[BOOKWORK]

1 a) The answer should describe how an unbiased junction has a built in potential caused by recombination of electrons and holes, leaving the exposed acceptor and donor ions which create the field. When a forward bias is applied the potential is reduced allowing current to flow across the junction from the p-type to the n-type material and vice versa. In reverse bias the ~~built in~~ potential is increased and only a small current caused by thermal generation of carriers will flow (called the saturation current). In forward bias The proportion of current caused by holes injected into the n-type material, where they recombine is the hole current. Similarly the proportion of current caused by electron in the p-type material is the electron current.

Light is produced when ~~the~~ an electron and hole recombine, releasing energy. The amount of energy released is equivalent to the "ionization energy" (the energy required to break a bond).

[10]

[SIMPLE PROBLEM]

b) The diode equation is

$$I = I_o \left[\exp\left(\frac{qV}{kT}\right) - 1 \right] \qquad [1]$$

[equation is in list at beginning of paper]

$$\therefore \quad V = \frac{kT}{q} \ln \left[\frac{I}{I_o} + 1 \right]$$

Assuming $\frac{kT}{q} \approx \frac{1}{40}$ eV then $V = 0.59\,V$ [2]

(c) [HIDDEN]

Cross-sectional area of 9×10^{-8} m [1]

$t_n = 1 \times 10^{-4}$ m $\quad t_p = 5 \times 10^{-7}$ m

$n = 1 \times 10^{24}\ m^{-3} \quad p = 1 \times 10^{22}\ m^{-3}$

$\mu_e = 0.5\ m^2 V^{-1} s^{-1} \quad \mu_h = 0.03\ m^2 V^{-1} s$

~~In each case~~ $\rho_n = \dfrac{1}{n q \mu_e} \quad \rho_p = \dfrac{1}{n q \mu_h}$

$\rho_n = 1.25 \times 10^{-5}\ \Omega m \quad \rho_p = 2.08 \times 10^{-2}$ m [2]

$R_n = \dfrac{\rho_n l}{A} \quad R_p = \dfrac{\rho_p l}{A}$

$R_n = 0.014\ \Omega \quad R_p = 0.0115\ \Omega$ [2]

$R_T = 0.129\ \Omega$

From (b) $I = 20$ mA $\quad V_R = I R_T = 2.6 \times 10^{-3}$ V

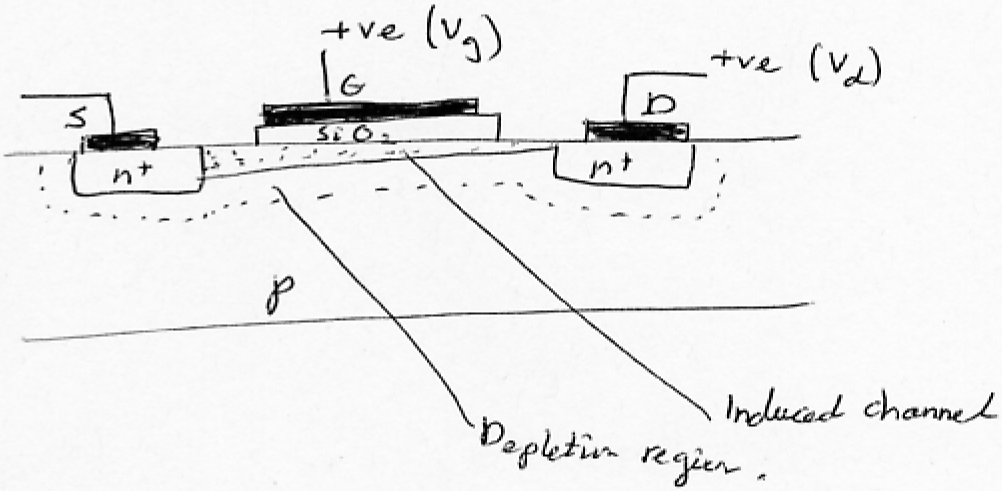
Total VOLTAGE drop = $V_{junction} + V_R$

$\simeq 0.59$ V as $V_R \ll V_{junction}$.

[2]

2(a) [BOOK WORK]

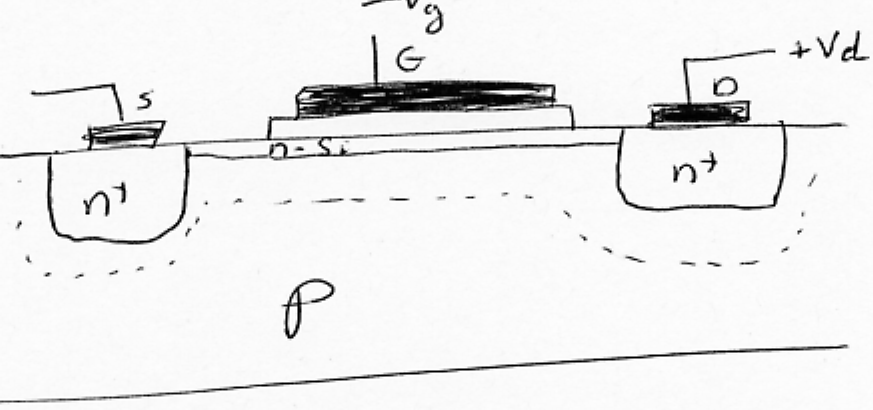
In enhancement mode the transistor consists of two heavily doped n^+ regions in a p-type region of Si. SiO_2 is used to provide an insulator for the gate.



Under zero gate bias no current can flow as the source-drain is effectively two back-to-back diodes. However if a +ve bias is applied to the gate electrons can be attracted from the n^+ regions to form an ~~the~~ induced channel between source and drain. This channel narrows towards the drain end due to the positive bias at this contact. If the drain ~~value~~ voltage is high enough the channel current saturates as the channel becomes pinched off at this end. By changing the gate voltage the value of I as the current saturates can be modified. As increasing the magnitude of the gate bias increases the channel conduction the device is said to be in enhancement mode. ~~In a dep~~

2(a) ctd

In depletion mode there is a thin n-channel below the gate created

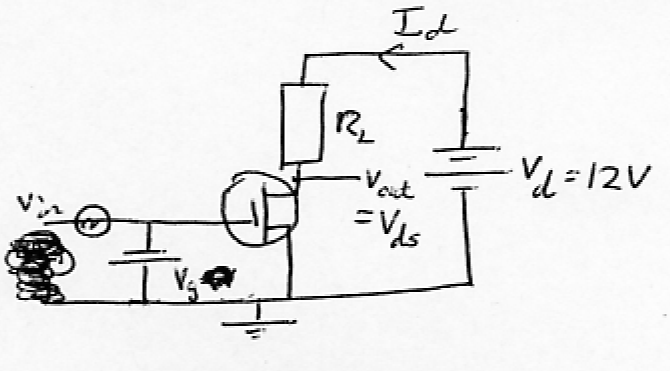


As there is a pre-existing channel current can easily flow from source to drain at zero gate bias, which will saturate if V_d is high enough. Applying a negative voltage to the gate DEPLETES electrons out of the channel causing the maximum current through the channel to reduce.

[10]

2(b) [HIDDEN]

Simple "common source" amplifier



~~For 10V peak to peak we need a minimum and maximum voltage across the transistor V_{ds} = 1V and [illegible] respectively~~

[4]

For a voltage gain of 100 we need an output of $\pm 2V$ (or 4 V peak-to-peak)

[2]

Now $\tilde{i}_d = g_m \tilde{V}_{gs}$

$$= 80mS \times 40mV$$

$$= 3200 \times 10^{-6} A = 3.2mA$$

[2]

We need a value of load resistor that will give a voltage drop difference of 4V if the current changes by 3.2mA

$$R_L = \frac{V}{i} = \frac{4}{3.2 \times 10^{-3}} = \underline{\underline{1.25k\Omega}}$$

[2]

3(a) [Bookwork]

At room temperature (or any temperature above 0K) thermal energy is sufficient to allow a small number of electrons to be thermally excited out of their bonds, generating a free-electron and a free-hole which can wander around the material. These free particles will exist until they meet up with a free particle of the opposite type when they will recombine, with the free electron falling back into a bond, annihilating the hole [3]

The rate of recombination, R will depend on the concentration of electrons and holes in the material and in ~~the~~ equiliborum the concentration of electrons and holes should be a constant meaning that Generation Rate = Recombination Rate. [2]

i.e. $G = R \propto np$

In intrinsic material $n_i = p_i$ and $R \propto n_i^2$ [1]

In n-type material the generation rate must remain the same and hence $G = R \propto n \cdot p_n$ [1]

Combining the above we have $p_n = \dfrac{n_i^2}{n}$ [1]

(b) [BOOKWORK]

~~Assume trav.~~
At the p^+n junction there will be a high concentration of holes being injected into the n-type material. These will diffuse into the block, recombining with majority carrier electrons as they go. Hence the concentration of holes will (exponentially) fall as one goes further away from the p^+ layer with the characteristic length depending on the diffusion coefficient and minority carrier lifetime. [3]

(c) [HIDDEN]
We need to first calculate the minority carrier diffusion length:

$$L_h = \sqrt{D_h \tau_h} \quad \text{where} \quad D_h = \frac{kT}{q}\mu_h \qquad [2]$$

Substituting given values [$\mu_h(Si) = 0.045\, m^2 V^{-1} s^{-1}$, $\tau_h = 200\,ns$]
and assuming $\frac{kT}{q} = 1/40\ eV$

we get $D_h = 1.125 \times 10^{-3}\ m^2 s^{-1}$ [1]

and hence $L_h = 15\,\mu m$ [1]

Now $\frac{p}{p_0} = \exp\left(-\frac{x}{L_h}\right) \quad \therefore x = -L_h \ln\left(\frac{p}{p_0}\right)$

where $p/p_0 = 0.98$

Hence $x = 3\,\mu m$. [2]

[HIDDEN]

d) The light will induce electron-hole pairs in the base

Holes can be swept into the collector by diffusion in the base

Electrons will recombine with holes injected from the emitter, effectively forward biassing this junction, giving current gain to the photodetected signal [3]

[BOOKWORK - EASY]

4 a) In a metal the bonding is very different from in a semiconductor or insulator. This means that electrons in the outermost states can easily move away from their host atom giving a high density of free-charge carriers and hence the resistivity of the material is low

In an insulator the outermost electrons are strongly held in bonds and are unable to move hence there are virtually no charge carriers and the material does not conduct easily

In a semiconductor the outermost electrons are in bonds that can release them if moderate amounts of energy (heat, visible light) are applied. The conductivity is intermediate [6]

[BOOKWORK - MORE OBSCURE]

b) We can represent bonding states and non-bonding states in the semiconductor as the ~~conduction~~ valence band (VB) and ~~valence~~ conduction (CB) band, respectively. Electrons can conduct if they are in the CB, ~~conduction band~~ and holes can conduct in the VB. There is a gap between the bands, equal to the ionization energy, W_g. If Si is doped with As then the fifth electron (not involved in the bonding) forms a state near the top of the gap, just below the CB edge. The fifth electron will sit here. However ~~with~~ at room temperature it can gain enough energy to jump out of the bond into the CB and travel through the material. Similarly B doped Si forms a state just above the VB edge which is empty (i.e. contains a hole). An electron in the VB can easily gain the small amount of energy required to jump into the state releasing the hole to travel around the material. In both cases the free charge carriers density increased, increasing

4(c) HIDDEN.

Assume all the depletion thickness is on the p-side of the junction (from n^+-p) [1]

The maximum capacitance achievable is when the device is unbiased $V = 0V$. [1]

From ~~states~~ equations given

$$d_j = \left(\frac{2\varepsilon_0\varepsilon_r V_0}{qN_a}\right)^{1/2} \quad [1]$$

and $$C = \frac{\varepsilon_0\varepsilon_r A}{d} \quad \text{(Not given)} \quad [1]$$

Combining and rewriting we get

$$N_a = \frac{2V_0 C_j^2}{q\,\varepsilon_0\varepsilon_r A^2} \quad [1]$$

Now

$$\left.\begin{aligned}
V_0 &= 0.7\ V \\
C &= 1\times10^{-9}\ F \\
\varepsilon_r &= 12 \\
\varepsilon_0 &= 8.85\times10^{-12}\ F/m \\
q &= 1.6\times10^{-19}\ C \\
A &= \pi r^2 = \pi\,(4\times10^{-4}\,m)^2 = 5\times10^{-7}\,m^2
\end{aligned}\right\} N_a = 3.27\times10^{23}\,m^{-3}$$

[2]