CLASS TEST

Sl.:01SK_EC_ABCDEFG_10624

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ELECTRONIC DEVICES

ELECTRONICS ENGINEERING

Date of Test : 10/06/2024

ANSWER KEY

1. (a)
2. (c)
3. (b)
4. (c)
5. (a)
6. (a)
7. (c)
8. (c)
9. (a)
10. (b)
11. (b)
12. (b)
13. (a)
14. (a)
15. (c)
16. (b)
17. (b)
18. (b)
19. (b)
20. (d)
21. (a)
22. (b)
23. (c)
24. (c)
25. (c)
26. (b)
27. (b)
28. (a)
29. (a)
30. (c)

DETAILED EXPLANATIONS

1. **(a)**

Zener breakdown voltage is less because in higher doping region, depletion layer width is small and a small reverse voltage is able to break the covalent bond and gives sudden increase in current.

Hence, zener breakdown voltage V_1 corresponds to point A.

2. **(c)**

We know that,

Collector current, $I_C = \beta I_B + (1+\beta) I_{CO}$

$$I_C = \beta I_B + \beta I_{CO} + I_{CO}$$

$$\therefore \quad \beta = \frac{I_C - I_{CO}}{I_B + I_{CO}}$$

but,
$$\alpha = \frac{\beta}{1+\beta} = \frac{\dfrac{I_C - I_{CO}}{I_B + I_{CO}}}{1 + \dfrac{I_C - I_{CO}}{I_B + I_{CO}}} = \frac{I_C - I_{CO}}{I_B + I_{CO} + I_C - I_{CO}}$$

$$\therefore \quad \alpha = \frac{I_C - I_{CO}}{I_C + I_B}$$

3. **(b)**

Given, Oxide thickness $(t_{ox}) = 50$ nm

Capacitance per unit area,
$$C = \frac{\epsilon_{ox}}{t_{ox}} = \frac{3.45 \times 10^{-11}}{50 \times 10^{-9}}\ \text{F/m}^2 = 6.9 \times 10^{-4}\ \text{F/m}^2$$

$$\therefore \quad C = 69\ \text{nF/cm}^2$$

4. **(c)**

Given, Collector current, $I_C = 1$ mA

Since, $I_C = 1\ \text{mA} > 0 \Rightarrow$ BJT not in cut-off region.

Emitter current $I_E = 1.2$ mA

But $I_E = I_B + I_C$

$\Rightarrow$ $I_B = I_E - I_C = 0.2$ mA

$$\beta = \frac{I_C}{I_B} = \frac{1\ \text{mA}}{0.2\ \text{mA}} = 5 < \beta_{\min}$$

$\therefore$ BJT is in saturation region.

5. **(a)**

The conductors have the positive temperature coefficient of resistance. The conductors have almost linear increase in resistivity.

6. **(a)**

In a forward biased pn-junction diode, the current flow is due to diffusion of majority carriers and recombination of minority carriers.

7. (c)

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T \quad \text{(Eienstein's equation)}$$

$$\Rightarrow \quad \frac{48}{\mu_n} = \frac{12}{\mu_p}$$

$$\Rightarrow \quad 4 = \frac{\mu_n}{\mu_p}$$

$$\mu_p + \mu_n = 100 \qquad \text{(given)}$$

$$5\mu_p = 100$$

$$\mu_p = 20$$

$$\mu_n = 80 \text{ cm}^2/\text{V-sec}$$

8. (c)

Given, resistivity, $\rho = 1.5\ \Omega\text{-cm}$

Hall coefficient, $R_H = -1250 \text{ cm}^3/\text{C}$

Since, R_H is negative, the charge carriers are electrons.

Mobility, $\mu_e \approx \sigma |R_H|$

$$= \frac{1}{\rho}|R_H| = \frac{1}{1.5}\times 1250$$

$$\therefore \quad = 833 \text{ cm}^2/\text{V-sec}$$

9. (a)

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

γ = emitter injection efficiency, $\gamma = \frac{98}{100} = 0.98$

β^* = base transport factor, $\beta^* = \frac{99-1.98}{99} = 1 - \frac{2}{100} = 0.98$

α = common base current gain = $\gamma\beta^*$ = 0.98 × 0.98 = 0.9604

10. (b)

$$\lambda \le \frac{1.24}{E_g(\text{in eV})}\,\mu\text{m}$$

$$\lambda_{(\max)} = \frac{1.24}{2.5}\,\mu\text{m} = 0.496\,\mu\text{m} = 4960\ \text{Å}$$

11. (b)

Given, MOSFET is operated in saturation region and channel length modulation is present,

$\therefore$ Drain current, $$I_D = \mu_n C_{ox}\frac{W}{2L}(V_{GS}-V_T)^2\,[1+\lambda V_{DS}] \qquad \text{...(i)}$$

Drain to source conductance,

$$g_{ds} = \frac{\partial I_D}{\partial V_{DS}} = \mu_n C_{ox}\frac{W}{2L}(V_{GS}-V_T)^2\,(\lambda) \qquad \text{...(ii)}$$

From equation (i), we can write,

$$\frac{I_D}{1+\lambda V_{DS}} = \mu_n C_{ox}\frac{W}{2L}(V_{GS}-V_T)^2$$

We can re-write equation (ii) as,

$$g_{ds} = \frac{I_D}{1+\lambda V_{DS}}\cdot\lambda$$

or,
$$g_{ds} = \frac{I_D}{\frac{1}{\lambda}+V_{DS}}$$

12. **(b)**

The current,
$$I_D = \frac{5\text{ V}-1.6\text{ V}}{R}$$

$$I_D = \frac{3.4\text{ V}}{R} \qquad \text{...(i)}$$

But it is given, to produce 1 mcd, $I_{D\,(\min)} = 4\text{ mA}$

So,
$$\frac{3.4\text{ V}}{R} \geq 4\text{ mA}$$

$$R \leq \frac{3.4}{4}\text{ k}\Omega = 850\ \Omega$$

$$R_{(\max)} = 850\ \Omega$$

13. (a)

$$P_n = P_{n0}\,e^{0.5/V_t}$$

$$P_{n0} = \frac{n_i^2}{n_{n0}} = \frac{10^{20}}{5\times10^{15}} = 2\times10^4\text{ cm}^{-3}$$

$$P_n = 2\times10^4\,e^{20} \approx 10\times10^{12}\text{ cm}^{-3}$$

14. **(a)**

The Fermi potential,
$$\phi_{fp} = \frac{kT}{q}\ln\left[\frac{N_a}{n_i}\right]$$

$$\phi_{fp} = 0.026\ln\left[\frac{10^{16}}{1.5\times10^{10}}\right]$$

$$\phi_{fp} = 0.35\text{ V}$$

The maximum space charge width

$$x_{d\,(\max)} = \left[\frac{4\varepsilon_{si}\phi_{fp}}{eN_a}\right]^{1/2} = \left[\frac{4\times1.04\times10^{-12}\times0.35}{1.6\times10^{-19}\times10^{16}}\right]^{1/2}\text{ cm}$$

$$= 3.02\times10^{-5}\text{ cm}$$

$$x_{d\,(\max)} = 0.302\ \mu\text{m}$$

15. **(c)**

Given current equation of a *PN* junction diode is,

$$I(T) = I_s(T_0)\exp[0.057(T - T_0)]\ ;\ T_0 = 300\text{ K}$$

$$I(T) = I_s(300)\exp[0.057(T - 300)] \qquad \text{...(i)}$$

At $T = 300$ K,

$$I(300) = I_s(300)\exp[0.057(300 - 300)]$$

$$\therefore \qquad I(300) = I_s(300) \qquad \text{...(ii)}$$

It is given that, at a temperature (assume T_1) the current is twice its value at $T = 300$ K.

The new current at T_1 is

$$I(T_1) = 2I(300) \qquad \text{...(iii)}$$

But, $$I(T_1) = I_s(300)\exp[0.057(T_1 - 300)] \qquad \text{...(iv)}$$

Substitute equation (iii) in equation (iv),

$$2I(300) = I_s(300)\exp[0.057(T_1 - 300)]$$

From equation (ii),

$$I(300) = I_s(300)$$

$$2I_s(300) = I_s(300)\exp[0.057(T_1 - 300)]$$

$$2 = \exp[0.057(T_1 - 300)]$$

$$ln\,2 = 0.057(T_1 - 300)$$

$$\therefore \qquad T_1 = 312.16\text{ K}$$

$$T_1 = 313\text{ K}$$

16. **(b)**

Given that,

Reverse saturation current density, $J_s = 3.6 \times 10^{-11}$ A/cm^2

Photo current density, $J_L = 15$ mA/cm^2

The open-circuit voltage of a solar cell is,

$$V_{OC} = V_t \ln\left[1 + \frac{J_L}{J_s}\right] = 0.026\ln\left[1 + \frac{15\times10^{-3}}{3.6\times10^{-11}}\right]$$

$$V_{OC} = 0.516\text{ V}$$

17. **(b)**

Diffusion potential (or) built in potential,

$$V_{bi} = \text{Area under the electric field distribution curve}$$

$$= \text{Area under given curve (which resembles triangle)}$$

$$V_{bi} = \frac{1}{2}\times\text{Base}\times\text{height} = \frac{1}{2}\times(W_P + W_N)\times(-E)$$

magnitude of diffusion potential

$$|V_{bi}| = \left|\frac{1}{2}\times(W_P + W_N)\times(-E)\right|$$

$$= \frac{1}{2}\times 4\ \mu\text{m}\times 15\times10^4\ \text{V/m}$$

$$|V_{bi}| = 0.3\text{ V}$$

18. **(b)**

As drain is connected to gate for both MOSFETs, they will be in saturation mode of operation.

i.e.,
$$I_{D1} = I_{D2}$$
$$K_1(V_{GS1} - V_T)^2 = K_2(V_{GS2} - V_T)^2$$

Since, $K \propto W$; $K_2 = 2K_1$
$$K_1(V_{GS1} - V_T)^2 = 2K_1(V_{GS2} - V_T)^2$$

But
$$V_{GS1} = 5 - V_0$$
$$V_{GS2} = V_0$$
$$(5 - V_0 - 1.5)^2 = 2(V_0 - 1.5)^2$$
$$3.5 - V_0 = \sqrt{2}(V_0 - 1.5)$$
$$3.5 - V_0 = \sqrt{2}\,V_0 - 2.12$$
$$2.414\,V_0 = 5.62$$
$$V_0 = 2.33\text{ V}$$

19. **(b)**

$$C_T \propto \frac{1}{\sqrt{V_{bi} + V_{RB}}}$$
$$\frac{C_{T1}}{C_{T2}} = \frac{\sqrt{V_{bi} + V_{RB2}}}{\sqrt{V_{bi} + V_{RB1}}}$$

at $V_{RB1} = 0$ V, $C_{T1} = 1$ μF.

at $V_{RB2} = -6$ V, $C_{T2} = 0.5$ μF.

$$\frac{C_{T1}}{C_{T2}} = \frac{\sqrt{V_{bi} + V_{RB2}}}{\sqrt{V_{bi} + V_{RB1}}}$$
$$\frac{1}{0.5} = \sqrt{\frac{-6 + V_{bi}}{V_{bi}}}$$
$$\therefore \quad V_{bi} = -2\text{ V}$$

20. **(d)**

We know that,

Diode voltage V_D decreases by 2.5 mV per 1°C rise in temperature.

Given, temperature, $T_1 = 20°\text{C}$
$$\frac{\Delta V_D}{\Delta T} = -2.5\text{ mV/°C}$$
$$\frac{V_{D2} - V_{D1}}{(T_2 - 20)} = -2.5 \times 10^{-3}$$
$$\therefore \quad \frac{(600 - 700) \times 10^{-3}}{-2.5 \times 10^{-3}} = T_2 - 20$$
$$\therefore \quad T_2 = 60°\text{C}$$

21. **(a)**

We know that,

Potential function, $$\phi_s = V_T \ln\left(\frac{n_0}{n_i}\right)$$

or, $$\phi_s = V_T \ln\left[\frac{N_D}{n_i}\right]$$

Let potential at 1 μm distance is ϕ_{s1},

$$\therefore \quad \phi_{s1} = V_T \ln\left[\frac{N_{D2}}{n_i}\right] \quad \text{...(i)}$$

$$\phi_{s1} = V_T \ln\left[\frac{10^{16}}{n_i}\right]$$

Let potential at 2 μm distance is ϕ_{s2},

$$\therefore \quad \phi_{s2} = V_T \ln\left[\frac{N_{D1}}{n_i}\right] \quad \text{...(ii)}$$

It is given magnitude of potential difference,

i.e., $$|\phi_{s1} - \phi_{s2}| = 0.12 \text{ V}$$

$$V_T \ln\left[\frac{N_{D2}}{N_{D1}}\right] = 0.12 \text{ V}$$

$$\therefore \quad \frac{N_{D2}}{N_{D1}} = e^{\frac{0.12}{0.026}}$$

$$\Rightarrow \quad N_{D1} = 9.89 \times 10^{13} \text{ cm}^{-3}$$

22. **(b)**

Since two MOSFETs are operated in saturation mode,

$$I_{DN} = \mu_n C_{ox} \frac{W_n}{2L}(V_{GSN} - V_{TN})^2$$

or, $$I_{DN} = \mu_n C_{ox} \frac{W_n}{2L}(V_{OV})^2$$

where, overdrive voltage $V_{OV} = V_{GSN} - V_{TN}$

Similarly, $$I_{DP} = \mu_p C_{ox} \frac{W_p}{2L}(V_{GSP} - V_{TP})^2$$

or, $$I_{DP} = \mu_p C_{ox} \frac{W_p}{2L}(V_{OV})^2$$

where, overdrive voltage $V_{OV} = V_{GSP} - V_{TP}$

given, $I_{DN} = I_{DP}$

$$\mu_n C_{ox} \frac{W_n}{2L}(V_{OV})^2 = \mu_p C_{ox} \frac{W_p}{2L}(V_{OV})^2$$

$$\therefore \quad \frac{W_n}{W_p} = \frac{\mu_p}{\mu_n} = 0.4$$

In the given question, it is asking that,

$$\frac{W_p}{W_n} = \frac{1}{0.4} = 2.5$$

23. **(c)**

24. **(c)**

Fill factor of solar cell is,

$$\text{F.F.} = \frac{\text{Maximum power obtained}}{V_{oc} \times I_{sc}}$$

$$0.65 = \frac{65 \times 10^{-3}}{V_{oc} \times I_{sc}}$$

$$\therefore \quad V_{oc} \times I_{sc} = \frac{65 \times 10^{-3}}{0.65} = 100 \text{ mW}$$

$\therefore$ Option (c) satisfies the result ($V_{oc} \times I_{sc}$ = 40 mA × 2.5 V = 100 mW)

25. **(c)**

Given, $\mu_n C_{ox} \frac{W}{L} = 1.5 \times 10^{-3}$ A/V^2

$$V_T = 0.65 \text{ V}$$
$$V_{GS} = 4 \text{ V}$$
$$V_{DS} = 6 \text{ V}$$

Power dissipation in the MOSFET is,

$$P = V_{DS} \times I_{DS}$$

where, I_{DS} is drain to source saturation current.
Since the MOSFET is operating in saturation region,

$$I_{DS} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)^2$$

$$= \frac{1}{2} \times 1.5 \times 10^{-3}(4 - 0.65)^2$$

$$I_{DS} = 8.42 \times 10^{-3} \text{ A}$$

Power dissipation, $P = 6 \times 8.42 \times 10^{-3}$

$\therefore$ $P = 50.50$ mW

26. **(b)**

The steady state increase in conductivity,

$$\Delta\sigma = q(\mu_n + \mu_p)(\delta p)$$

In steady state, $\delta p = g' \tau_{po}$

where, g' is the uniform generation rate.

$$\therefore \quad \Delta\sigma = q(\mu_n + \mu_p)(g' \tau_{po})$$

$$2 = (1.6 \times 10^{-19})\,(8500 + 400)g' \times 10^{-7}$$

$$\therefore \quad g' = 1.404 \times 10^{22}\ \text{cm}^{-3}\ \text{s}^{-1}$$

27. (b)

$$J_p = -qD_p\frac{dp}{dx}$$

for $x \le w,$

$$\frac{dp}{dx} = \frac{p(0)-p_0}{0-w} = \frac{-(p(0)-p_0)}{w}$$

$$J_p = \frac{qD_p\,(p(0)-p_0)}{w} = \text{positive constant}$$

for $x \ge w,$

$$\frac{dp}{dx} = 0$$

$$\Rightarrow \quad J_p = 0$$

28. (a)

$$q\,\phi(x) = E_F - E_i(x)$$

$$q\,\phi(0) = E_F - E_i(0) = kT\,ln\left(\frac{N_D(0)}{n_i}\right)$$

$$\phi(0) = \frac{kT}{q}ln\left(\frac{N_D(0)}{n_i}\right)$$

$$\phi(x = 5\mu\text{m}) = \frac{kT}{q}ln\left(\frac{N_D(5\mu\text{m})}{n_i}\right)$$

$$V_0 = \phi(0)-\phi(x=5\mu\text{m}) = \frac{kT}{q}ln\left(\frac{N_D(0)}{N_D(5\mu\text{m})}\right)$$

$$= 0.026\,ln\left(\frac{10^{20}}{10^{15}}\right)\text{V} \simeq 0.3\ \text{V}$$

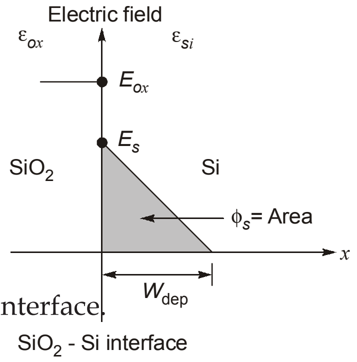
29. (a)

$$\phi_s = \text{surface potential}$$

$$= \frac{1}{2}E_s\,W_{\text{dep}}$$

$$E_s = \frac{2\phi_s}{W_{\text{dep}}} = \frac{2\times 0.035}{0.4}\ \text{V}/\mu\text{m}$$

$$E_s = 0.175\ \text{V}/\mu\text{m}$$



Boundary condition of electrostatic field should be satisfied at the interface.

So, $$\varepsilon_{ox}E_{ox} = \varepsilon_{si}E_s$$

$$E_{ox} = \frac{\varepsilon_{si}E_s}{\varepsilon_{ox}} = 3E_s$$

$$E_{ox} = 0.525\ \text{V}/\mu\text{m}$$

$$E_{ox} = \frac{V_{ox}}{t_{ox}}$$

$$V_{ox} = E_{ox}t_{ox} = 0.525 \times 1.8 \text{ V} = 0.945 \text{ V}$$

$$V_G = V_{ox} + \phi_s = 0.98 \text{ V}$$

30. (c)

Force due to magnetic field, $$\vec{F}_m = q\vec{v}_d \times \vec{B} = q\mu_p \vec{E}_{\text{applied}} \times \vec{B} = \frac{q\mu_p V_x}{L}\hat{x} \times (-10\,\hat{z})$$

$$= \frac{100\,q\mu_p}{L}\hat{y}$$

$$\vec{F}_{ei} = \text{force due to induced Hall electric field} = -\vec{F}_m$$

$$= \frac{100\,q\mu_p}{L}(-\hat{y}) = q\vec{E}_{\text{ind}}$$

$$\vec{E}_{\text{ind}} = \frac{100\mu_p}{L}(-\hat{y})$$

As $\vec{E}_{\text{ind}}$ in $(-\hat{y})$ direction, V_H is +ve

$$V_H = W\left|\vec{E}_{\text{ind}}\right| = \frac{W(100)\mu_p}{L} = \frac{W(100)\left(500 \times 10^{-4}\right)}{2W} = 2.5 \text{ V}$$

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