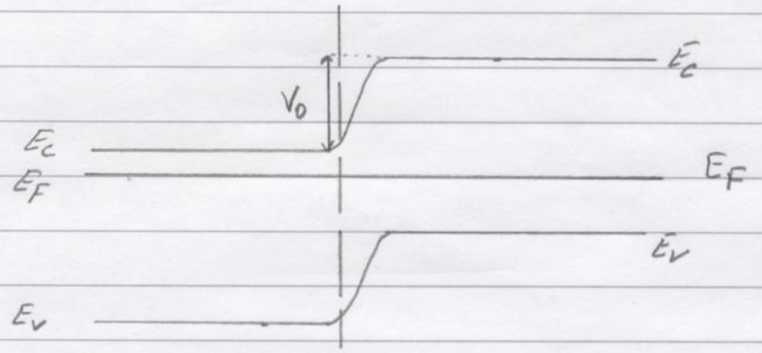
d)



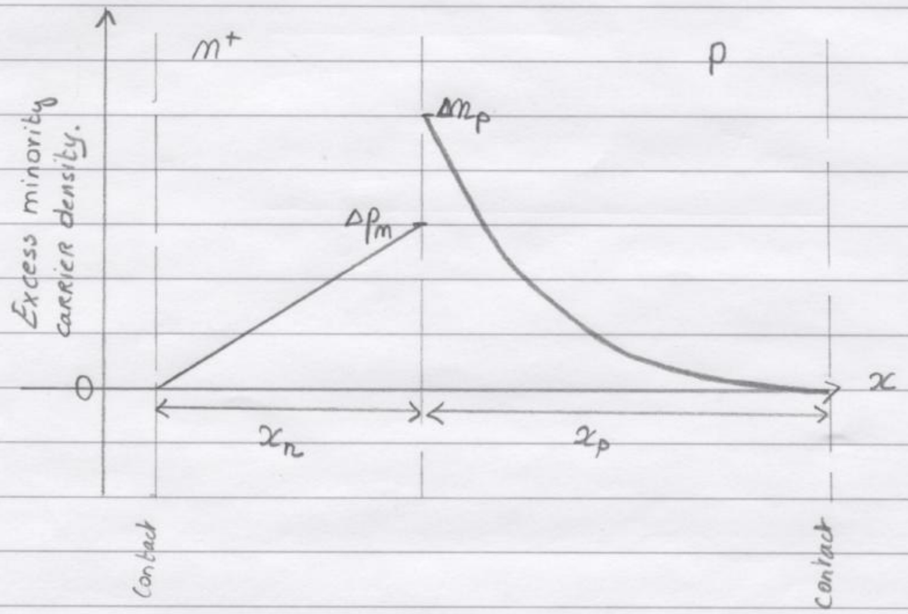
Should be an exponentially decreasing curve that goes to zero @ $x = L$.

e) The main cause of delay in a BJT is the charge in the base region. This charge needs to be completely removed before the collector current can become zero.

3 a) Energy band diagram



b)



Note: • variation in n^+ layer linear
• variation in p layer exponential.

c) $Q_p = \frac{e \times \Delta p_n \times x_n \times A}{2} = \frac{e\left(p_n' - p_{n0}\right) \times x_n \times A}{2} = A\,\frac{e\, x_n}{2}\, p_{n0}\left(\exp\left(\frac{V_{EB}}{V_T}\right) - 1\right)$

$$= \frac{e\, x_n\, n_i^2}{2 N_D}\left(\exp\left(\frac{V_{EB}}{V_T}\right) - 1\right) \times A$$

$$Q_n = -e \times A \times \int_0^{x_p} \Delta n_p \exp\left(-\frac{x}{L_n}\right) dx$$

$$= e \times A \times \Delta n_p\, L_n \exp\left(\frac{-x}{L_n}\right)\Big|_0^{x_p}$$

$$Q_n \cong +e\,A\,(n_p' - n_{p_0})\,L_n\,(0-1)$$

$$= -\frac{e\,A\,n_i^2}{N_A}\,L_n\left(\exp\left(\frac{V_{EB}}{V_T}\right)-1\right)$$

d) since n^+p junction $I_{tot} \simeq I_n$

$I_n = \dfrac{Q_n}{\tau_n}$ Recombination current.

$$I_n = -\frac{e\,A\,\Delta n_p\,L_n}{\tau_n}$$

$$J_n = \frac{I_n}{A} = \frac{-1.6\ 10^{-19}\,C\ \ 2\ 10^{12}\,cm^{-3}\ \ 500\ 10^{-7}\,cm}{0.1\ 10^{-6}\,s}$$

$$= -16\ 10^{-5}\ \frac{A}{cm^2}$$

e) i) $I = 0\,A$ open circuit.

ii) $V_d > 0\,V$ forward bias voltage remains until excess charge is removed.

4. a) Key contributions were as follows:

i) Wilhelm Roentgen: Discovered X-rays

Heinrich Hertz: Discovered radio waves

[2]

ii) Alexander Graham Bell: Invented the telephone

Guglielmo Marconi: Invented the radio

John Logie Baird: Invented the television

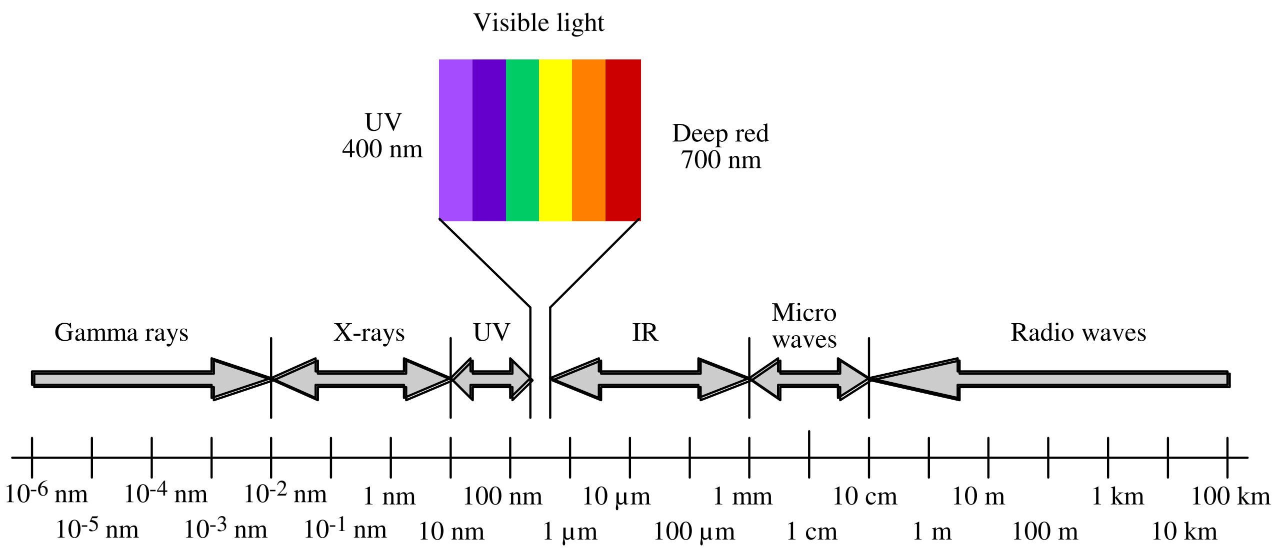
[3]

iii) John Tyndall: Demonstrated light guidance by total internal reflection in a water jet

Charles Kao and George Hockham: Proposed low loss optical fibre communications

[2]

b)



[1 mark for each band = 7]

c) Radio waves – main difficulty is diffraction; overcome using phased arrays

[2]

Microwaves – main difficulty is attenuation; overcome by avoiding water absorption frequency.

[2]

Light waves – main difficulty is scattering; overcome by confinement inside an optical fibre.

[2]

5. a) The phase velocity is the velocity of a single travelling wave.

The group velocity is the velocity of a group of waves, which can represent a modulated carrier and hence describe information propagation.

[3]

The two constituent waves with frequencies $\omega + \Delta\omega$ and $\omega - \Delta\omega$ must have corresponding propagation constants $k + \Delta k$ and $k - \Delta k$. The combined signal can therefore be written as:

$A(z, t) = A_0\{\exp\{j[(\omega + \Delta\omega)t - (k + \Delta k)z\} + \exp\{j[(\omega - \Delta\omega)t - (k - \Delta k)z\}\}$ or

$A(z, t) = A_0\{\exp[j(\Delta\omega t - \Delta kz)] + \exp[-j(\Delta\omega t - \Delta kz)]\} \exp[j(\omega t - kz)]$ or

$A(z, t) = 2A_0 \cos(\Delta\omega t - \Delta kz) \exp[j(\omega t - kz)]$

This result describes a carrier with a modulating envelope in the form of a travelling cosinusoidal wave. The velocity of the envelope is $v_g = \Delta\omega/\Delta k$. **[3]**

b) If the dispersion characteristic of the ionosphere is $\omega = \sqrt{[\omega_p^2 + c^2k^2]}$, then:

$v_{ph} = \omega/k = \sqrt{[(\omega_p^2/k^2) + c^2]}$ and

[3]

$v_g = d\omega/dk = c^2/\sqrt{[(\omega_p^2/k^2) + c^2]}$

[3]

For the atmosphere, which has $\omega_p = 0$, $\omega = ck$, so:
$v_{ph} = \omega/k = c$

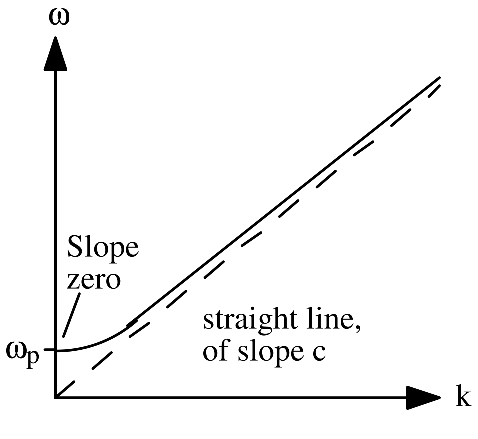
[3]

$v_g = d\omega/dk = c$

[3]

c) The dispersion diagram is as shown below. Since v_g tends to zero when ω tends to ω_p, there can be no transmission of information in this frequency range.

[3]



[3]

d) Rewriting the equation for the dispersion characteristic, we get: $\omega^2 = \omega_p^2 + c^2k^2$
Hence $k = (1/c)\sqrt{(\omega^2 - \omega_p^2)}$.
If $\omega < \omega_p$, this result can be written as $k = \pm j(1/c)\sqrt{(\omega_p^2 - \omega^2)} = \pm jk'$

[3]

A wave solution $A(z, t) = A_0 \exp[j(\omega t - kz)]$ then becomes $A(z, t) = A_0 \exp(j\omega t) \exp(\pm k'z)$, i.e. an exponentially decaying wave.
The significance of this result is that waves with angular frequencies less than ω_p will not be able to penetrate the ionosphere; instead, they will be reflected (as Marconi found).