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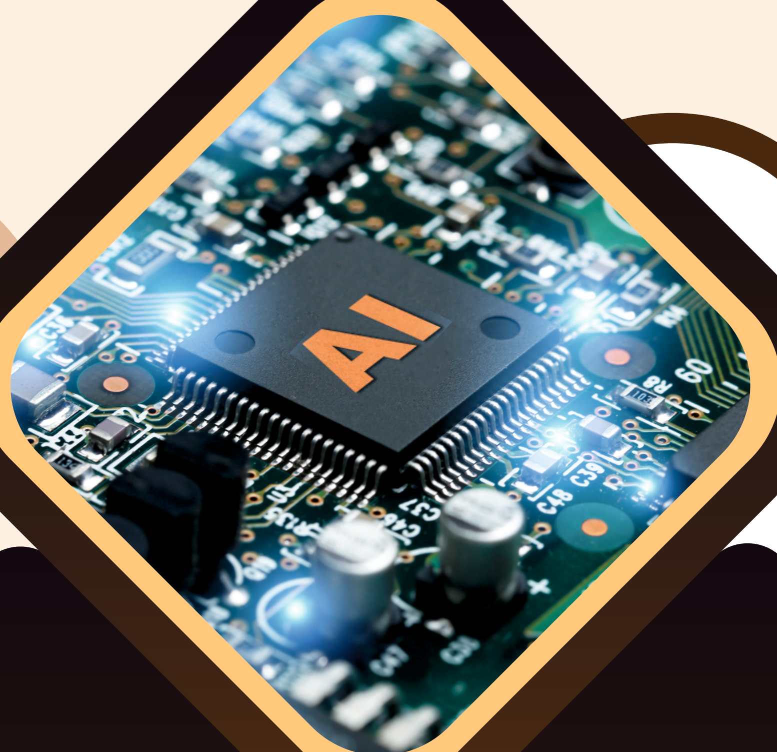


Electronics & Communication Engineering

ELECTRONIC DEVICES

Text Book: Theory with worked out Examples and Practice Questions

Chapter 1 Basics of Semiconductors

(Solutions for Text Book Practice Questions)

01. Ans: (a)

Sol: $N_D = 5\times10^{22}\times\frac{1}{10^9}\,cm^{-3}$

$= 5\times10^{13}\ cm^{-3}$

According to mass action law

$np = n_i^2$

$n_n p_n = n_i^2$

$N_D\,p_n = n_i^2\ \ (\because n_n \simeq N_D)$

$p_n = \frac{n_i^2}{N_D}$

$p_n = \frac{(1.5\times10^{10})^2}{5\times10^{13}}$

$= 4.5\times10^6\ cm^{-3}$

02. Ans: (b)

Sol: According to law of mass action $n.p = n_i^2$

Where n_i = intrinsic carrier concentration.

N_D = doping concentration for a n- type material.

Majority carrier concentration

$n \cong N_D$

$p = \frac{n_i^2}{N_D}$

$p\alpha\frac{1}{N_D}$

03. Ans: (b)

Sol: V = 5V

L = 100 mm

$\mu_n = 3800\ cm^2/V\text{-sec}$

$\mu_p = 1800\ cm^2/V\text{-sec}$

$V_{dn} = \mu_n E$

$= 3800\times\frac{V}{L}$

$= 3800\times\frac{5}{100\times10^{-1}}$

= 1900 cm/sec

04. Ans: (d)

Sol: For the n-type semiconductor with $n = N_D$ and $p = n_i^2/N_D$, the hole concentration will fall below the intrinsic value because some of the holes recombine with electrons.

05. Ans: (c)

Sol: $N_A = \frac{10^{15}}{1.6}$ acceptor/cm^3

$\mu_n = 4000\ cm^2/V\text{-sec}$

$\mu_p = 2000\ cm^2/V\text{-sec}$

$\sigma_p = p\,q\,\mu_p$

$= N_A q\mu_p$ ($\because$ 100% doping efficiency)

$= \frac{10^{15}}{1.6}\times1.6\times10^{-19}\times2000$

= 0.2 mho/cm

06. Ans: (d)

Sol: According to mass action law.

$np = n_i^2$

$n_n p_n = n_i^2$

$n_p p_p = n_i^2$

$n_p N_A \simeq n_i^2$

$N_D p_n \simeq n_i^2$

07. Ans: (a)

Sol: $R_H = 3.6\times10^{-4}\ m^3/c$

$\rho = 9\times10^{-3}\ \Omega\text{–m}$

Let us consider n-type semiconductor

$$R_H = \frac{1}{nq}$$

$$n = \frac{1}{qR_H} = \frac{1}{1.6\times10^{-19}\times3.6\times10^{-4}}$$

$$= 1.736\times10^{22}\ m^{-3}$$

08. Ans: (b)

Sol: At equilibrium

No. of e^- density = No. of hole density

$\because$ given e^- density is $n(x_1) = 10\,n(x_2)$

$\Rightarrow n(x_1)$ is majority

$\Rightarrow n(x_2)$ is minority

$\therefore\ p(x_2) = 10p(x_1)$

09. Ans: (b)

Sol: $\rho_p = 3\times10^3\ \Omega - m$

$\mu_p = 0.12\ m^2/V\text{-sec}$

$V_H = 60mV$

$$\rho_p = \frac{1}{\sigma_p}$$

$$3\times10^3 = \frac{1}{p\,q\,\mu_p}$$

$$p = \frac{1}{3\times10^3\times1.6\times10^{-19}\times0.12}$$

$P = 1.736\times10^{16}\ m^{-3}$

$$R_H = \frac{1}{pq} = \frac{1}{1.736\times10^{16}\times1.6\times10^{-19}}$$

$= 360\ m^3/C$

10. Ans: (b)

Sol: $J_{drift} = n\mu_n qE + p\mu_P qE$

$J_{drift} = [(n.q)\mu_n + (p.q)\mu_p]E$

$J_{drift} = [\rho_n\mu_n + \rho_p\mu_p]$

$J\alpha$ 'ρ'

$\downarrow$

Charge concentration

11. Ans: (c)

Sol: $D_n = 20\ cm^2/s$

$\mu_n = 1600\ cm^2/V\text{–}s$

$$\frac{D}{\mu} = \frac{kT}{q} = V_T$$

$$\Rightarrow V_T = \frac{20}{1600} = 12.5\,mV$$

12. Ans: (d)

Sol: Conductivity of a semiconductor,

$\sigma = (n\mu_n + p\mu_P)q$

Where, $\mu_n \rightarrow$ mobility of electrons

$\mu_p \rightarrow$ mobility of holes

$n \rightarrow$ electron concentration

$p \rightarrow$ hole concentration

$q \rightarrow$ electron charge

13. Ans: (c)

Sol: $N_A = 2.29\times10^{16}$

$$E_{Fi} - E_{Fp} = kT\ln\left(\frac{N_A}{n_i}\right)$$

$$= 0.02586\ln\left(\frac{2.29\times10^{16}}{1.5\times10^{10}}\right)$$

$= 0.3682$ eV

$\simeq 0.37$ eV

14. Ans: (b)

Sol: Given,

2 wires $\therefore$ W_1 & W_2

$d_2 = 2d_1$ where d = diameter of wire

$L_2 = 4L_1$ where L = length of wire

Relation between resistances of W_1 & W_2

$$R = \frac{\rho.L}{A} = \frac{\rho L}{\pi r^2} \qquad r = \frac{d}{2}$$

$$R = \frac{\rho.L}{\pi\frac{d^2}{4}} = \frac{4\rho L}{\pi d^2} \qquad R \propto \frac{L}{d^2}$$

$$\frac{R_1}{R_2} = \frac{\frac{L_1}{d_1^2}}{\frac{L_2}{d_2^2}} = \frac{L_1}{d_1^2} \times \frac{d_2^2}{L_2} = \frac{L_1}{d_1^2} \times \frac{(2d_1)^2}{4L_1}$$

$$\Rightarrow \frac{R_1}{R_2} = 1 \qquad \therefore R_1 = R_2$$

15. Ans: (c)

Sol: Hall voltage, V_H is inversely proportional to carrier concentration

$$\Rightarrow \frac{V_{H2}}{V_{H1}} = \frac{P_1}{P_2} = \frac{P_1}{2P_1}$$

$$\therefore V_{H2} = \frac{1}{2} V_{H1}$$

16. Ans: (b)

Sol: $\frac{D}{\mu} = \frac{kT}{q} = V_T$

$$\therefore D = \frac{0.36 \times 1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}}$$

$= 9.315 \times 10^{-3} m^2/sec$

Diffusion length, L = $\sqrt{D\tau}$

$= \sqrt{9.315 \times 10^{-3} \times 340 \times 10^{-6}}$

$= 1.77 \times 10^{-3} m$

17. Ans: (a)

Sol: In intrinsic semiconductor,

Number of electron = Number of holes

18. Ans: (a, b, c & d)

Sol: (a) Continuity equation for holes is given by

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\frac{\partial J_p}{\partial x} + G^1 - \frac{\delta p}{\tau}$$

Similarity continuity equation for electrons is

$$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\partial J_n}{\partial x} + G^1 - \frac{\delta n}{\tau}$$

These equations describe the rate of change of minority carries with time.

(b) Einstein's equation

$\frac{D_n}{\mu_n} = V_T$ and $\frac{Dp}{\mu p} = V_T \rightarrow$ Diffusion constant and mobility are related

(c) Poisson's equation is given by

$$\frac{\partial^2 v}{\partial x^2} = \frac{-\rho}{\in} \text{ and } E = \frac{-\partial v}{\partial x}$$

charge density and electric field are related

(d) Diffusion equation

$$J_{P_{Diff}} = -qD_P \frac{dp}{dx} \text{ and } J_{n_{Diff}} = qD_n \frac{dn}{dx}$$

Rate of change of carrier concentration in the space.

19. Ans: (c)

Sol: $N_A = 10^{16}/cm^3$

$G' = 10^{20}/cm^3\text{-S}$

$\tau = 100\mu s$

$n_i = 10^{10}/cm^3$

Steady state excess carriers

$\delta p = \delta n = \delta$

$\delta = G'\tau = 10^{20} \times 100 \times 10^{-6}$

$\delta = 10^{16}/cm^3$

$p_p = p_{p_0} + \delta = 2 \times 10^{16}/cm^3$

$n_p = n_{p_0} + \delta \cong \delta = 10^{16}/cm^3$

$p_p n_p = 2 \times 10^{32}/cm^6$

20. Ans: (a)

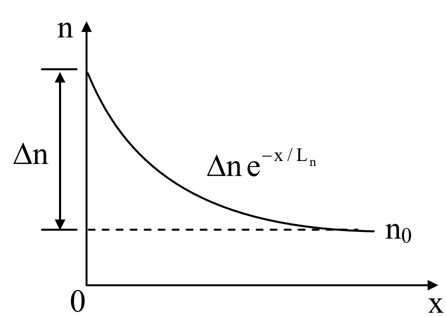
Sol: From given data,

$p_0 = 10^{17}/cm^3$,

$n_i = 10^{10}/cm^3$

$L_n = 2\mu m$ and $L_p = 1\mu m$

At x = 0, $\Delta n = 10^{14}/cm^3$,



$\delta n = n e^{-x/L_n}$

At x = 2μm,

$\delta n = 10^{14} \times e^{-2\mu/2\mu} = 3.678 \times 10^{13}/cm^3$

$n = n_0 + \delta n$

$$n_0 = \frac{n_i^2}{p_o} = \frac{10^{20}}{10^{17}} = 10^3 / cm^3$$

$n = 10^3 + 3.678 \times 10^{13}$

$\approx 3.678 \times 10^{13}/cm^3$

$= 0.37 \times 10^{14}/cm^3$

21. Ans: (c)

Sol: For n-type, as we know at constant temperature,

if DOPING ↑↑ ⇒ E_F move towards E_C.

For $E_C - E_F \geq 3KT$ [Boltzmen Approximation]

$$n = n_c \exp\left[\frac{E_F - E_C}{KT}\right]$$

$$\Rightarrow E_C - E_F = KT \log_e \left|\frac{N_C}{n}\right|$$

For $n = n_1$, Let $E_C - E_F = E_C - E_{F_1}$

$n = n_2$, Let $E_C - E_F = E_C - E_{F_2}$

$$\Rightarrow (E_C - E_{F_1}) - (E_C - E_{F_2}) = KT \log_e \left|\frac{N_C}{n_1}\right| - KT \log_e \left|\frac{N_C}{n_2}\right|$$

$$\Rightarrow (E_C - E_{F_1}) - (E_C - E_{F_2}) = KT \log_e \left|\frac{n_2}{n_1}\right|$$

$$\Rightarrow (E_C - E_{F_2}) = (E_C - E_{F_1}) - KT \log_e \left|\frac{n_2}{n_1}\right|$$

$$\Rightarrow E_C - E_{F_2} = 200m - 26m \log_e |0.5|$$

$$\Rightarrow E_C - E_{F_2} = 218 meV$$

22. Ans: (b, c and d)

Sol: Since electron concentration gradient

⇒ Diffusion of carrier exist from B → A and B → C

⇒ Diffusion current exist between A → B and C → B

Since at equilibrium balance diffusion

⇒ Drift current exist from B → A and B → C

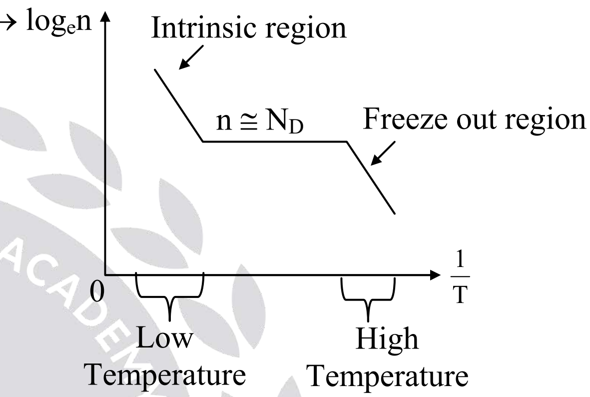
As Drift is due to electron field

⇒ $\overline{E}$ directs from B → A and B → C

23. Ans: (b)

Sol: Given n-type, Si, non-degenerating doping

Then →



24. Ans: 2.25

Sol: $p = 1.5 n_i$

$np = n_i^2$

$n \times 1.5 n_i = n_i^2$

$$n = \frac{1}{1.5} n_i$$

$A\, pq\, \mu_p E = A n q \mu_n E$

$p\, \mu_p = n \mu_n$

$$1.5 n_i \mu_p = \frac{1}{1.5} n_i \mu_n$$

$$\frac{\mu_n}{\mu_p} = 1.5 \times 1.5 = 2.25$$

25. Ans: 69.9

Sol: $p = N_V e^{-(E_F - E_V)/KT}$

$$KT(400K) = KT(300K) \times \frac{400}{300}$$

$$= 0.026 \times \frac{4}{3}$$

$$= 0.035 eV \;(or)\; 0.03466$$

$$N_V = 2\left(\frac{2\pi m_p KT}{h^2}\right)^{\frac{3}{2}}$$

$$N_V \alpha T^{3/2}$$

$$N_V(400K) = N_V(300K) \times \left(\frac{400}{300}\right)^{\frac{3}{2}}$$

$$= 10^{19} \times \left(\frac{4}{3}\right)^{\frac{3}{2}}$$

$$= 1.54 \times 10^{19}/cm^3$$

$p = 1.54 \times 10^{19} \times e^{-0.35/0.035}$

$p = 6.99 \times 10^{14}/cm^3$

$= 69.9 \times 10^{13}/cm^3$

26. Ans: 0.177 (Range: 0.17 to 0.19)

Sol: Given non-degenerative semiconductor, n-type

Given 5% neutral donor atoms

$\Rightarrow$ Donor atoms not yet ionized.

Let call them as N_D^O

If ionized donor $\rightarrow$ N_D^+

Given N_D^O = 5% N_D = $0.05N_D$.

$\therefore$ N_D^+ = 5% N_D = $0.05N_D$.

Given $(E_C - E_F)$ = 0.25 eV and V_T = 20mV

Since, $a = \frac{N_D^+}{N_D} = \frac{1}{1 + 2\exp\left[\frac{E_F - E_D}{KT}\right]}$

Degenerative factor $\rightarrow$ 2

$$\Rightarrow 0.95 = \frac{1}{1 + 2\exp\left[\frac{E_F - E_D}{KT}\right]}$$

By solving $E_F - E_D = -72.7$meV

$\therefore$ $E_D - E_F$ = 72.7meV.

Given, $E_C - E_F$ = 0.25eV

and $E_D - E_F$ = 0.0727 eV $\rightarrow$ we got.

$\therefore$ $E_C - E_F - E_D + E_F = 0.25 - 0.0727$

$\therefore$ $E_C - E_D = 0.177$

27. Ans: (b)

Sol: Since, Intrinsic resistivity,

$$\rho_i = \frac{1}{\sigma_i} = \frac{1}{n_i q(\mu_n + \mu_p)}$$

$$= \frac{1}{2.5 \times 10^{16} \times 1.6 \times 10^{-19} \times (0.15 + 0.05)}$$

$$= \frac{1}{2.5 \times 0.2 \times 1.6 \times 10^{-19} \times 10^{16}}$$

$\therefore$ ρ_i = 1.25kΩ-m

28. Ans: (b)

Sol: Given: $\mu_n = 0.38m^2$/V-sec at T = 300°K

As $D_n = \mu_n V_T = \mu_n . \frac{T}{11600}$

At $300^\circ K, D_n = 0.38 \times \frac{300}{11600}$

$\therefore$ $D_n = 98.26cm^2$/sec

29. Ans: (a)

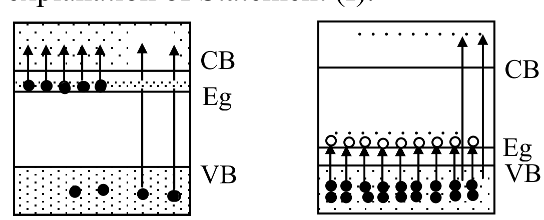
Sol: In P-type, as doping increases hole concentration p increases. According to mass action law $n_p = \frac{n_i^2}{p_p}$ $\Rightarrow$ electron concentration decreases.

30. Ans: (b)

Sol: In intrinsic semiconductor, electron hole pairs are generated due to external energy $\Rightarrow$ true. electron mobility is 2 to 3 times more than hole mobility $\Rightarrow$ true. Both the statements are true but statement II is not a correct explanation of statement I.

31. Ans: (a)

Sol: Both Statement (I) and Statement (II) are true and Statement (II) is the correct explanation of Statement (I).

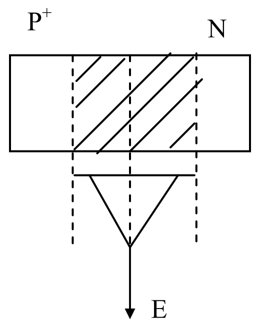


n-type P-type

Chapter 2 PN Junction Diode

01. Ans: (c)

Sol:



In P^+, '+' indicates heavily region and 'N' indicates lightly doped region.

02. Ans: (a)

Sol: $w = \sqrt{\frac{2\varepsilon V_0}{q}\left[\frac{1}{N_D}+\frac{1}{N_A}\right]}$

$$\frac{w_2}{w_1} = \sqrt{\frac{V_0 - V_{R2}}{V_0 - V_{R1}}}$$

$$\frac{w_2}{2\mu m} = \sqrt{\frac{0.8-(-7.2)}{0.8-(-1.2)}}$$

$w_2 = 4\ \mu m$.

03. Ans: (a)

Sol: $I = \left[\frac{AeD_P p_{n0}}{L_P} + \frac{AeD_n n_{P0}}{L_n}\right]$

$$\Rightarrow I = \frac{AeD_p p_{no}}{L_P}$$

$$\frac{I}{A} = \frac{eD_P p_{no}}{L_P}$$

$$= \frac{1.602\times10^{-19}\times12\times10^{12}}{1\times10^{-3}}$$

$= 1.92\ mA/cm^2$

04. Ans: (c)

Sol: $1\ mA = I_{GO}(e^{V_G/\eta V_T} - 1) = I_{SO}(e^{V_S/\eta V_T} - 1)$

$$\frac{I_{GO}}{I_{SO}} = \frac{e^{0.718/(2\times0.026)}}{e^{0.1435/(1\times0.026)}} \cong 4000 = 4\times10^3$$

05. Ans: (c)

Sol: In a PN Junction diode the dynamic conductance $g_m = \frac{\Delta I}{\Delta V}$, $g_m = \frac{I_C}{V_T}$

i.e. $g_m \propto I_C$

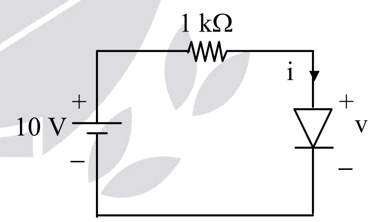
06. Ans: (d)

Sol: i - v characteristic of the diode

$i = \frac{v-0.7}{500}$ A, $v \geq 0.7$ V ….. (1)

From the given circuit, Loop equation :

$v = 10 - 1000\ i$, $v \geq 0.7$ V ….. (2)



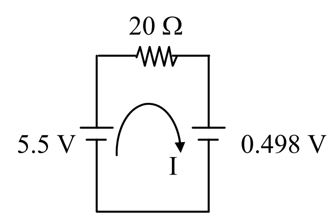
Eliminating 'v' from (1) and (2) :

$$i = \frac{10-1000\ i - 0.7}{500} = \frac{9.3}{500} - 2i$$

$$3i = \frac{9.3}{500},\quad i = \frac{3.1}{500}A = 6.2\ mA$$

07. Ans: (b)

Sol: Given,



$V_\gamma = 0.498$ V

$V_T = 2$ mV

$\therefore I = \frac{5.5-0.498}{20}$

$= 0.2501 \Rightarrow 250$ mA

08. Ans: (a)

Sol: Given $I_2^1 = I_1 \times 32$

Given $T_1 = 40°C$ $\quad T_2 = ?$

$$I_2^1 = I_1\left(2^{\frac{T_2-T_1}{10}}\right)$$

$$I_1 \times 32 = I_1\left(2^{\frac{T_2-T_1}{10}}\right)$$

$$2^5 = 2^{\frac{T_2-T_1}{10}}$$

$$\Rightarrow \frac{T_2 - T_1}{10} = 5$$

$T_2 - T_1 = 50$ $\quad T_2 = 50 + T_1$

$T_2 = 90°C$

09. Ans: (b)

Sol: For either Si (or) Ge

$$\frac{dV}{dT} \cong -2.5\ mV/^0C$$

To maintain constant current

$$\frac{(V_2 - 700mV)}{(40-20)}\ \frac{V}{^oC} = -2.5 \times 10^{-3}\ \frac{V}{^oC}$$

$\rightarrow V_2 = 650$ mV

10. Ans: (b)

Sol: $C = \frac{\varepsilon_0\varepsilon_r A}{d} \Rightarrow \frac{C}{A} = \frac{\varepsilon_0\varepsilon_r}{d}$

$$= \frac{11.7\times 8.85\times 10^{-12}}{10\times 10^{-6}}$$

$= 10.36\ \mu F/m^2$

11. Ans: (a, b & c)

Sol: $V_b = E_{Fn} - E_{Fi} + E_{Fi} - E_{FP}$

$$= \frac{KT}{q}\ell n\left(\frac{N_D}{n_i}\right) + \frac{KT}{q}\ell n\left(\frac{N_A}{n_i}\right)$$

$$V_b = \frac{KT}{q}\ell n\left[\frac{N_A N_D}{n_i^2}\right]$$

$$N_A \ \&\ N_D \uparrow \rightarrow \frac{KT}{q}\ell n\left[\frac{N_A N_D}{n_i^2}\right]\uparrow \rightarrow V_b\uparrow$$

12. Ans: (d)

Sol: At equilibrium, there is no net flow of electrons and holes across the junction. Now for net electron current to be zero, the diffusion and drift components must cancel out each other, for which both the currents should be of the same magnitude, but flowing in opposite direction.

13. Ans: 0.42

Sol: $W_1 = \sqrt{\frac{\eta\varepsilon_s V_{BI}}{qN_{effect}}}$ At equilibrium

$W_2 = \sqrt{\frac{\eta\varepsilon_s (V_{BI} - V_F)}{qN_{effect}}}$ under F.B

$$\frac{W_1}{W_2} = \sqrt{\frac{V_{BI}}{V_{BI} - V_F}}$$

$$\Rightarrow \frac{1}{0.6} = \sqrt{\frac{0.65}{0.65 - V_F}}$$

$$\Rightarrow \frac{1}{0.36} = \frac{0.65}{0.65 - V_F}$$

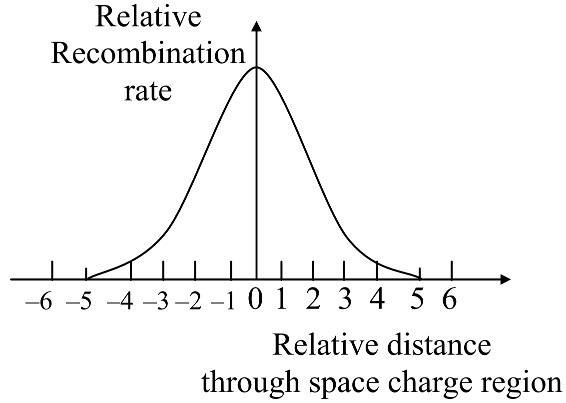
$0.65 - VF = (0.65 \times 0.36)$

$V_F = 0.416V$

$= 0.42V$

14. Ans: (b)

Sol: The maximum recombination rate U_{max} does not occurs at the edges of the depletion region in the device. So, statement (b) is false.



15. Ans: 35.87

Sol: $I_R = 0.75\ I_S$

$I_D = -0.75\ I_S$

$I_S\left(e^{V_D/V_T} - 1\right) = -0.75 I_S$

$e^{V_D/V_T} = 0.25$

$V_D = V_T \ln(0.25)$

$V_R = -V_T \ln(0.25)$

$$= -\frac{1.38\times10^{-23}\times300}{1.6\times10^{-19}}\times -1.386$$

$= 35.87\text{mV}$

16. Ans: (d)

Sol: $A = 1\ cm^2$

$P_{in}\ (/cm^2) = 100\ mW/cm^2$

$\eta = 0.15$, $V_{oc} = 0.7$, fill factor = 0.8

Thickness = 200 μm

$$\text{Power } (/cm^2) = \frac{100mW/cm^2}{200\times10^{-4}} = 5\,W/cm^3$$

$$\eta = \frac{V_m I_m}{P_{in}} \quad \text{Fill factor } = \frac{V_m I_m}{V_{oc} I_{SC}}$$

$V_m I_m = \eta P_{in}$

$$I_{SC} = \frac{V_m I_m}{V_{oc}(\text{Fill Factor})} = \frac{0.75}{0.7\times0.8}$$

$= 1.339\,A/cm^3$

$$I = \frac{Q}{t} \Rightarrow Q = I\,t = 1.339\,A\text{-s/cm}^3$$

$Q = nq$

$$\Rightarrow n = \frac{Q}{q} = \frac{1.339\,C/cm^2}{1.6\times10^{-19}\,C} = 0.84\times10^{19}\,/cm^3$$

Optical generation rate = 0.84×10^{19} /Cm^3-s

17. Ans: 8.2 V

Sol: $N_A = 5\times10^{16}\ cm^3$, $N_D = 10\times10^{16}/cm^3$

$\phi_{bi} = 0.8V$

We know that $x_n N_D = x_p N_A \Rightarrow \dfrac{N_D}{N_A} = \dfrac{x_p}{x_n}$

$\dfrac{N_D}{N_A} = 2 \Rightarrow x_p = 2x_n$

As $x_n = 0.2$ μm $\Rightarrow x_p = 0.4$ μm

So, width depletion region, W = 0.6 μm

$$W = \sqrt{\frac{2\varepsilon(V_0+V_R)}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)}$$

$$0.6\times10^{-4} = \sqrt{\frac{2\times12\times8.85\times10^{-14}(0.8+V_R)}{1.6\times10^{-19}}\left(\frac{1}{5\times10^{16}}+\frac{1}{10\times10^{16}}\right)}$$

$$\frac{0.36\times10^{-8}\times1.6\times10^{-19}\times5\times10^{16}}{2\times12\times8.85\times10^{-14}\times1.5} = (V_R + 0.8)$$

$V_R = 8.2395$ Volts

18. Ans: 4.12 (Range 4.00 to 4.26)

Sol: $I_L = 1$ mA, $V_m = 0.3$ V,

$V_T = 30\ mV = 30\times10^{-3} = 3\times10^{-2} = 0.03$ V

$I = I_L - I_0\left(e^{V/V_T} - 1\right)$

For maximum power condition, we get

$$\left(1+\frac{V_m}{V_T}\right)e^{V_m/V_T} = 1+\frac{I_L}{I_0}$$

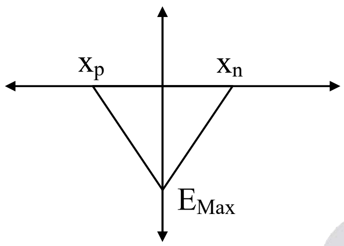
$$\left(1+\frac{0.3}{0.03}\right)e^{0.3/0.03} = 1+\frac{I_L}{I_0}$$

$$11\times e^{10} = 1+\frac{I_L}{I_0} \Rightarrow I_0 = 4.12\ nA$$

Chapter 3 Zener Diode

01. Ans; 16.32

Sol: Since $N_A = N_D = 10^{17}\ /cm^3$, then electric field profile is



Hence, If W → total depletion width,

Then $x_p = \frac{W}{2}$ and $x_n = \frac{W}{2}$

As $|E_{max}| = \left|\frac{qN_A x_p}{\varepsilon}\right| = \left|\frac{qN_D x_n}{\varepsilon}\right|$

$\Rightarrow E_{max} = \frac{qN_A W}{2\varepsilon}$

Since, we know that, breakdown voltage,

$V_{Br} = \int_{-x_p}^{x_n} E_{Max}.dx$ [∵ area of triangle]

$\Rightarrow V_{Br} = \frac{1}{2}E_{Max}.[x_n + x_p]$

$= \frac{1}{2}E_{Max}.[2x_n] = E_{Max}.[x_n]$

$\Rightarrow V_{Br} = E_{Max}.\left[\frac{W}{2}\right] = \frac{E_{Max}}{2}\left[\frac{2\varepsilon E_{Max}}{qN_A}\right]$

$\therefore V_{Br} = \frac{(11.8)(8.85\times10^{-14})(5\times10^5)^2}{(1.6\times10^{-19})(10^{17})}$

$\therefore V_{Br} = 16.32\ V$

02. Ans: (b)

Sol: $V_a = ?$

$V_j = 5V$

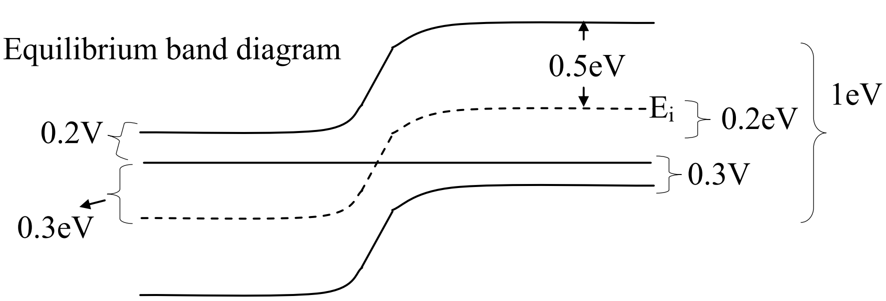
$V_a = V_D$

Since universally

$V_j = V_{bi} - V_D$

$5V = V_{bi} - V_a$ ------(1)

At Equilibrium band diagram



Now to find V_{bi} → examiner given band diagram at equilibrium,

From Energy graph,

$$[E_i - E_F]_{p-side} = kT\log_e\left|\frac{N_A}{n_i}\right|$$

and $$[E_F - E_i]_{n-side} = kT\log_e\left|\frac{N_D}{n_i}\right|$$

So, $$V_{bi} = \frac{1}{q}\left[[E_i - E_F]_{p-side} + [E_F - E_i]_{n-side}\right]$$

$qV_{bi} = 0.2eV + 0.3eV$

$\Rightarrow V_{bi} = 0.5V$

Now substituting the values in equation (1) we get

$\Rightarrow V_a = V_{bi} - 5 = -4.5V$

03. Ans: 0.54

Sol: Since, temperature coefficient,

$$\frac{dV_z}{V_2}/dt \times 100 = 0.072 \text{ given}$$

$$\therefore \frac{dV_z \times 100}{10(100-25)} = 0.072$$

$$\Rightarrow dV_z = 0.54\text{ V}$$

04. Ans: 94.27

Sol: Since,

$$[I_{02}]_{40^oC} = [I_{01}]_{25^oC} \times 2^{\left[\frac{40-25}{10}\right]} = 14.14\,\mu A$$

Since, for safety operation,

Maximum power dissipation in Diode ≤ Power dissipation by heat Sink

∴ Power dissipation in diode at operating breakdown at 40°C → 100 × 14.14 μW

Power dissipation by chasis

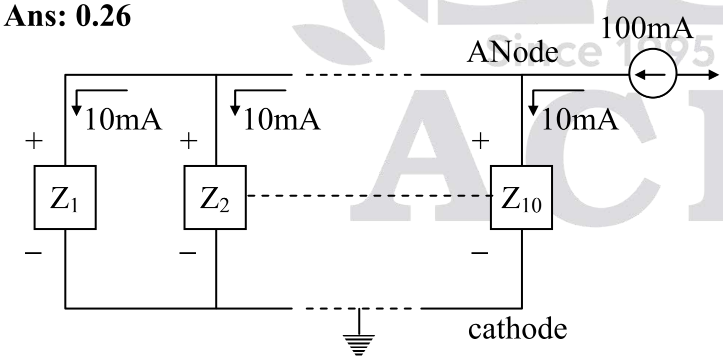
→ θ(watt) × (40 – 25)°C

∴ 100 V × 14.14 μA ≤ θ × (40 – 25)°C

θ = 94.27 μW/°C

05. Ans: 0.26

Sol:



All diodes are Forward biased and identical.

$$R_{eq} = \frac{R_D}{n} = \frac{R_D}{10}$$

Examiner given $r_d \neq 0$

where 100mA = 10 I_{DQ}

And not specified about R_{DC}

$\Rightarrow I_{DQ} = 10\text{ mA}$

$$\Rightarrow R_D \cong r_d = r_{dyn} = \frac{\eta V_T}{I_{DQ}} = \frac{26mV}{10mA} = 2.6\Omega$$

$$\therefore R_{eq} = \frac{2.6}{10} = 0.26\Omega$$

06. Ans: 5.09

Sol: Since for Silicon p^+n junction,
V_{Br} = 100 V and $N_D = 5\times10^{15}$ /cm^3 given.
So, by neglecting V_{bi} from $(V_{Br} + V_{bi})$, we get,
Depletion width on n-side,

$$x_n \cong \sqrt{\left[\frac{2\varepsilon}{q}.\frac{1}{N_D}.V_{Br}\right]}$$

$$\therefore\ x_n = 5.09\,\mu m$$

07. Ans: (a)

Sol: Given $N_D = 10^{15}$ /cm^3 and $N_A = 10^{19}$ /cm^3
Ohmic region is not a valid term for p-n junction operation.
Zener breakdown is not possible here, because we need both sides heavily (or) extreme heavily doping
So, only chance is either Avalanche (or) punch through.
If W_{dep} completely occupies light doping region, [here n-region] then applied operation is punch through (or) reach through. Else it must be Avalanche.
Since,

$$x_n = \sqrt{\left[\frac{2\varepsilon}{q}[V_{bi} + V_{Br}]\left[\frac{1}{N_A + N_D}\right].\left[\frac{N_A}{N_D}\right]\right]}$$

$$x_n \cong 18.24\,\mu m\ [\because V_{Br} + V_{bi} \simeq V_{Br}]$$

Since, given length of n-region is 22 μm
Where x_n = 18.24 μm
$\therefore\ x_n < [\text{Length}]_{\text{n-region}}$
⇒ operation is in Avalanche breakdown

08. Ans: (b) (updated key)

Sol: Given, V_{Br} = 300 V.
Since $p^+n \Rightarrow x_n$ will be more than x_p [depletion width]
So, the minimum thickness of n-region to Ensure Avalanche breakdown is →

$$x_n \cong \sqrt{\left[\frac{2\varepsilon}{q}.\frac{1}{N_D}.V_{Br}\right]}$$ → i.e., it must be depletion width approximately the thickness of n-region as Avalanche breakdown Voltage is large Voltage. If it is punch through voltage, then x_n will be absolute thickness of n-region

$$\therefore\ x_n = \sqrt{\frac{2(11.8)(8.85\times10^{-14})(300)}{(1.6\times10^{-19})(10^{15})}} = 20\,\mu m$$

09. Ans: (a)

Sol: Since, $W_{dep} = \sqrt{\left[\frac{2\varepsilon}{q}.\frac{1}{N_D}.[V_{bi} + V_{Br}]\right]}$

[∴ p^+n junction]

$$\therefore\ W_{dep} = \sqrt{\frac{2(11.8)\times(8.85\times10^{-14})(0.956+13)}{1.6\times10^{-19}\times10^{17}}}$$

$$\therefore\ W_{dep} = 4.27\times10^{-5}\ \text{cm}$$

Given n-region width = 1μm
∴ As $(W_{depletion})_{\text{n-region}}$ < (n-region) width
⇒ Avalanche breakdown

10. Ans: (a)

Sol:

- In PN junction diode break down depends on doping. As doping increases breakdown voltage decreases.
- In Zener diode breakdown is less than 6 V.
- It has Negative Temperature coefficient (operate in R.B).
- Avalanche diode breakdown greater than 6 V.

11. Ans: (b)

Sol: Both statement (I) and (II) are true but statement (II) is not a correct explanation of statement (I) because DC voltage stabilizer circuit can be implemented by using other components like Op-Amp also. There is no need that only Zener diode to be used.

Chapter 4 Special Purpose Diodes

01. Ans: (a)

Sol: Tunnel diode

It is highly doped S.C (1 : 10^3)

It is an abrupt junction (step) with both sides heavily doped made up of Ge (or) GaAs .

It carries both majority and minority currents.

It can be used as oscillator

Operate in Negative Resistance region

Operate as fast switching device .

02. Ans: (c)

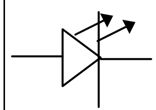
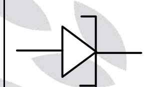
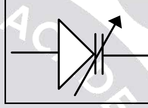
Sol: The values of voltage (V_D) across a tunnel-diode corresponding to peak and valley currents are V_P and V_V respectively. The range of tunnel-diode voltage V_D for which the slope of its I-V_D characteristics is negative would be $V_P \le V_D < V_V$.

03. Ans: (c)

Sol: Schottky diode is made of metal and semiconductor to decrease the switching times, hence it can be used for high frequency applications.

04. Ans: (a)

Sol:

Symbol	**Circuit name**	**Applications**
	LED	Direct Band gap
	Tunnel diode	Fast Switching circuits
	Varactor diode	Electronic Tuning

05. Ans: (a)

Sol: The tunnel diode has a region in its voltage current characteristics where the current decreases with increased forward voltage known as its negative resistance region. This characteristic makes the tunnel diode useful in oscillators and as a microwave amplifier.

Chapter 5 Bipolar Junction Transistor

01. Ans: (b)

Sol: $\alpha = \beta/(1+\beta) = 0.9803$

$\alpha = \beta^* \gamma^*$

$\rightarrow \beta^* = 0.9803/0.995$

$= 0.9852$

02. Ans: (d)

Sol: $I_C = 4mA$

$r_0 > 20k\Omega$

$$r_0 = \frac{V_A}{I_C}$$

$$\frac{V_A}{I_C} > 20k\Omega$$

$V_A > 20k\Omega \times I_C$

$V_A > 20 \times 10^3 \times 4 \times 10^{-3}$

$V_A > 80$

03. Ans: (b)

Sol: $V_A = 100$ V

$I_C = 1$ mA

$V_{CE} = 10$ V

$$I_{CQ}\left(1+\frac{V_{CE}}{V_A}\right) = I_C$$

If $V_A \rightarrow \infty$

$\Rightarrow I_C = I_{CQ} = 1mA$

04. Ans: (b)

Sol: The phenomenon is known as "Early Effect" in a bipolar transistor refers to a reduction of the effective base-width caused by the reverse biasing of the base-collector junction.

05. Ans: (a)

Sol: Given $\alpha = 0.995$, $I_E = 10mA$,

$I_{co} = 0.5mA$

$I_{CEO} = (1 + \beta)\, I_{CBO}$

$$I_{CEO} = \left(1+\frac{\alpha}{1-\alpha}\right)I_{CBO}$$

$I_{CEO} = (1+199) \times 0.5 \times 10^{-6}$

$I_{CEO} = 100\mu A$

06. Ans: (a)

Sol: I_{CBO} is equal to I_{CO}. Reverse leakage current double for every Ten degrees rise in temperature.

07. Ans: (b)

Sol: Given base width $W_B = 50\times10^{-6}$ cm

Base doping $N_B = 2\times10^{16}$ cm^{-3}

$\epsilon_r\epsilon_0 = \epsilon$ & $\epsilon = 10^{-12}$ F/cm

$$V_{punch} = \frac{qN_B W_B^2}{2\epsilon}$$

$$= \frac{1.6\times10^{-19}\times2\times10^{16}\times\left(50\times10^{-6}\right)^2}{2\times10^{-12}}$$

$$V_{punch} = \frac{1.6\times2\times2500}{2}\times10^{-3} = 4V$$

08. Ans: (a)

Sol: $\alpha = 0.98$

$I_B = 40\ \mu A$

$I_{CBO} = 1\ \mu A$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = 49$$

For a CE active BJT

$I_C = \beta\, I_B + (1+\beta)\, I_{CBO}$

$= 49 \times 40 \times 10^{-6} + 50 \times 10^{-6}$

$= 2.01$ mA

09. Ans: (b)

Sol: $I_{CBO} = 0.4\ \mu A$

$I_{CEO} = 60\ \mu A$

$I_{CEO} = (1+\beta)\, I_{CBO}$

$$1+\beta = \frac{I_{CEO}}{I_{CBO}}$$

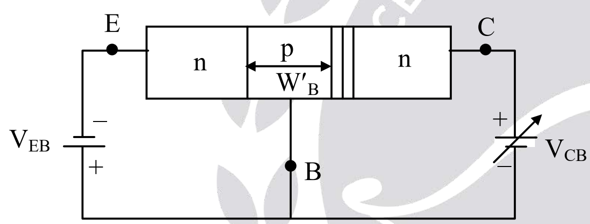
$$= \frac{60}{0.4} = 150$$

$\beta = 150 - 1 = 149$

$$\alpha = \frac{\beta}{1+\beta} = \frac{149}{150} = 0.993$$

10. Ans: (c)

Sol: Variation of base width due to reverse biased voltage across collector - base junction is known as "Early Effect".



As V_{CB} increases, effective base width (W'_B) decreases.

11. Ans: (b, c & d)

Sol: Condition for saturation

$$\beta\left[\frac{V_{BB}-V_{BE}}{R_B}\right] \ge \frac{V_{CC}-V_{CE(set)}}{R_C}$$

$$50\left[\frac{5-0.7}{50\times10^3}\right] \ge \frac{10-0.2}{Rc}$$

$$4.3\text{ mA} \ge \frac{9.8v}{R_c} \Rightarrow R_c \ge \frac{9.8v}{4.3mA}$$

$\Rightarrow R_C \ge 2279.07\Omega$

12. Ans: (a & c)

Sol: (a) Intrinsic semiconductor $n = p = n_i$

(c) Consider continuity equations

$$\frac{\partial \delta n}{\partial t} = \frac{1}{q}\frac{\partial J_n}{\partial x} + G' - \frac{\delta n}{\tau} \quad \text{--- (1)}$$

$$\frac{\partial \delta p}{\partial t} = -\frac{1}{q}\frac{\partial J_p}{\partial x} + G' - \frac{\delta p}{\tau} \quad \text{--- (2)}$$

Under steady state $\frac{\partial}{\partial x} = 0,\ G' = R'$

$\delta n = \delta p$

(1) – (2)

$$\Rightarrow \frac{1}{q}\frac{\partial}{\partial x}(J_n + J_p) = 0$$

$$\Rightarrow \frac{1}{q}\frac{\partial J}{\partial x} = 0 \quad (\therefore\ J = J_n + J_p)$$

$$\Rightarrow \frac{\partial J}{\partial x} = 0$$

(d) $\mu_n \propto T^{-m}$

Ge

m = 2.5 for electron

m = 2.7 for hole

Si

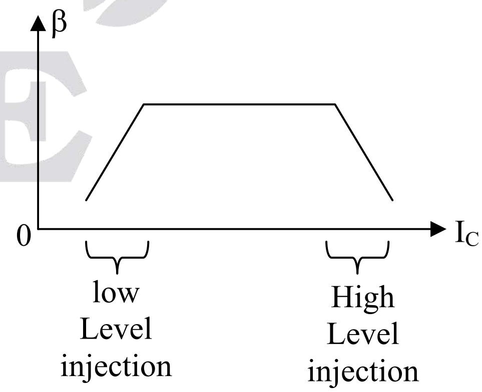
m = 1.66 for electron

m = 2.33 for hole

Beyond T > 300 K mobility of electron decreases with increase in temperature.

13. Ans: (b, c & d)

Sol: Since we know →



Also in saturation $\beta_{sat} < \beta_{F,\ active}$ is true

Also as Doping↑↑ → I_C ↑↑ → Break down voltage ↓↓

∴ Higher β → Lesser Break down voltage

∴ option (b, c & d) are true.

14. Ans: (a)

Sol: Both Statement (I) and Statement (II) are true and Statement (II) is the correct explanation of Statement (I).

At very high temperature, extrinsic semiconductors will behave as intrinsic i.e., charge carriers will remains constant.

15. Ans: (b)

Sol:

Junction		**Region of operation**
E - B	C - B	
F. B	F.B	Saturation Region
F.B	R.B	Active Region
R.B	F.B	Inverse active Region
R.B	R.B	Cut-off Region

16. Ans: (c)

Sol: High power transistors are made of Si to withstand high temperature

: Silicon is an indirect band gap material.

Chapter 6 Junction Field Effect Transistor

01. Ans: (d)

Sol: $V_G \rightarrow 4.2$ V to 4.4 V

$I_D \rightarrow 2.2$ mA to 2.6 mA

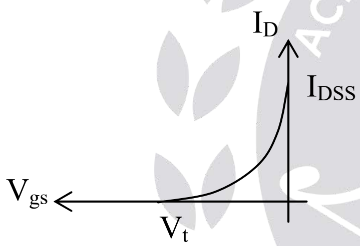
$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

$$= \frac{(2.6-2.2)\times 10^{-3}}{4.4-4.2}$$

$$= 2\ m\mho$$

02. Ans: (c)

Sol:



$V_{gs} = V_t$ $\quad$ $I_D = 0$

$V_{gs} = 0$ $\quad$ $I_D = I_{DSS}$

03. Ans: (b)

Sol: $I_{Dmax} = I_{Dss} = 10$ mA

$V_P = -4V$

$V_{GS} = -1$ V

$$I_D = I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)^2$$

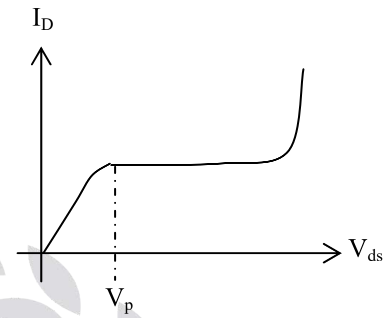
$$= 10\times 10^{-3}\left(1-\frac{-1}{-4}\right)^2$$

$$= 10\times 10^{-3}\times\left(\frac{3}{4}\right)^2$$

$$= 5.625 \text{ mA}$$

04. Ans: (d)

Sol:



Drain current remains constant at pinch off region even if the drain voltage increases.

05. Ans: (c)

Sol: JFET acts as a voltage controlled current source.

06. Ans: (a)

Sol: Mobility of electron is higher than mobility of hole

<u>Si</u>

Electron mobility : $1350\ cm^2/v-s$

Hole mobility : $450\ cm^2/v-s$

<u>Ge</u>

Electron mobility : $3600\ cm^2/v-s$

Hole mobility : $1800\ cm^2/v-s$

: Low leakage current means high input impedance

: Reverse bias increases, channel width reduces (wedge shaped).

07. Ans: (c)

Sol: $V_P = -8$ V

$I_{DSS} = 12$ mA

From the given circuit,

$V_G = -5$ V

$V_S = 0$ V

$V_{GS} = -5$ V

V_{DS} at which pinch-off region means

$(V_{DS})_{min} = V_{GS} - V_P$
$= -5 - (-8)$
$= -5 + 8$
$= 3$ V

08. Ans: (d)

Sol: P. Voltage controlled device –FET (3)

Q. Current controlled device –BJT (1)

R. Conductivity modulation device-- IMPATT diode (4)

S. Negative conductance device -UJT (2)

09. Ans: (d)

Sol: $I_{DSS} = 12$ mA

$V_P = -6$ V

$V_{GS} = 0$ V

$V_{DS} = 7$ V

At $V_{GS} = 0$V, $I_D = I_{DSS}$

$$= 12\text{mA} \quad \left(\because I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2\right)$$

10. Ans: (d)

Sol:

Device :	Application
A. Diode	Rectifier (3)
B. Transistor	Amplifier (1)
C. Tunnel diode	Oscillator (2)
D. Zener diode	Reference Voltage (4)

11. Ans: (a)

Sol: $g_{m0} = \left|\frac{2I_{DSS}}{V_p}\right| = \frac{2\times 25\times 10^{-3}}{10} = 5$

12. Ans: (b)

Sol: BJT is current controlled current source

($R_i = 0$; $R_o = \infty$)

Gain × B.W is high

FET is voltage controlled current source

($R_i = \infty$; $R_o = 0$)

Gain × B.W is low

UJT is a negative resistance device and can be used as an oscillator

UJT can be used as switch but can't be amplification.

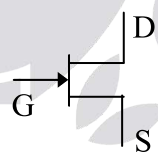
13. Ans: (a)

Sol: In FET majority carriers only exist.

In BJT majority & minority carriers exist.

14. Ans: (a)

Sol:



N - channel FET

Input resistance of FET is of the order of tens (or) hundreds of mega ohms (MΩs)

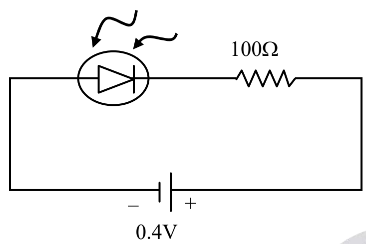
: V_{gs} is reverse bias.

: In reverse bias very small leakage current I_{CO} flows through the gate.

Chapter 7 Optoelectronic Devices

01. Ans: (a)

Sol:



By KVL,

$0.4 - 100\times 1.8\times 10^{-3} - V_P = 0$

$V_P = 0.4 - 100\times 1.8\times 10^{-3}$

$= 0.22$ V

$V_P = r_p I$

$$r_p = \frac{V_P}{I}$$

$$= \frac{0.22}{1.8\times 10^{-3}}$$

$= 122.22\ \Omega$

02. Ans: (b)

Sol: If illumination doubled then current passing through the photo diode is doubled

$I_D = 2\times 1.8 = 3.6$mA

Voltage across photo diode is

$= 0.4 - 3.6\times 10^{-3}\times 100$

$= 0.4 - 0.36$

$V_p = r_p I_p$

$$r_p = \frac{V_p}{I_p}$$

$$= \frac{0.04}{3.6}\times 10^{3}$$

$= 0.01111\times 10^{3}$

$= 11.11\Omega$

03. Ans: (b)

Sol: Avalanche photo diodes are preferred over PIN diodes in optical communication because Avalanche photo diodes are (APDs), extracted from avalanche gain and excess noise measurement and higher sensitivity. PIN diodes generate more noise.

04. Ans: (c)

Sol: Photo diode always operates in reverse bias. When no light falls on photo diode, Small amount of reverse saturation current flows through the device called "dark current".

05. Ans: (a)

Sol: Give,

$E_g = 1.12$ eV,; $\lambda_1 = 1.1\ \mu$m

$\lambda_2 = 0.87\ \mu$m; E_{g2} =?

$$E_g = \frac{12400\,A^0}{\lambda} \Rightarrow E_g \alpha \frac{1}{\lambda}$$

$$\frac{E_{g_1}}{E_{g_2}} = \frac{\lambda_2}{\lambda_1}$$

$$\Rightarrow E_{g_2} = E_{g_1}\times\frac{\lambda_1}{\lambda_2} = 1.12\times\frac{1.1}{0.87}$$

$= 1.416$ eV

06. Ans: (a)

Sol: Sensitivity of photo diode depends on light intensity and depletion region width.

07. Ans: (d)

Sol: $I_D = \dfrac{24-1.8}{820} = 0.02707$ A $= 27.07$ mA

08. Ans: (c)

Sol: Photo diode operate in R.B: Photo diode works on the principle of photo electric effect.

09. Ans: (b)

Sol: Voltage across PN junction diode resulting in current which in turn produce photons and light output. This inversion mechanism also called injection electro luminescence observed in LED's.

10. Ans: (b)

Sol: $\lambda = 890\ A^o$

$$\lambda = \frac{1.24\times10^{-6}}{E_G}\ m$$

$$= \frac{1.24\times10^{-6}}{890\times10^{-10}}$$

$= 13.93$ eV

11. Ans: (d)

Sol: Solar cell converts optical (sunlight) energy into electrical energy.

12. Ans: (b)

Sol: $R = 0.45$ A/W

$P_0 = 50\ \mu W$

$$R = \frac{I_P}{P_0}$$

$I_P = R\ P_0$

$= 0.45 \times 50$

$= 22.5\ \mu A$

Load current $= I_P + I_0$

$= 22.5\ \mu A + 1\mu A$

$= 23.5\ \mu A$

13. Ans: (d)

Sol: LED: F.B

Photo diode: R.B

Zener diode: R.B

Ordinary diode: F.B

Tunnel diode: F.B

Variable capacitance diode: R.B

Avalanche diode: R.B

14. Ans: (c)

Sol: Tunnel diode is always operated in forward bias and light operated devices are operated in reverse bias. (Avalanche photo diode).

15. Ans: (b)

Sol: LED's and LASER's are used in forward bias.

Photo diodes are used in reverse bias.

Chapter 8 MOSFET

01. Ans: (c)

Sol: $V_T = 1$

$V_{DS} = 5 - 1 = 4$ V

$V_{GS} = 3 - 1 = 2$ V

$V_{GS} - V_T = 2 - 1 = 1$ V

$V_{DS} > V_{GS} - V_T$

$4 > 1 \rightarrow$ Saturation

02. Ans: (d)

Sol: In active region (or) saturation region, channel is pinched off. Number of carriers present in the channel decreases from source end to drain end due to potential increases from source to drain.

03. Ans: (d)

Sol: $$\frac{I_{D_2}}{I_{D_1}} = \frac{K_n[V_{GS2} - V_T]^2}{K_n[V_{GS1} - V_T]^2}$$

$$\frac{I_{D_2}}{1\,mA} = \frac{[1400-400]^2}{[900-400]^2}$$

$$I_{D_2} = 4\,mA$$

04. Ans: (d)

Sol: $A = 1$ sq $\mu m = 10^{-12}$ m^2

$d = 1\ \mu m = 1 \times 10^{-6}$ m

$N_D = 10^{19}/cm^3$

$n_i = 10^{10}$

No. of holes = concentration × volume

Volume = A × d = 10^{-18} m

$$p = \frac{n_i^2}{n} = \frac{10^{20}}{10^{19}}$$

$$= 10\,holes/cm^3 = 10 \times 10^6\,holes/m^3$$

$\therefore$ No. of holes = $10 \times 10^6 \times 10^{-18}$

= 10^{-11} holes

≈ 0

05. Ans: (b)

Sol: 1) since it has n-type source & drain, it is n-channel MOSFET.

2) Drain current flows only when $V_{GS} > 2V$, it implies it has threshold voltage (V_{th}) of +2V

$\Rightarrow$ It is enhancement type MOSFET.

3) $V_{Th} = +2V$

4) $g_m = \mu_n C_{ox} \frac{W}{L}[V_{GS} - V_{Th}]$,

transconductance depends upon electron mobility.

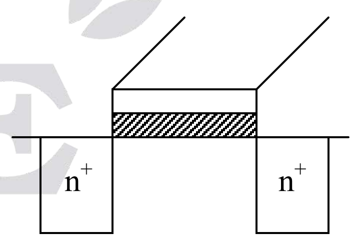
06. Ans: (b)

Sol: $$C_{sbo} = \frac{\epsilon_{si} A}{d}$$

d = 10 nm

$\epsilon_{si} = \epsilon_{rsi}\ \epsilon_0$

$= 11.7 \times 8.9 \times 10^{-12}$ F/m



$A = (0.2\mu \times 1\mu) + (0.2\mu \times 1\mu) + (0.2\mu \times 1\mu)$

$= 3(0.2\mu \times 1\mu) = 0.6 \times 10^{-12}$ m^2

$$C_{sbo} = \frac{11.7 \times 8.9 \times 10^{-12} \times 0.6 \times 10^{-12}}{10 \times 10^{-9}}$$

$C_{sbo} = 6.24 \times 10^{-15}$

≈ 7 fF

In practical IC, this cap will provided to front and back sides also then area may be

$A = (0.6\times10^{-12}) + (0.2\mu\times1\mu) + (0.2\mu\times1\mu)$

$A = 0.68 \times 10^{-12}\ m^2$

$$C_{sbo} = \frac{11.7\times8.9\times10^{-12}\times0.68\times10^{-12}}{10\times10^{-9}} = 7fF$$

07. Ans: (a)

Sol: $L_{ov} = \delta = 20$ m

$d = 10$ nm, $w = 1$ µm

$\in_{rsi} = 11.7$, $\in_{rox} = 3.9$

$\in_0 = 8.9 \times 10^{-12}$ F/m

$$C_{ov} = C_{ox}\, w\, L_{ov} = \frac{\in_{ox}}{t_{ox}} w L_{ov}$$

$$= \frac{\in_{rox}\in_0}{t_{ox}} w L_{ov}$$

$$= \frac{3.9\times8.9\times10^{-12}\times1\times10^{-6}\times20\times10^{-9}}{1\times10^{-9}}$$

$= 0.69 \times 10^{-15} = 0.69$ fF ≈ 0.7 fF

08. Ans: (a)

Sol: $A = 1 \times 10^{-4}$ cm^2

$\in_{si} = 1 \times 10^{-12}$ F/cm

$\in_{ox} = 3.5 \times 10^{-13}$ F/cm

$C_0 = 7$ pF

$$C_0 = C_{ox}\,A = \frac{\in_{ox} A}{t_{ox}}$$

$$t_{ox} = \frac{\in_{ox}}{C_0} A = \frac{3.5\times10^{-13}\times1\times10^{-4}}{7\times10^{-12}}$$

$= 5\times10^{-6}$ cm $= 50$ nm

09. Ans: (b)

Sol: $$\frac{C_0C_d}{C_0+C_d} = 1pF$$

$$\frac{7C_d}{C_d+7} = 1 \Rightarrow C_d = \frac{7}{6}pF$$

$$C_d = C_{dep}\,A = \frac{\in_{si}}{d}A$$

$$d = \frac{\in_{si}}{C_d}A$$

$$= \frac{1\times10^{-12}}{\frac{7}{6}\times10^{-12}}(1\times10^{-4})\,cm = 0.857\,\mu m$$

10. Ans: (b)

Sol: $V_{Th} = 0.5V$

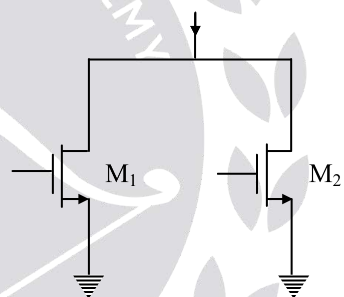
$V_G = 3V$

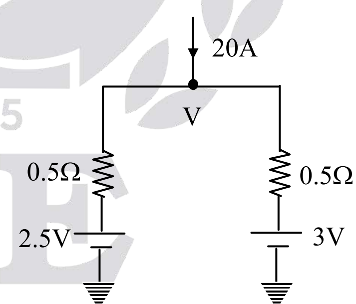
Pinch-off occurs when

$V_D = V_G - V_{Th} = 3 - 0.5 = 2.5V$

11. Ans: (a)

Sol:





$$20 = \frac{V-2.5}{0.5} + \frac{V-3}{0.5}$$

V = 7.75 Volts

$$I_{D_1} = \frac{7.75-2.5}{0.5} = 10.5A$$

$$I_{D_2} = \frac{7.75-3}{0.5} = 9.5\,A$$

12. Ans: (a & c)

Sol: $X_{dmax} = \sqrt{\dfrac{2\in_s \phi_t}{qN_A}} = \sqrt{\dfrac{4\in_s \phi_F}{qN_A}}$

$$\phi_F = V_t \ln\left(\frac{N_A}{n_i}\right) = 0.026 \ln\left(\frac{10^{15}}{1.5\times10^{10}}\right)$$

$= 0.29V$

$$X_{d\,max} = \sqrt{\frac{4\times11.7\times8.854\times10^{-14}\times0.29}{0.6\times10^{-19}\times10^{15}}}$$

$= 8.67\times10^{-5}$ cm$= 8.67\times10^{-7}$m $= 0.867\mu$m

$|Q_{dinv}| = qN_A X_{dmax}$

$= 1.6\times10^{-19}\times10^{15}\times0.867\times10^{-5}$

$= 1.39$ nc/cm^2

$$C_{ox} = \frac{\in_{ox}}{t_{ox}} = \frac{3.9\times8.854\times10^{-14}}{10\times10^{-7}}$$

$= 3.45\times10^{-7}$ F/cm^2 $= 0.345$ µF/cm^2

$$V_T = \frac{|Q_{dinv}|}{C_{ox}} + Q_t = \frac{|Q_{dinv}|}{C_{ox}} + 2\phi_F$$

$$= \frac{1.39\times10^{-9}}{0.345\times10^{-6}} + 2\times0.29$$

$= 0.58V$

13. Ans: (a, c & d)

Sol: $V_{TH} = \dfrac{\sqrt{2qN_A \in_s (2\phi_B)}}{C_{ox}} + 2\phi_B + V_{BF}$,

$$C_{ox} = \frac{\in_{ox}}{t_{ox}}$$

As V_{TH} is proportional to channel dopant concentration and gate-oxide thickness.

$\therefore$ V_{TH} can be increased by increasing channel dopant concentration & gate-oxide thickness and also V_{TH} can be increased by increasing channel length.

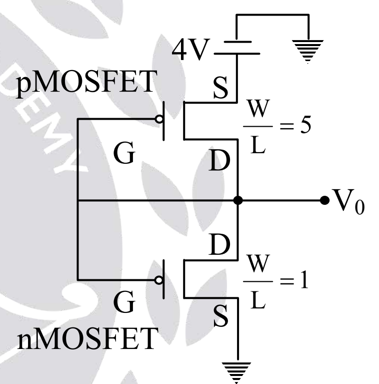
14. Ans: (a)

Sol: Given C-V characteristics of MOS capacitor with p-type substrate for high frequencies.
Point-P possible in accumulation mode
Point-Q possible in flat band mode
Point-R possible in inversion mode
So, option (a) is correct.

15. Ans: (c)

Sol: Since G and D are shorted both NMOS and PMOS are in saturation

$$I_{D_n} = I_{D_p}$$



$$\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_n (V_{GSn} - V_{Th})^2 = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_p (V_{GSp} - |V$$

$300 \times 1 \times (V_0 - 1)^2 = 40 \times 5 \times (4 - V_0 - 1)^2$

$3(V_0 - 1)^2 = 2(3 - V_0)^2$

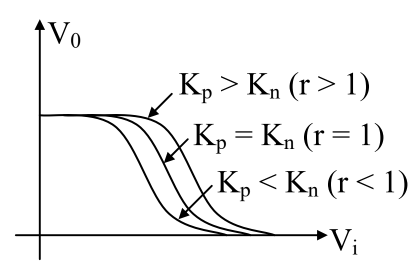
$1.22(V_0 - 1) = (3 - V_0)$

$1.22V_0 - 1.22 = 3 - V_0$

$2.22V_0 = 4.22$

$\Rightarrow V_0 = 1.9V$

Alternate Method:



If $K_p = K_n$, then $V_0 = \frac{V_{DD}}{2}$

From the given information, compare K_p and K_n

$\mu_p C_{ox}\left(\frac{W}{L}\right)_p$ $\qquad$ $\mu_n C_{ox}\left(\frac{W}{L}\right)_n$

$40 \times C_{ox} \times 5$ $\qquad$ $300 \times C_{ox} \times 1$

$\Rightarrow K_p < K_n$

From the above graph it is very clear that for $K_p < K_n$

$V_0 < \frac{V_{DD}}{2}$

$\Rightarrow V_0 < 2V$

16. Ans: 5.6

Sol: Since we know in inversion region,

$Q_{in} = C_{ox}(V_G - V_T)$

Inversion charge density

$\Rightarrow$ From this we can find V_T

as given $Q_{in} = 2.2\mu C/cm^2$

$C_{ox} = 1.7\ \mu F/cm^2$

$V_G = 2V$

$\Rightarrow V_T = V_G - \frac{Q_{in}}{C_{ox}}$

$\Rightarrow V_T = 2 - \frac{2.2}{1.7} = 0.706\text{Volt}$

Now Q_{in} at $V_G = 4V$

$Q_{in} = 1.7\ \mu F/cm^2\ [4 - 0.706]$

$Q_{in} = 5.6\ \mu C/cm^2$

17. Ans: (b)

Sol: Beyond V_T ($V > V_T$), almost where is no expansion of the depletion region. The necessary negative charge at the interface or surface is provided by electrons.

At $V = V_T$, the width of the depletion region reaches a maximum value, $x_d = x_{dmax}$.

18. Ans: 25.5

Sol: $I_{D,sat} = \frac{1}{2}\mu_n C_{ox} \times \frac{W}{L}(V_{GS} - V_{TH})^2$

$= \frac{1}{2} \times 800 \times 3.45 \times 10^{-7} \times \frac{10}{1} \times (5 - 0.7)^2$

$= 25.5\text{mA}$

19. Ans: 0.231

Sol: $1 - e^{-\alpha x} = 0.5$

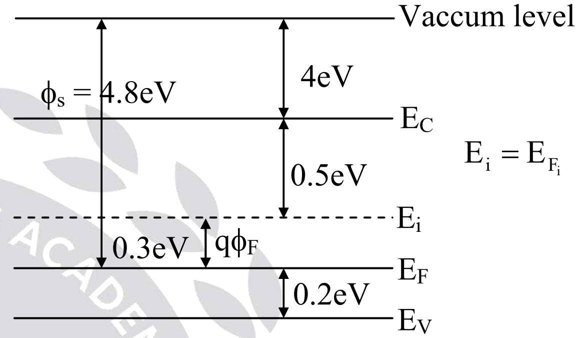
$e^{-\alpha x} = 0.5$

$x = \frac{-\ln(0.5)}{\alpha} = \frac{-\ln(0.5)}{3 \times 10^4}\text{cm}$

$= 0.231\mu m$

20. Ans: (b)

Sol:



$\phi_s = 4eV + 0.5eV + 0.3eV = 4.8eV$

$V_{TH} = -0.16V$, $C_{ox} = 100nF/cm^2$

$\phi_m = 3.87eV$

$V_T - V_{FB} = \frac{|Q_{dinv}|}{C_{ox}} + \phi_t$

$V_{FB} = \phi_{ms}$ ($\because$ No oxide charge)

$V_{FB} = \phi_{ms} = \phi_m - \phi_s = 3.87 - 4.8 = -0.93$

$\phi_t = 2\phi_F$, $\phi_F = 0.3V$

$\phi_t = 2 \times 0.3 = 0.6V$

$-0.16 - (-0.93) = \frac{|Q_{dinv}|}{100n} + 0.6$

$|Q_{dinv}| = 0.17 \times 100 \times 10^{-9} = 17 \times 10^{-9}$

$= 1.7 \times 10^{-8}C/cm^2$

21. Ans: (b)

Sol: $t_{ox} = 10nm, \frac{\partial V_T}{\partial |V_{BS}|} = 50mV/V$

$|V_{BS}| = 2V$, $|V_{BS}|\ 2_{\phi B}$

$V_T = V_{TO} + \gamma\left[\sqrt{|V_{BS}| + 2\phi_B} - \sqrt{2\phi_B}\right]$

$V_{TO} = V_T\big|_{|VBS|} = 0$

$\gamma = \frac{\sqrt{2qN_A\varepsilon_s}}{C_{ox}}$ – body effect parameter

Since $|V_{BS}| >> 2\phi_B$

$$V_T \approx V_{TO} + \gamma\sqrt{|V_{BS}|}$$

$$\frac{\partial V_T}{\partial |V_{BS}|} = \gamma \frac{1}{2\sqrt{|V_{BS}|}}$$

$$50\times10^{-3} = \gamma\frac{1}{2\sqrt{2}}$$

$$\gamma = 2\sqrt{2}\times50\times10^{-3} = 141.42\times10^{-3}\sqrt{V}$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{4\times8.85\times10^{-14}}{10\times10^{-7}}$$

$$= 3.54\times10^{-7}\,F/cm^2$$

$$\gamma = \frac{\sqrt{2qN_A\varepsilon_S}}{C_{ox}} \Rightarrow N_A = \frac{\gamma^2C_{ox}^2}{2q\varepsilon_S}$$

$$N_A = \frac{(141.42\times10^{-3})^2\times(3.54\times10^{-7})^2}{2\times1.6\times10^{-19}\times12\times8.85\times10^{-14}}$$

$$= 7.37\times10^{15}/cm^3$$

22. Ans: 4.32 (Range: 4.10 to 1.50)

Sol: Given t_{ox} = 100nm

$Q'_{ox} = 10^{-8}\,C/cm^2$

N-MOS, [P-substrate]

Metal Work function

$\rightarrow q\phi_m = 4.6eV$

$(\varepsilon_r)_{Sio2} = 4$

$(\varepsilon_0) = 8.85\times10^{-14}$F/cm

Given V_{FB} = 0V

Need to find $q\phi_{Si}$ = _____?

As $V_{FB} = \phi_{ms} - \frac{Q'_{ox}}{C_{ox'}}$

$$\Rightarrow 0 = \phi_m - \phi_s - \frac{Q'_{ox}}{C_{ox'}}$$

$$\Rightarrow \phi_s = \phi_m - \frac{Q'_{ox}}{C_{ox'}} = 4.6 - \frac{10^{-8}}{\frac{\varepsilon_{ox}}{t_{ox}}}$$

$\therefore q\phi_s \cong 4.32eV$

Chapter 9 Biasing

JFET Biasing

01. Ans: (c)

Sol: $R_D = \frac{V_{DD} - V_D}{I_D} = \frac{20V - 12V}{2.5mA} = 3.2\,K\Omega$

In self bias

$V_{GS} = -I_D R_S$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$$

$$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right)$$

$V_{GS} = -1.06$ V

$$R_S = \frac{V_{GS}}{-I_D} = \frac{-1}{-2.5} = 400\,\Omega$$

02. Ans: (b)

Sol: $V_G = V_{GS} + I_D R_S$

$$I_D = \frac{16-8}{1.8\,K} = 4.4\,mA$$

$$V_G = \frac{16 \times 47}{138} = 5.45\,V$$

$$R_S = \frac{V_G - V_{GS}}{I_D} = \frac{5.4-(-2V)}{4.4\,m} = 1.68K\Omega$$

03. Ans: (c)

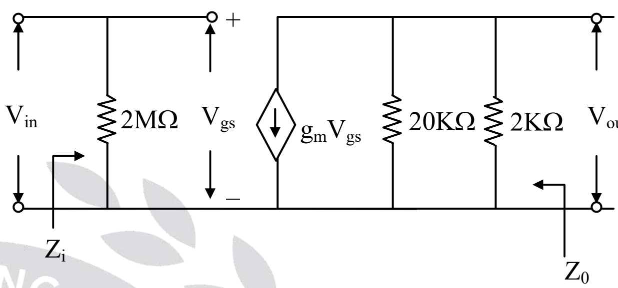
Sol: $V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 30\text{ V} - 4\text{ mA}(3.3K + 1.5K)$

$V_{DS} = 10.8$ V

04. Ans: (b)

Sol: AC analysis,



$Z_i = 2M\Omega,\quad Z_0 = 20K\Omega \,||\, 2K\Omega$

$$\Rightarrow Z_0 = \frac{20}{11}K\Omega$$

05. Ans: (a)

Sol: $$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_p}\right]^2$$

$$= 10 \times 10^{-3}\left[1 - \frac{-2}{-8}\right]^2 = 5.625mA$$

KVL at output loop,

$-20 + (2 \times 10^3 I_D) + V_{DS} = 0$

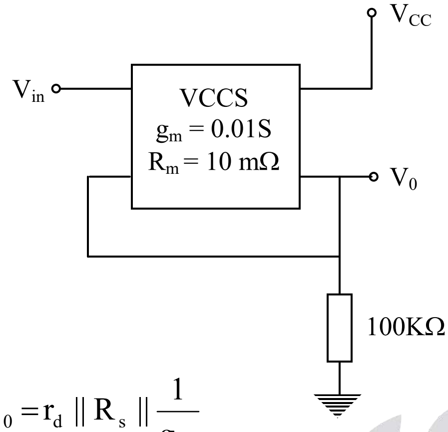
$V_{DS} = 20 - (2 \times 10^3 \times 5.625 \times 10^{-3})$

$= 8.75V$

06. Ans: (b)

Sol: By observing,

The circuit is common drain i.e., source follower circuit.



$$R_0 = r_d \parallel R_s \parallel \frac{1}{g_m}$$

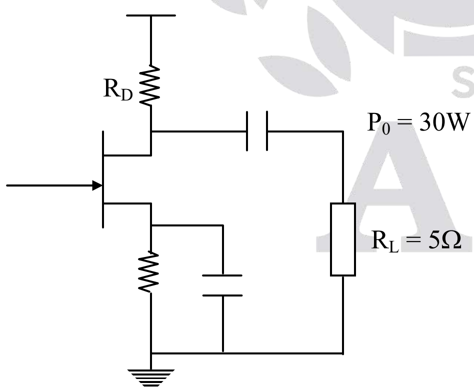
$$= 10\ M\Omega \parallel 100\ K\Omega \parallel 100\ \Omega$$

$$= 100\ \Omega$$

FREQUENCY ANALYSIS

01. Ans: (d)

Sol:



$$P_0 = \frac{V_0^2}{R_L}$$

$$30 \times 5 = V_0^2$$

$$V_0 = 12.25\ V$$

$$A_V = \frac{V_0}{V_i}$$

$$A_{v\,(dB)} = 20\log_{10} A_v$$

$$20 = 20\log_{10} A_v$$

$$A_v = 10^1 = 10$$

$$\frac{V_0}{V_i} = 10$$

$$V_i = \frac{V_0}{10} = \frac{12.25}{10}V = 1.225\,V$$

02. Ans: (b)

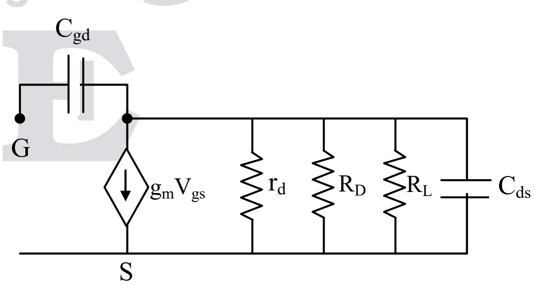
Sol: $A_{v(dB)} = 20\log_{10} A_v$

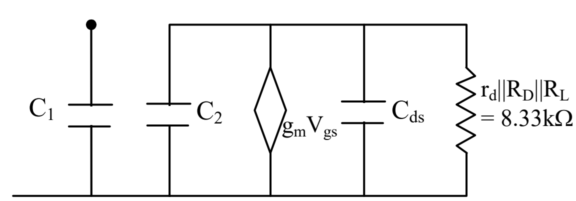
$$50 = 20\log_{10} A_v$$

$$A_v = 10^{(5/2)} = 316.228$$

03. Ans: 6.123×10^6 Hz

Sol: Small signal equivalent

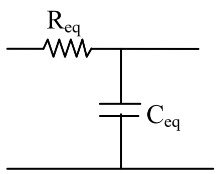




$$C_2 = C_{gd}\left(1 - \frac{1}{A_v}\right),$$

A_v = mid-band,

gain = $g_m(r_d||R_D||R_L) = -16.66$



$$C_2 = 2pF\left(1 - \frac{1}{-16.66}\right) = 2.12\ pF$$

$$f_H = \frac{1}{2\pi C_{eq} R_{eq}}$$

$C_{eq} = 1 + 2.12 = 3.12$ pF, $R_{eq} = 8.33k\Omega$

$\Rightarrow f_H = 6.123 \times 10^6$ Hz

MOSFET BIASING

01. Ans: (b)

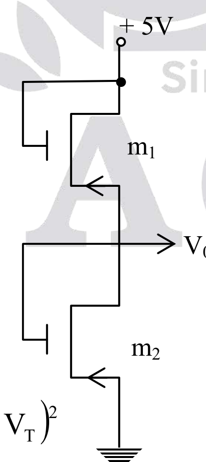
Sol: $V_T = 0.8$

$K_n = 30 \times 10^{-6}$

$$\left(\frac{W_1}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 40$$

$V_{D_1} = +5$

$I_{D_1} = I_{D_2}$



$$\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS_1} - V_T)^2$$

$$= \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2 (V_{GS_2} - V_T)^2$$

$$V_{GS_1} = V_{D_1} - V_0$$

$$= +5 - V_0$$

$$V_{GS_2} = V_{G_1} - V_S$$

$$= V_0 - 0 = V_0$$

$$\left(\frac{W}{L}\right)_1 (5 - (V_0) - 0.8)^2 = \left(\frac{W}{L}\right)_2 (V_0 - 0.8)^2$$

$V_0 = 2.5V$

02. Ans: (a)

Sol: $\left(\frac{W}{L}\right)_1 (V_{GS_1} - V_T)^2 = \left(\frac{W}{L}\right)_2 (V_{GS_2} - V_T)^2$

$40\ (4.2 - V_0)^2 = 15(V_0 - 0.8)^2$

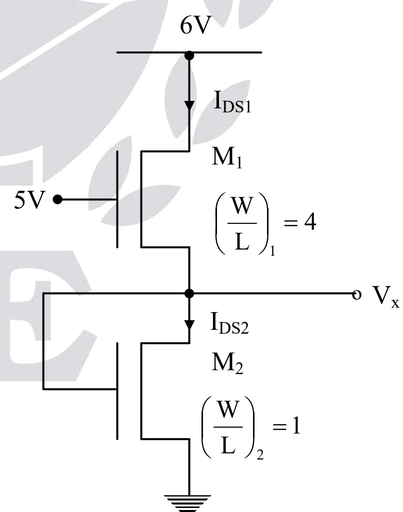
$V_0 = 2.91$ V

03. Ans: (c)

Sol: From figure $I_{DS1} = I_{DS2}$.

$$\frac{1}{2}\mu_n C_{0x}\left(\frac{W}{L}\right)_1 (V_{GS_1} - V_t)^2$$

$$= \frac{1}{2}\mu_n C_{0x}\left(\frac{W}{L}\right)_2 (V_{GS_2} - V_t)^2$$



$$\therefore\ 4(5 - V_x - V_t)^2 = 1(V_x - V_t)^2$$

$$(\because V_{GS1} = V_G - V_x = 5 - V_x)$$

$$\Rightarrow 2(5 - V_x - V_t) = (V_x - V_t)$$

$$\therefore\ V_x = 3V$$

04. Ans: (d)

Sol: $\frac{V_2}{V_i} = \frac{g_m R_s}{1 + g_m R_s}$ ----- (1)

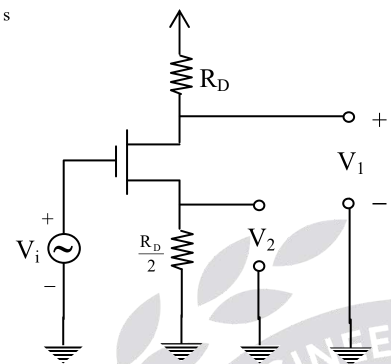
$\frac{V_1}{V_i} = \frac{-g_m R_D}{1 + g_m R_s}$ ----- (2)

(1) ÷ (2) ⇒

$\frac{V_2}{V_1} = \frac{R_s}{-R_D}$

$\frac{V_2}{V_1} = \frac{-1}{2}$

$V_1 = -2V_2$



Chapter 10 CMOS & Device Technology

01. Ans: (c)

Sol: $\overline{A(B+C)+DE}$

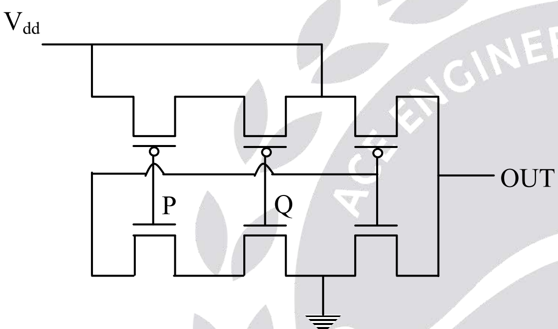
After option (c) as above answer.

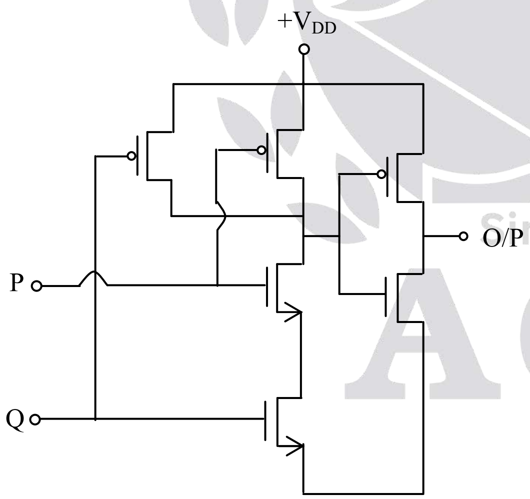
02. Ans: (a)

Sol: $\overline{\bar{x}_1 + x_2}$

03. Ans: (d)

Sol:





AND gate

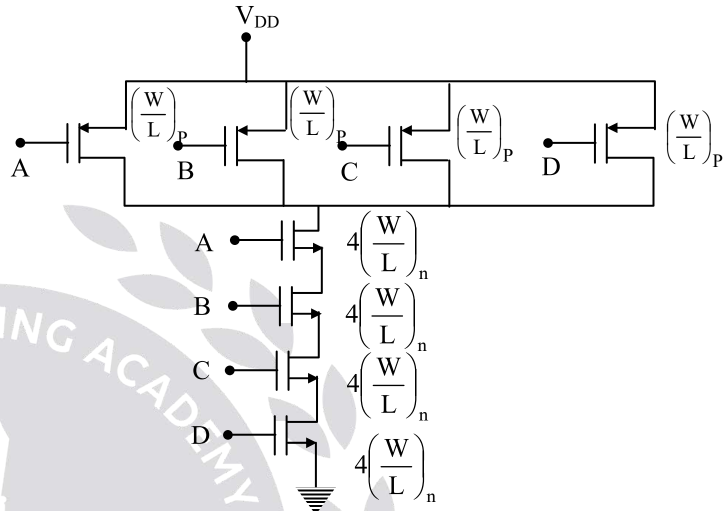
04. Ans: (b)

Sol: $n = \dfrac{1}{2Nf}$

$$n = \frac{1}{2\times5\times10\times10^{6}} = 10^{-8}\ \text{sec} = 10\,\text{n sec}$$

05. Ans: (a, b & c)

Sol:



For basic inverter $W_N = 2\mu m$, to get symmetrical voltage transfer characteristics

$$\frac{W_P}{W_n} = \frac{\mu_n}{\mu_p} = 3$$

$W_P = 3W_n = 6\mu m$

* Width of NMOS in NAND gate $= 4W_n$
  $= 8\mu m$

* Width of PMOS in NAND gate $= W_P$
  $= 6\mu m$

Device Technology Key

01. (c)	02. (b)	03. (d)
04. (b)	05. (a)	