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Electronic Devices & Circuits Imp. Questions with Solutions

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Example: 1

A 2 cm long bar of N type Ge has a cross section of 2 mm × 2 mm. The resistivity of the material is 40 ohm – cm and the life time of carriers is 200 microseconds.

A. Find the resistance of the bar

B. Find the donor concentration

C. Find the the resistance of the bar when it is illuminated such that 10^{14} photons strike it every second. Assume that each photon generates an electron–hole pair and these pairs are distributed uniformly all over the bar.

Sol:

A. $R = \frac{\rho L}{A} = \frac{40\times 2}{0.2\times 0.2} = 2000\, ohms$

B. Since the resistivity is comparable with intrinsic resistivity of Ge which is 45 ohm – cm, this is a lightly doped material and therefore, accurate formula must be used.

$$\therefore \sigma\left(n\mu_n + p\mu\right) q\; p = \frac{n_i^2}{n}$$

$$\therefore \frac{1}{40} = \left(3800n + 1800\frac{6.25\times 10^{26}}{n}\right)\times 1.6\times 10^{-19}$$

$$\therefore 3800n - \frac{1}{40\times 1.6\times 10^{-19}} + \frac{1800\times 6.25\times 10^{24}}{n} = 0$$

$n^2 - 4.11 \times 10^{13}n + 2.96 \times 10^{26} = 0$

$$\therefore n = \frac{4.11\times 10^{13} \pm \left[67.57\times 10^{26} - 4\times 2.96\times 10^{26}\right]^{1/2}}{2}$$

= 5.785×10^{13} electrons/cm^3 (Ignoring the negative sign)

$$\therefore p = \frac{n_i^2}{n} = \frac{6.25\times 10^{26}}{5.785\times 10^{13}} = 1.08\times 10^{13}\, holes / cm^3$$

$N_D = n - p = 5.785 \times 10^{13} - 1.08 \times 10^{13}$

= 4.7×10^{13} donors /cm^3

C. When illuminated, 10^{14} election – hole pairs are crated every second which last for 200 micro second on average. i.e. in 200 microseconds, 2×10^{10} e-h pairs are created and destroyed. Thus the excess number of holes and electrons will stabilize to 2×10^{10} in the sample. But sample volume is 2 × 0.2 × 0.2 = 0.08 cm^3

n' = excess electron concentration = $\frac{2\times 10^{10}}{0.08} = 2.5\times 10^{11}$ electrons/cm^3

p' = excess hole concentration= $\frac{2\times 10^{10}}{0.08} = 2.5\times 10^{11}$ holes/cm^3

$p = 1.08 \times 10^{13} + 2.5 \times 10^{11} = 1.105 \times 10^{13}$

and

$n = 5.785 \times 10^{13} + 2.5 \times 10^{11} = 5.81 \times 10^{13}$

$\sigma = (n\mu_n + p\mu_p)\, q$

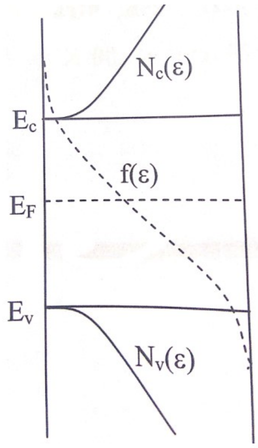
$= (85.81 \times 10^{13} \times 3800 + 1.105 \times 10^{13} \times 1800) \times 1.6 \times 10^{-19}$

$= 0.5249$ mho/cm

$$\therefore R = \frac{L}{\sigma A} = \frac{2}{0.5249 \times 0.2 \times 0.2} = 9525.6\ ohms.$$

Example: 2

The Fermi-Dirac probability function and the density of states function in Si sample are as shown in figure. Assume the Boltzman approximation to be valid and determine the energy level at which the electron concentration is maximum in the conduction band.



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Sol: Give the profile of the Fermi-Dirac probability function and the density of states function in silicon and these appear to be usual.

The electron concentration in conduction band is given as the product of these two profiles

n(E) = N(E). f(E)

In Conduction band $N(E) \propto \sqrt{E - E_c}$

$$f(E) \propto \left(\frac{\left(-\left(E - E_f\right)\right)}{kT} \right)$$

$$n(E) = N(E) f(E) \propto \sqrt{E - E_c} \exp\left(\frac{\left(-\left(E - E_F\right)\right)}{kT} \right)$$

$$= \alpha \sqrt{E - E_c} \exp\left(\frac{-\left(E - E_c\right)}{kT} \right) \exp\left(\frac{-\left(E_c - E_F\right)}{kT} \right)$$

Let E – E$_c$ = x

Then N(E). f(E) $\propto \sqrt{x}\exp\left(\frac{-x}{kT}\right)$

Now, to find the maximum value

$$\frac{d\left(N(E).f(E)\right)}{dx}=\frac{1}{2}x^{-1/2}\exp\left(\frac{-x}{kT}\right)$$

$$\frac{-1}{kT}x^{1/2}\exp\left(\frac{-x}{kT}\right)=0$$

This yields

$$\frac{1}{2x^{1/2}}=\frac{x^{1/2}}{kT}$$

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

Then the maximum value occurs at

$$E=E_c+\frac{kT}{2}$$

Example: 3

Show that the reverse saturation current I$_0$ is given by $I_0=Aq\left(\frac{D_p}{L_pN_D}+\frac{D_n}{L_nN_A}\right)n_i^2$ and also as $I_o=AV_T\sigma_i^2\frac{m}{(m+1)^2}\left(\frac{1}{L_p\sigma_n}+\frac{1}{L_n\sigma_p}\right)$ where $m=\frac{\mu_n}{\mu_p}$ and σ_i, σ_p and σ_n are conductivities of intrinsic, p= type and n-type regions respectively

Sol:

The hole diffusion current in a p-n junction diode is given as

$$I_{pn}(x)=\frac{AqD_pp_{n_0}}{L_P}\left(e^{v/v_T}-1\right)e^{-x/Lp}$$

and at $x=0,\quad I_{pn}(0)=\frac{AqD_pP_{n_0}}{L_P}\left(e^{v/vr}-1\right)$

Similarly the electron diffusion current in a p-n junction diode is given as

$$I_{np}(x)=\frac{AqD_nn_{p_0}}{L_n}\left(e^{v/v_T}-1\right)e^{-x/Ln}$$

and at $x = 0, \quad I_{np}(0) = \frac{AqD_n n_{p_0}}{L_n}\left(e^{v/v_T} - 1\right)$

Reverse saturation currect is $I(0) = I_0 = I_{pn}(0) + I_{np}(0)$ for a very large reverse biase.

$$\Rightarrow I_0 = \frac{AqD_p P_{n_0}}{L_P} + \frac{AqD_n n_{p_0}}{L_n} = \frac{AqD_p \frac{n_i^2}{N_D}}{L_P} + \frac{AqD_n \frac{n_i^2}{N_A}}{L_n} \text{ (By mass-action law)}$$

According to Einstein relation $D_p = V_T \mu_p$ and $D_n = VT\ \mu_n$

$$\Rightarrow I_0 = Aq\left(\frac{V_T \mu_p}{L_p N_D} + \frac{V_T \mu_n}{L_n N_A}\right)n_i^2$$

$$= Aq^2 V_T \mu_n \mu_p \left(\frac{1}{L_p N_D \mu_n q} + \frac{1}{L_n N_A \mu_p q}\right)n_i^2$$

$$= AV_T q^2 n_i^2 \left(\mu_n + \mu_p\right)^2 \frac{1}{\left(\mu_n + \mu_p\right)^2} \times \mu_n \mu_p \left(\frac{1}{L_p \sigma_n} + \frac{1}{L_n \sigma_p}\right)$$

$$= AV_T \sigma_i^2 \frac{\mu_n \mu_p}{\mu_p^2 \left(\frac{\mu_n}{\mu_p} + 1\right)}\left(\frac{1}{L_p \sigma_n} + \frac{1}{L_n \sigma_p}\right)$$

$$\Rightarrow I_0 = AV_T \sigma_i^2 \frac{m}{(m+1)^2}\left(\frac{1}{L_p \sigma_n} + \frac{1}{L_n \sigma_p}\right)$$

Where $m = \frac{\mu_n}{\mu_p}$

Example: 4

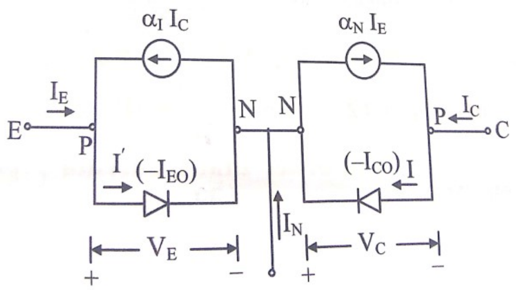
A bipolar transistor has two junctions either one of which may be forward or reverse – biased. Therefore, we have four modes of operations – normal,
cut – off saturation and inverse region. With the single set of equations describing these four regions.

Sol: Bipolar junction transistors have two junctions (EBJ and CBJ). From this we have four modes of operations as follows.

EBJ	CBJ	Operational region
FB	RB	Active
FB	FB	Saturation
RB	RB	Cutoff
RB	FB	Inverse active

The Ebers– Molls model

- This model is valid for both forward and reverse static voltages applied across the transistor junction. It should be noted that we have omitted the base-spreading resistance and have neglected the difference between I_{CBO} an I_{CO}.
- The Ebers – Moll model for a p-n-p transistor is shown below.



- It consists of two ideal diodes connected back with reverse saturation currents sources shunting the ideal diodes. For a p-n-p BJT, I_{CO} and I_{EO} are negative so that $-I_{CO}$ and I_{EO} are having (+) ve values.

Now apply KCL to the collector node of given figure above.

$$I_c = -\alpha_N I_E + I = -\alpha_N I_E + I_0\left(e^{Vc/vt} - 1\right)....(i)$$

Where, I = diode current

$I_0 = -I_{CO}$ and a_N = current gain in normal operation

$I_C = -\alpha_N I_E - I_{CO}\,(e^{VC/VT} - 1)$ …….(ii)

Subscript 'N' denotes the transistor used in the normal manner. If we assume inverted mode then new eq^n formed is,

$I_E = -\alpha_I - I_{EO}\,(e^{Ve/VT} - 1)$ …….(iii)

Where, α_1 = inverted common base current gain

A physical analysis by using Ebers – Moll Model reveals that the parameters a_N, ai, I_{CO} and I_{EO} are not independent, but are related by the condition.

$\alpha_I I_{CO} = \alpha_N I_{EO}$….(iv)

Since, $I_B = -(I_E + I_C)$……..(v)

If three of 4-parameters (α_N, α_I, I_{CO} and I_{EO}) are known Ebers – Moll equations allow calculations of the three currents for given values of junction voltage V_C and V_E also then we determine the mode of operations.

Example: 5

Draw and explain the drain and transfer characteristics of a p-channel enhancement type MOSFET. What is meant by threshold voltage? Discuss three different ways by which the threshold voltage can be reduced.

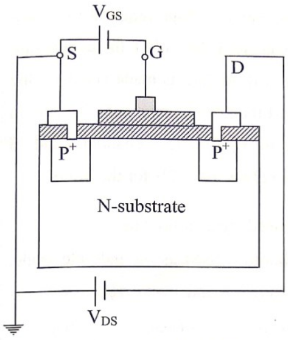
Sol: The transfer characteristics of a p channel enhancement type MOSFET can be well explained by considering the working mechanism of the MOSFET.

Working of a P – channel EMOSFET:

In a MOSFET the gate to source terminal is reverse biased and the drain to source terminal is forward biased. For a P-Channel E-MOSFET V_{GS} is negative voltage applied and V_{SD}, is positive voltage applied and the substrate is connected to the V_{DD}. The circuit diagram of a P-Channel EMOSFET is represented as below:

Initially channel will not be formed in the MOSFET till $|V_{GS}| < |V_T|$ (Threshold voltage) and current through the FET is zero and this region of operation is called cutoff region. When the applied voltage V_{GS} exceeds the threshold voltage minority carriers i.e., the holes from the n-substrate and holes from the p^+ wells are acquired to form the channel. As soon as the channel is formed when source to drain voltage is applied flow of charge carriers takes place and hence the current I_D. As the source to drain voltage is increased current increases linearly and hence this region of operation is known as ohmic or linear region. As the source to drain voltage is still increased the more number of holes are accumulated towards drain than at the source which results in reduction of channel passage which is nothing but channel length modulation and hence current I_D reduces and becomes constant and this region of operation is called as saturation region and the point at which the current I_D is constant is called pinchoff voltage.

The characteristics of a P-Channel E-MOSFET area represented as below:



P-channel E-MOSFET

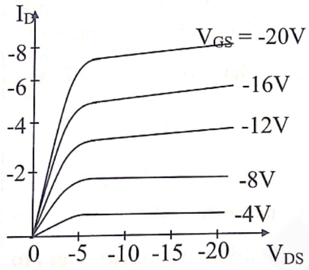


Fig: Drain characteristics of P – channel enhancement

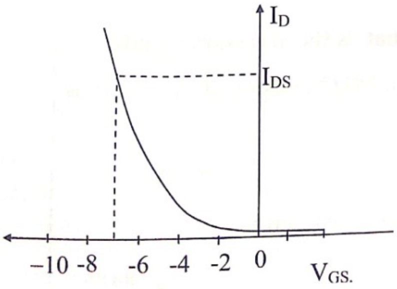


Fig: Transfer characteristic of P-Channel enhancement type

THRESHOLD VOLTAGE

Threshold voltage is defined as the minimum voltage required to let the MOSFET into conduction state in P-channel E-MOSFET is conduction takes place when $V_{GS} < V_T$ or $|V_{GS}| > |V_T|$. As V_{GS} in made negative, the current $|I_D|$ increases slowly at first, and then much more rapidly with an increase in $|V_{GS}|$.Typically the value of V_T for the P-channel standard MOSFET is −4V, and the power supply voltage of −12V for the drain.

Three methods by which V_T can be reduced are as following:

1. Polycrystalline silicon doped with boron is used as the gate electrode, This reduces contact potential difference and hence reduces V_T as whole.
2. If silicon crystal uses [100] direction orientation the value of $V_T$reduces one-half that obtained with <111> orientation.

3. The silicon nitride approach makes use of a layer of Si_3N_4 and SiO_2, whose dielectric constant is about twice that of SiO_2 and as a result decreases V_T.