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Important Questions *for* GATE 2022

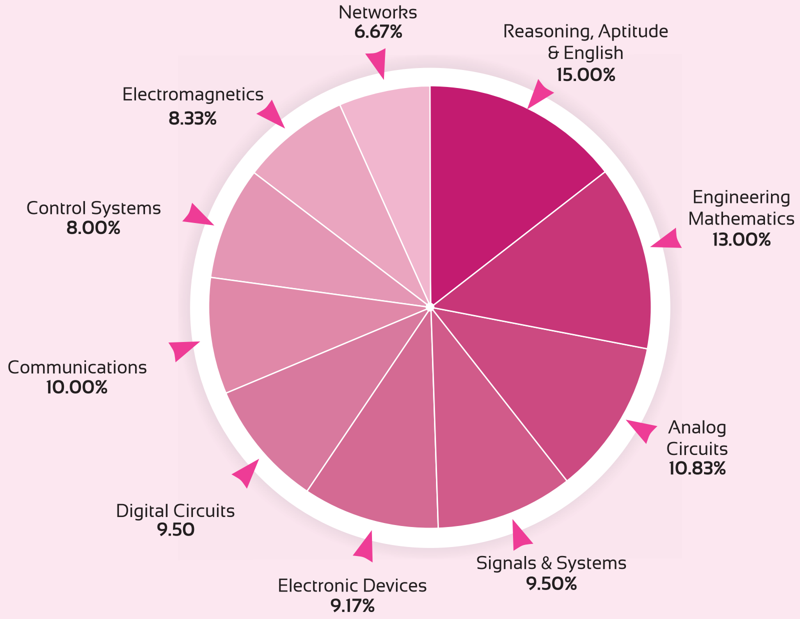
ELECTRONICS ENGINEERING

Day 8 of 8

Q.176 - Q.200 (Out of 200 Questions)

Electronic Devices and Signals & Systems

SUBJECT-WISE WEIGHTAGE ANALYSIS OF GATE SYLLABUS



Subject	Average % (last 5 yrs)*
Reasoning, Aptitude & English	15.00%
Engineering Mathematics	13.00%
Analog Circuits	10.83%
Signals & Systems	9.50%
Electronic Devices	9.17%
Digital Circuits	9.50%
Communications	10.00%
Control Systems	8.00%
Electromagnetics	8.33%
Networks	6.67%
Total	**100%**

Electronic Devices and Signals & Systems

Q.176 A Si diode has a forward current of 1 mA and carrier life time $\tau = 10^{-7}$ sec and maximum diffusion capacitance of 1 nF. The above Si diode is operating at a temperature of
(Assume $\eta = 2$ for Si)

(a) 480 K
(b) 580 K
(c) 680 K
(d) 693 K

Q.177 Consider an n-type silicon semiconductor at $T = 300$ K in which $N_d = 10^{16}$ cm^{-3} and $N_a = 10^{13}$ cm^{-3}. The intrinsic carrier concentration is assumed to be $n_i = 1.5 \times 10^{10}$ cm^{-3}. Then the equilibrium hole concentration is

(a) 1.50×10^4 cm^{-3}
(b) 1.75×10^4 cm^{-3}
(c) 2.25×10^4 cm^{-3}
(d) 2.75×10^4 cm^{-3}

Q.178 A silicon pn junction diode has acceptor concentration of 10^{15}/cm^3 and donor concentration of 10^{16}/cm^3. The reverse bias voltage across the junction is –4.5 V. Then the maximum electric field $|E_{\max}|$ at the junction is equal to ____________ kV/cm.
(Assume, $n_i = 1.5 \times 10^{10}$/cm^3, $\varepsilon = 11.7\varepsilon_0$, $V_T = 26$ mV)

Q.179 For an intrinsic semiconductor, assume the effective mass of hole is 0.5 times the effective mass of electron. Then how far is the intrinsic Fermi energy from the midgap energy.
(Assume $kT = 0.0259$ eV)

(a) 0.024 eV above
(b) 0.024 eV below
(c) 0.013 eV above
(d) 0.013 eV below

Q.180 An NMOS device operating with a small drain-source voltage serves as a resistor. If the overdrive voltage is 1.8 V, then the minimum on-resistance that can be achieved with

$$\mu_n C_{ox} \frac{W}{L} = 4 \text{ mA/m}^2 \text{ is}$$

(a) 139 Ω
(b) 239 Ω
(c) 278 Ω
(d) 340 Ω

Q.181 The conductivity of two sides of a step graded silicon diode is $\sigma_p = 0.25$ ℧/cm and $\sigma_n = 0.55$ ℧/cm. Then the potential barrier height is equal to
(Assume, $\mu_p = 500$ cm^2/V-sec; $\mu_n = 1300$ cm^2/V-sec, $V_T = 26$ mV,
intrinsic concentration, $n_i = 1.5 \times 10^{10}$/cm^3)

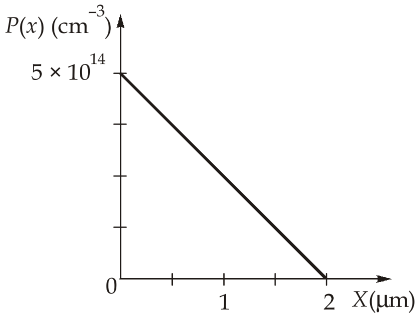
(a) 0.50 V
(b) 0.63 V
(c) 0.75 V
(d) 0.86 V

Q.182 A MOSFET carriers a drain current of 1 mA with $V_{DS} = 0.6$ V in saturation region. If V_{DS} is increases so that the corresponding increases in drain current is 50% above the previous value. Then new value of V_{DS} is __________ V.
(Assume, channel length parameter $\lambda = 0.1$ V^{-1})

Q.183 Consider two p^+n silicon junctions at T = 300 K reverse biased at V_R = 10 V. The impurity doping concentrations in junction A are $N_a = 10^{18}$ cm^{-3} and $N_d = 10^{15}$ cm^{-3}, and those in junction B are $N_a = 10^{18}$ cm^{-3} and $N_d = 10^{16}$ cm^{-3}. Then the maximum electric field $|E_{\max}|$ ratio for junction A to junction B is __________.
(Assume $V_{bi} << |V_R|$)

Q.184 An NMOS device has oxide capacitance $C_{ox} = 10$ F/m^2, $W = 5$ µm, $L = 0.1$ µm and $V_{GS} - V_{TH} = 1$ V. Then the total charge stored in the channel of NMOS is equal to
(Assume, $V_{DS} = 0$)
(a) 25 µC
(b) 50 µC
(c) 75 µC
(d) 100 µC

Q.185 The excess hole population in an n-type silicon sample is shown below. The minority carrier life time in this sample is 10^{-4} sec, the hole mobility is 640 cm^2/V-sec, and cross section of the sample is 10^{-4} cm^2.



The hole current in the above silicon sample is ________ × 10^{-4} A.
(Assume, V_T = 26 mV)
(a) 3.33×10^{-4} A
(b) 1.66×10^{-4} A
(c) 9.75×10^{-4} A
(d) 6.66×10^{-4} A

Q.186 An ideal n-channel MOSFET is first operated in saturation region with threshold voltage of 0.8 V, the transconductance is found to be 2 mS. If the same MOSFET is operating in linear region at V_{DS} = 2 V, then transconductance is found to be 1.5 mS. Then the value of Gate to source voltage (V_{GS}) when MOSFET operating in saturation region is ___________ V.

Q.187 The fill factor in a solar cell will depend on which of the following
(a) Open circuit voltage
(b) Short circuit current
(c) Area of maximum power rectangle in I-V characteristics
(d) All of the above

Q.188 Consider two p$^+$n diodes which are identical except for the fact that in diode *A* the minority carrier life time is infinite making $L_n >> W_N$, while in diode *B* the minority carrier lifetime is finite and small enough that $L_p < W_N$, where W_N is the width of the *n*-type side and L_p is the minority carrier diffusion length.

Then which of the following statements are correct?

S1: diode *B* has large saturation current compared to diode *A*.

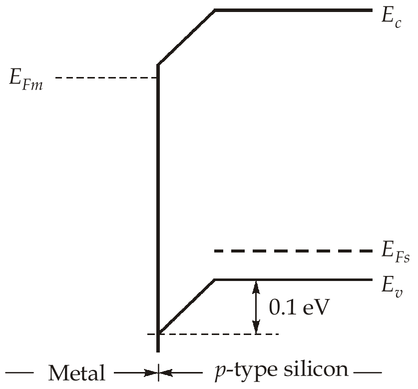
S2: diode *A* has wide space charge layer under thermal equilibrium.

(a) only S1
(b) only S2
(c) Both S1 and S2
(d) Neither S1 nor S2

Q.189 Two ideal p$^+$n junction diodes maintained at room temperature are identical except that I_{D_1} = 2.5 mA and I_{D_2} = 2 mA. If the diffusion lengths of the diodes be L_{p1} and L_{p2}. Then the ratio $\frac{L_{p1}}{L_{p2}}$ is ________.

Q.190 In a semiconductor, the effective density of states in valence band at 300 K is 1.04×10^{19} cm^{-3}. The fermi level is 0.27 eV above the edge of valence band (E_v). Assume that effective mass of hole equal to effective mass of electron. Then the hole concentration in the valence band at 400 K is ________ $\times 10^{15}$ cm^{-3}.

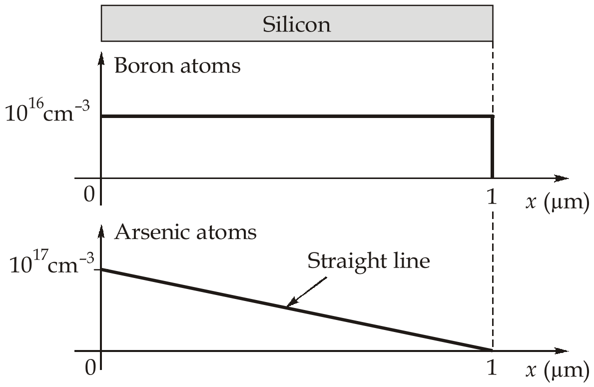
Q.191 A Schottky barrier is formed between a metal having a work function of 4.7 eV and a *p*-type silicon having electron affinity of 4 eV. The acceptor doping concentration in the *p*-type silicon is 10^{17} cm^{-3}. The device is operating at 300 K, where kT = 0.026 eV and intrinsic carrier concentration in silicon is $n_i = 10^{10}$ cm^{-3}. For a particular forward bias, the simplified energy band diagram of the device is shown in the figure below.



If the energy gap of silicon is 1.1 eV, then the magnitude of the forward biasing voltage is equal to ______ V.

Q.192 In a step-graded *p-n* junction with ideality factor of 1 at *T* = 300 K, the magnitude of the reverse-bias voltage required to reach 50% of its reverse saturation current is ________ mV. [Assume that, $k = 1.38 \times 10^{-23}$ J/K and $q = 1.6 \times 10^{-19}$ C]

Q.193 An intrinsic silicon sample is doped from two different impurity sources whose concentrations vary along the length of the bar as shown in the figure below:



After the process of doping, the bar is kept under equilibrium at room temperature. There exists a built-in electric field inside the semiconductor due to the variation of resultant doping profile. The peak of this electric field (magnitude) exists at x equal to ______ μm.

Q.194 The output of a causal LTI system is related to the input $x(t)$ by the equation,

$$\frac{dy(t)}{dt} + 10y(t) = \int_{-\infty}^{\infty} x(\tau)z(t-\tau)d\tau - x(t)$$

where $z(t) = e^{-t}u(t) + 3\delta(t)$. Then the impulse response of the system is

(a) $\frac{1}{9}e^{-t}u(t) + \frac{1}{9}e^{-10t}u(t)$
(b) $\frac{1}{9}e^{-t}u(t) + \frac{17}{9}e^{-10t}u(t)$
(c) $\frac{17}{9}e^{-t}u(t) + \frac{1}{9}e^{-10t}u(t)$
(d) $\frac{17}{9}e^{-t}u(t) + \frac{17}{9}e^{-10t}u(t)$

Q.195 The energy of the signal $x(t) = 2e^{-\pi t^2}$ is ____________.

Q.196 Let $g(t) = x(t)\cos^2 t * \frac{\sin t}{\pi t}$, Assume that $x(t)$ is real and $X(\omega) = 0$ for $|\omega| \geq 1$, then the Fourier transform of $g(t)$ is $G(\omega)$ equal to

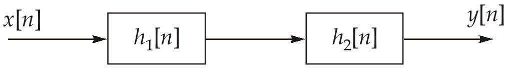
(a) $X(\omega)$
(b) $\frac{1}{2}X(\omega)$
(c) $X(\omega - 2)$
(d) $\frac{1}{4}X(\omega - 2)$

Q.197 An LTI system with impulse response $h_1[n] = \left(\frac{1}{3}\right)^n u[n]$ is connected in parallel with another causal LTI system with impulse response $h_2[n]$. The resulting parallel interconnection has the frequency response

$$H(e^{j\omega}) = \frac{-12 + 5e^{-j\omega}}{12 - 7e^{-j\omega} + e^{-j2\omega}}$$

Then the system $h_2[n]$ at $n = 0$ is equal to ____________.

Q.198 Consider the cascade of two LTI systems as shown below.



where, $h_1[n] = \sin 4n$ and $h_2[n] = \left(\frac{1}{2}\right)^n u[n]$ and the input is $x[n] = \delta[n] - \frac{1}{2}\delta[n-1]$. Then the output $y[n]$ is

(a) $\sin 4n$ (b) $2\sin 4n$
(c) $\sin 2n$ (d) $2\sin 2n$

Q.199 Consider a discrete time signal $x[n]$ whose discrete time Fourier transform is $X(e^{j\omega})$ where

$$X(e^{j\omega}) = \frac{1}{1-e^{-j\omega}}\left(\frac{\sin\frac{3}{2}\omega}{\sin\frac{\omega}{2}}\right) + 5\pi\delta(\omega) \ ; -\pi < \omega \leq \pi$$

Then the value of $x[n]$ at $n = 3$ is ____________.

Multiple Select Questions (MSQ)

Q.200 A Ge sample at room temperature has intrinsic carrier concentration $n_i = 1.5 \times 10^{13}/\text{cm}^3$ and is uniformly doped with donor of $3 \times 10^{16}/\text{cm}^3$ and acceptor of $2.5 \times 10^{15}/\text{cm}^3$.

The correct statements is/are

(a) Majority charge carrier concentration is $3 \times 10^{16}/\text{cm}^3$.
(b) Minority charge carrier concentration is $0.818 \times 10^{10}/\text{cm}^3$.
(c) Majority charge carrier concentration is $2.75 \times 10^{16}/\text{cm}^3$.
(d) Minority charge carrier concentration is $2.5 \times 10^{15}/\text{cm}^3$.

■■■■

Detailed Explanations

176. **(b)**

Given, $I_f = 1$ mA

Diffusion capacitance, $C_D = 1$ nF

$\eta = 2$

but, $$C_D = \frac{\tau I_f}{\eta V_T}$$

$$C_D = \frac{\tau I_f \times 11600}{\eta T} \qquad \left(\because V_T = \frac{T}{11600}\right)$$

$$10^{-9} = \frac{10^{-7} \times 10^{-3} \times 11600}{2 \times T}$$

$$T = 580 \text{ K}$$

177. **(c)**

Given,

donor concentration,

$$N_d = 10^{16} \text{ cm}^{-3}$$

acceptor concentration,

$$N_a = 10^{13} \text{ cm}^{-3}$$

We know that, the charge neutrality condition

$$n + N_a = p + N_d$$

From mass action law, $np = n_i^2$

and $$p = \frac{n_i^2}{n}$$

$$n + N_a = \frac{n_i^2}{n} + N_d$$

$$n^2 + nN_a = n_i^2 + nN_d$$

$$\therefore \quad n_i^2 + (N_d - N_a)n - n^2 = 0$$

or $$n^2 - (N_d - N_a)n - n_i^2 = 0$$

$$n = \frac{N_d - N_a}{2} + \sqrt{\left(\frac{N_d - N_a}{2}\right)^2 - n_i^2}$$

$$\therefore \quad n = \frac{10^{16} - 10^{13}}{2} + \sqrt{\left(\frac{10^{16} - 10^{13}}{2}\right)^2 - (1.5 \times 10^{10})^2}$$

$$n = 9.99 \times 10^{15}$$

$\therefore$ Hole concentration, $$p = \frac{n_i^2}{n} = \frac{(1.5 \times 10^{10})^2}{9.99 \times 10^{15}}$$

$$\therefore \quad p = 2.25 \times 10^4 \text{ cm}^{-3}$$

178. 38 (37 to 39)

We know that,

Maximum electric field in the reverse biased *pn* junction is

$$E_{\max} = -\frac{2}{W}(V_{bi} - V_R)$$

where, W = width of the depletion region ; V_{bi} = built-in voltage at the junction

$$V_{bi} = V_T \ln\left[\frac{N_a N_d}{n_i^2}\right] = 26\times10^{-3}\ln\left[\frac{10^{15}\times10^{16}}{(1.5\times10^{10})^2}\right]$$

$$\therefore \qquad V_{bi} = 0.637\text{ V}$$

Width of the depletion region,

$$W = \left[\frac{2\varepsilon}{q}\left[\frac{1}{N_a}+\frac{1}{N_d}\right](V_{bi}-V_R)\right]^{1/2}$$

$$= \left[\frac{2\times11.7\times8.854\times10^{-14}}{1.6\times10^{-19}}\left[\frac{1}{10^{15}}+\frac{1}{10^{16}}\right](0.637+4.5)\right]^{1/2}$$

$$W = 2.7\ \mu\text{m}$$

$\therefore$ Maximum electric field at the junction,

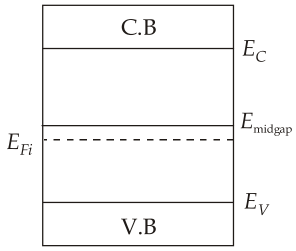
$$E_{\max} = \frac{-2(0.637+4.5)}{W} = \frac{-2(0.637+4.5)}{2.7\times10^{-4}}$$

$$|E_{\max}| \approx 38\text{ kV/cm}$$

179. (d)

For intrinsic semiconductor,

Intrinsic fermi energy,



$$E_{Fi} = E_{\text{midgap}} + \frac{3}{4}kT\ln\left(\frac{m_p^*}{m_n^*}\right)$$

Given, $\quad m_p^* = 0.5\ m_n^*$

$$\Rightarrow \qquad \frac{m_p^*}{m_n^*} = 0.5$$

$$E_{Fi} = E_{\text{midgap}} + \frac{3}{4}(0.0259)\ln(0.5)$$

$$E_{Fi} = E_{\text{midgap}} - 0.013\text{ eV}$$

180. (a)

We can use NMOS device as resistor in linear region of operation.

In linear region,

Drain current, $\quad I_D = \mu_n C_{ox}\dfrac{W}{L}\left[(V_{GS}-V_{TH})V_{DS} - \dfrac{V_{DS}^2}{2}\right]$

For small drain-source voltage,

$$I_D \approx \mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})V_{DS}$$

On-resistance of NMOS device can be written as,

$$R_{on} = \frac{V_{DS}}{I_D} = \frac{1}{\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})}$$

Given, $V_{GS} - V_{TH} = 1.8\text{ V}$

$$\mu_n C_{ox}\frac{W}{L} = 4\text{ mA/m}^2$$

$\therefore$ $$R_{on} = \frac{1}{4\times10^{-3}\times1.8} = 138.89\ \Omega \approx 139\ \Omega$$

181. **(b)**

We know that,

Conductivity in *p*-type material,

$$\sigma_p = N_a q\mu_p$$

$\therefore$ $$N_a = \frac{\sigma_p}{q\mu_p} = \frac{0.25}{1.6\times10^{-19}\times500}$$

$\therefore$ $$N_a = 3.125\times10^{15}/\text{cm}^3$$

Conductivity in *n*-type material,

$$\sigma_n = N_d q\mu_n$$

$\therefore$ $$N_d = \frac{\sigma_n}{q\mu_n} = \frac{0.55}{1.6\times10^{-19}\times1300}$$

$\therefore$ $$N_d = 2.64\times10^{15}/\text{cm}^3$$

$\therefore$ The potential barrier height,

$$V_{bi} = V_T\ln\left[\frac{N_aN_d}{n_i^2}\right] = 26\times10^{-3}\ln\left[\frac{3.125\times2.64\times10^{30}}{2.25\times10^{20}}\right]$$

$$V_{bi} = 0.63\text{ V}$$

182. **5.9 (5.50 to 6.50)**

We can write, drain current in saturation region as,

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

• $\therefore$ $$I_D \propto (1+\lambda V_{DS})$$

$$\frac{I_{D1}}{I_{D2}} = \frac{1+\lambda V_{DS1}}{1+\lambda V_{DS2}}$$

Given, $I_{D1} = 1\text{ mA}$

$$I_{D2} = 1.5(I_{D1}) = 1.5\text{ mA}$$

$$\lambda = 0.1\text{ V}^{-1};$$

$$V_{DS1} = 0.6\text{ V}$$

$\therefore$ $$\frac{1}{1.5} = \frac{1+(0.1\times0.6)}{1+(0.1\times V_{DS2})}$$

$$V_{DS2} = 5.9\text{ V}$$

183. **0.32 (0.25 to 0.40)**

We know that, maximum electric field,

$$E_{\max} = \frac{-2(V_{bi}+V_R)}{W}$$

or,

$$E_{\max} = \left\{\frac{2qV_R}{\varepsilon}\left[\frac{N_aN_d}{N_a+N_d}\right]\right\}^{1/2}$$

(∵ by neglecting V_{bi})

$$|E_{\max}| \propto \sqrt{N_d} \qquad \text{(for p}^+\text{n junction)}$$

∴

$$\frac{|E_{\max}|_A}{|E_{\max}|_B} = \sqrt{\frac{N_{dA}}{N_{dB}}} = \sqrt{\frac{10^{15}}{10^{16}}} = 0.32$$

184. **(b)**

For NMOS, the charge stored in the channel is

$$Q = CV$$

where, C is the gate capacitance per unit length

$$C = WC_{ox}$$

where, $V = V_{GS} - V_{TH}$ because no mobile charge exists for $V_{GS} < V_{TH}$.

∴

$$\begin{aligned} Q &= WC_{ox}(V_{GS} - V_{TH}) \\ &= 5 \times 10^{-6} \times 10 \times 1 \\ Q &= 50\ \mu\text{C} \end{aligned}$$

185. **(d)**

We know that,

Hole current, $$I_p = AJ_p$$

but, $$J_p = -qD_p\frac{dp(x)}{dx}$$

$$D_p = \mu_p V_T = 640 \times 26 \times 10^{-3} = 16.64\ \text{cm}^2/\text{sec}$$

∴

$$J_p = -1.6\times10^{-19}\times16.64\times\left[\frac{-5\times10^{14}}{2\times10^{-4}}\right]$$

$$J_p = 6.66\ \text{A/cm}^2$$

The hole current, $$I_p = AJ_p$$

$$I_p = 6.66 \times 10^{-4}\ \text{A}$$

186. **3.46 (3.20 to 3.80)**

First MOSFET operating in saturation region,

Drain current, $$I_{D1} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_T)^2$$

$$I_{D1} = \frac{K}{2}(V_{GS}-V_T)^2$$

Transconductance, $$g_{m1} = \frac{\partial I_{D1}}{\partial V_{GS}} = k(V_{GS}-V_T) \qquad \text{...(i)}$$

Hence, MOSFET operating in linear region,

Drain current, $$I_{D2} = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

Transconductance, $$g_{m2} = \frac{\partial I_{D2}}{\partial V_{GS}} = kV_{DS}$$

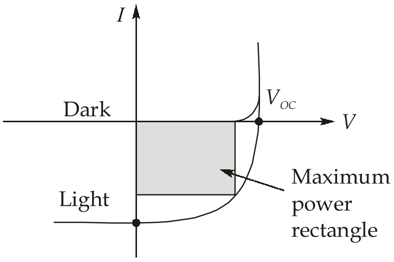
$$\therefore \quad \frac{g_{m1}}{g_{m2}} = \frac{(V_{GS} - V_T)}{V_{DS}}$$

$$\Rightarrow \quad \frac{2}{1.5} = \frac{V_{GS} - 0.8}{2}$$

$$\Rightarrow \quad V_{GS} = 3.46 \text{ V}$$

187. **(d)**

I - V characteristic curve of solar cell,



Fill factor, $$\text{FF} = \frac{\text{Area under maximum power rectangle}}{V_{OC} \cdot I_{SC}}$$

Where, V_{OC} = open circuit voltage, I_{SC} = short circuit current

188. **(a)**

S1: Because the saturation current varies inversely with the effective width of the diode given, $L_p < W_N$ in diode B, hence it has smaller effective width and thus the large saturation current.
S2: Incorrect
Both the diodes are similar, because the space charge layer width does not depend on τ.
i.e., space charge width of diode A is same as diode B.

189. **0.8 (0.7 to 0.9)**

We know that,
Diode current equation is,

$$I_D = Aq\left[\frac{D_p n_i^2}{L_p N_d} + \frac{D_n n_i^2}{L_n N_a}\right]\left[e^{\frac{V_D}{\eta V_T}} - 1\right]$$

for p$^+$n junction, $N_a >> N_d$

$$\therefore \quad I_{D1} \approx Aq \frac{D_p n_i^2}{L_{p_1} N_d}\left[e^{\frac{V_D}{\eta V_T}} - 1\right]$$

Similarly, $$I_{D2} \approx Aq\frac{D_p n_i^2}{L_{p_2} N_d}\left[e^{\frac{V_D}{\eta V_T}} - 1\right]$$

$$\therefore \quad \frac{I_{D_1}}{I_{D_2}} = \frac{L_{p_2}}{L_{p_1}}$$

$$\Rightarrow \quad \frac{L_{p_1}}{L_{p_2}} = \frac{2\text{ mA}}{2.5\text{ mA}} = 0.8$$

190. 6.43 (6.00 to 6.60)

Given,

Effective density of states at 300 K

$$N_v(300\text{ K}) = 1.04 \times 10^{19}\text{ cm}^{-3}$$

We know that, $$N_v = 2\left[\frac{2\pi m_p^* kT}{h^2}\right]^{3/2}$$

$$N_v \propto T^{3/2}$$

$$\therefore \quad \frac{N_v(400\text{ K})}{N_v(300\text{ K})} = \left(\frac{400}{300}\right)^{3/2}$$

$$\therefore \quad N_{v(400\text{ K})} = (1.04\times10^{19})\left(\frac{400}{300}\right)^{3/2}$$

$$N_{v(400\text{ K})} = 1.60 \times 10^{19}\text{ cm}^{-3}$$

∴ hole concentration, $$P = N_v \exp\left(\frac{-(E_F - E_v)}{kT}\right)$$

$$P = 1.60\times10^{19}\exp\left(\frac{-0.27}{0.03453}\right) \qquad \text{at } T = 400\text{ K}$$

$$\therefore \quad P = 6.43 \times 10^{15}\text{ cm}^{-3}$$

191. (0.17) (0.15 to 0.19)

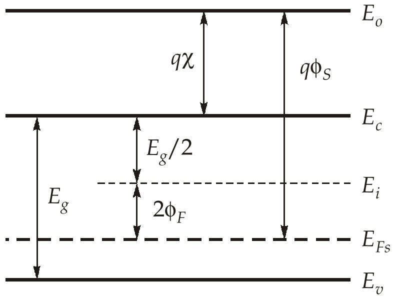
From the given energy band diagram, it is clear that,

$$q(V_o - V) = 0.1\text{ eV}$$

where, V_o = Potential barrier = $(\phi_s - \phi_m)$; V = Forward biasing voltage

Given that, $\phi_m = 4.7$ V

To calculate ϕ_s :



$$
\begin{aligned}
q\phi_s &= q\chi + \frac{E_g}{2} + q\phi_F \\
\phi_s &= \chi + \frac{E_g}{2q} + \phi_F \\
&= (4+0.55) + \frac{kT}{q}\ln\left(\frac{N_a}{n_i}\right) \\
&= 4.55 + 0.026\ln\,(10^7) \simeq 4.97\ \text{V} \\
V_o &= \phi_s - \phi_m = 4.97 - 4.7 = 0.27\ \text{V} \\
V_o - V &= 0.1\ \text{V} \\
V &= V_o - 0.1 = 0.27 - 0.1 = 0.17\ \text{V}
\end{aligned}
$$

192. (17.935) (17.80 to 18.10)

For a diode, $I_{AK} = I_o(e^{V_{AK}/V_T} - 1)$

When $I_{AK} = -0.50I_o$, $-0.50I_o = I_o(e^{V_{AK}/V_T} - 1)$

$$
\begin{aligned}
e^{V_{AK}/V_T} &= 0.50 \\
V_{AK} &= V_T\ln(0.50) = -V_T\ln(2) \\
V_T &= \frac{kT}{q} = \frac{1.38\times10^{-23}\times300}{1.6\times10^{-19}}\ \text{V} = \frac{1.38\times30}{1.6}\ \text{mV} = 25.875\ \text{mV}
\end{aligned}
$$

So, $V_{AK} = -(25.875)\ \ln(2) = -17.935\ \text{mV}$

$$V_R = |V_{AK}| = 17.935\ \text{mV}$$

193. (0.90) (0.88 to 0.92)

$$
\begin{aligned}
N_d(x) &= mx + C \\
m &= -\frac{10^{17}}{10^{-4}}\ \text{cm}^{-4} = -10^{21}\ \text{cm}^{-4} \quad (x \text{ is in cm}) \\
C &= 10^{17}\ \text{cm}^{-3}
\end{aligned}
$$

So, $N_d(x) = -10^{21}x + 10^{17}$ (x is in cm)

$$N_a(x) = 10^{16}\ \text{cm}^{-3}$$

The peak of the built-in electric field exists at the junction, which is the point where $N_d(x)$ is equal to $N_a(x)$.

So, $-10^{21}x + 10^{17} = 10^{16}$

$$
\begin{aligned}
x &= \frac{10^{17} - 10^{16}}{10^{21}}\ \text{cm} \\
&= 10^{-5}\ (10 - 1) = 9 \times 10^{-5}\ \text{cm} = 0.90\ \mu\text{m}
\end{aligned}
$$

194. (b)

Given, $\dfrac{dy(t)}{dt} + 10y(t) = \displaystyle\int_{-\infty}^{\infty} x(\tau)\,z(t-\tau)\,d\tau - x(t)$

By taking Fourier transform, on both sides

$$j\omega Y(\omega) + 10Y(\omega) = X(\omega)\ Z(\omega) - X(\omega)$$

But,
$$Z(\omega) = \frac{1}{1+j\omega}+3$$

$$\therefore \quad Y(\omega)[10+j\omega] = X(\omega)[Z(\omega)-1]$$

$$\therefore \quad H(\omega) = \frac{Y(\omega)}{X(\omega)} = \frac{Z(\omega)-1}{10+j\omega}$$

$$H(\omega) = \frac{\frac{1}{1+j\omega}+3-1}{10+j\omega} = \frac{1+2+2j\omega}{(1+j\omega)\,(10+j\omega)} = \frac{3+2j\omega}{(1+j\omega)\,(10+j\omega)}$$

By taking partial fraction expansion of $H(\omega)$,

$$H(\omega) = \frac{A}{1+j\omega}+\frac{B}{10+j\omega}$$

$$A = \left.\frac{3+2j\omega}{10+j\omega}\right|_{j\omega=-1} = \frac{1}{9}$$

$$B = \left.\frac{3+2j\omega}{1+j\omega}\right|_{j\omega=-10} = \frac{17}{9}$$

$$\therefore \quad H(\omega) = \frac{1/9}{1+j\omega}+\frac{17/9}{10+j\omega}$$

$\therefore$ Impulse response, $h(t) = \frac{1}{9}e^{-t}\,u(t)+\frac{17}{9}e^{-10t}u(t)$

195. **2.83 (2.50 to 3.00)**

$$x(t) \xleftrightarrow{FT} X(\omega)$$

$$2e^{-\pi t^2} \xleftrightarrow{FT} 2\cdot e^{-\frac{\omega^2}{4\pi}}$$

Energy,
$$E = \frac{1}{2\pi}\int_{-\infty}^{\infty}|X(\omega)|^2\,d\omega$$

$$E = \frac{1}{2\pi}\int_{-\infty}^{\infty}4\cdot e^{-\frac{\omega^2}{2\pi}}\,d\omega$$

$$= \frac{1}{2\pi}\int_{-\infty}^{\infty}4\cdot e^{-\frac{\omega^2}{2\pi}}\,d\omega$$

Compare with $\int_{-\infty}^{\infty} e^{-\frac{x^2}{2\sigma^2}}\,dx = \sigma\sqrt{2\pi}\,; \quad \sigma>0$

$$\because \quad x = \omega;$$

$$\sigma = \sqrt{\pi}$$

$$\therefore \quad E = \frac{1}{2\pi}4\sqrt{\pi}\times\sqrt{2\pi}$$

$$E = 2\sqrt{2}\text{ J} = 2.83\text{ J}$$

196. (b)

Given,
$$g(t) = x(t)\cos^2 t * \frac{\sin t}{\pi t}$$
$$X(\omega) = 0 \text{ for } |\omega| \geq 1$$

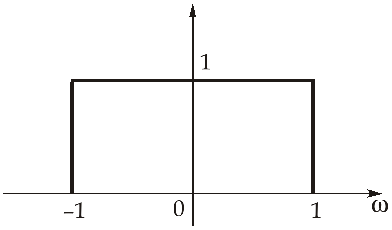
Let $y_1(t) = \cos^2 t$
$$y_1(t) = \frac{1+\cos 2t}{2}$$

By taking Fourier transform,
$$Y_1(\omega) = \pi\delta(\omega) + \frac{\pi}{2}\delta(\omega-2) + \frac{\pi}{2}\delta(\omega+2)$$

Let $y_2(t) = x(t)\ y_1(t) = x(t)\ \cos^2 t$
$$Y_2(\omega) = \frac{1}{2\pi}[X(\omega) * Y_1(\omega)]$$
$$= \frac{1}{2\pi}\left[X(\omega) * \left[\pi\delta(\omega) + \frac{\pi}{2}\delta(\omega-2) + \frac{\pi}{2}\delta(\omega+2)\right]\right]$$
$$\therefore \quad Y_2(\omega) = \frac{1}{2}X(\omega) + \frac{1}{4}X(\omega-2) + \frac{1}{4}X(\omega+2)$$

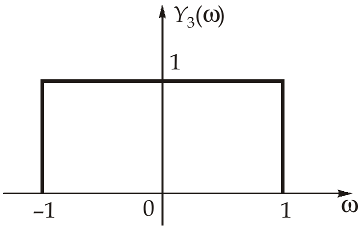
Let
$$y_3(t) = \frac{\sin t}{\pi t}$$

$$Y_3(\omega) =$$



Now,
$$g(t) = y_2(t) * y_3(t)$$
$$G(\omega) = Y_2(\omega)\ Y_3(\omega)$$
$$G(\omega) =$$

$$\left[\frac{1}{2}X(\omega) + \frac{1}{4}X(\omega-2) + \frac{1}{4}X(\omega+2)\right] \times$$



$$\therefore \quad G(\omega) = \frac{1}{2}X(\omega)$$

197. –2 (–3 to –1)

Given, frequency response of interconnection is
$$H(e^{j\omega}) = \frac{-12+5e^{-j\omega}}{12-7e^{-j\omega}+e^{-j2\omega}}$$

When two LTI systems are connected in parallel, the impulse response of the overall system $h[n]$ is the sum of the impulse responses of the individual systems.

$$\therefore \qquad h[n] = h_1[n] + h_2[n]$$

By using linearity property,

$$H(e^{j\omega}) = H_1(e^{j\omega}) + H_2(e^{j\omega})$$

Given that, $$h_1[n] = \left(\frac{1}{3}\right)^n u[n]$$

By taking DTFT,

$$H_1(e^{j\omega}) = \frac{1}{1-\frac{1}{3}e^{-j\omega}}$$

$$\therefore \qquad H_2(e^{j\omega}) = \frac{-12+5e^{-j\omega}}{12-7e^{-j\omega}+e^{-j2\omega}} - \frac{1}{1-\frac{1}{3}e^{-j\omega}}$$

$$\therefore \qquad H_2(e^{j\omega}) = \frac{-2}{1-\frac{1}{4}e^{-j\omega}} + \frac{1}{1-\frac{1}{3}e^{-j\omega}} - \frac{1}{1-\frac{1}{3}e^{-j\omega}}$$

$$\therefore \qquad H_2(e^{j\omega}) = \frac{-2}{1-\frac{1}{4}e^{-j\omega}}$$

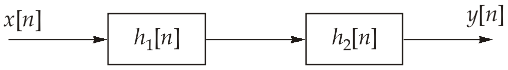
By taking inverse DTFT,

$$h_2[n] = -2\left(\frac{1}{4}\right)^n u[n]$$

at $n = 0$, $h_2[0] = -2$

198. **(a)**

Given LTI systems



$$y[n] = x[n]*[h_2[n]*h_1[n]]$$

or $$= [x[n]*h_2[n]]*h_1[n]$$

$$x[n]*h_2[n] = \left[\left(\frac{1}{2}\right)^n u[n]*\left(\delta[n]-\frac{1}{2}\delta[n-1]\right)\right]$$

$$= \left(\frac{1}{2}\right)^n u[n]-\frac{1}{2}\left(\frac{1}{2}\right)^{n-1} u[n-1]$$

$$= \left(\frac{1}{2}\right)^n u[n]-\left(\frac{1}{2}\right)^n u[n-1]$$

$$= \left(\frac{1}{2}\right)^n [u[n]-u[n-1]]$$

$$x[n]*h_2[n] = \delta[n]$$

$$\therefore \qquad y[n] = \delta[n]*\sin 4n$$

$$y[n] = \sin 4n$$

199. **4 (3 to 5)**

Given, $$X(e^{j\omega}) = \frac{1}{1-e^{-j\omega}}\left(\frac{\sin\frac{3}{2}\omega}{\sin\frac{\omega}{2}}\right) + 5\pi\delta(\omega) \;;\; -\pi < \omega \le \pi$$

Let $$X_1(e^{j\omega}) = \frac{\sin\frac{3}{2}\omega}{\sin\frac{\omega}{2}}$$

$$X_1(e^{j\omega}) \xleftrightarrow{IDTFT} x_1[n]$$

$$\frac{\sin\frac{3}{2}\omega}{\sin\frac{\omega}{2}} \xleftrightarrow{IDTFT} \begin{cases} 1, & |n| \le 1 \\ 0, & |n| > 1 \end{cases}$$

Using the accumulation property,

$$\sum_{k=-\infty}^{n} x_1(k) \xleftrightarrow{IDTFT} \frac{1}{1-e^{-j\omega}}X_1(e^{j\omega}) + \pi X_1(e^{j0})\cdot\sum_{k=-\infty}^{\infty}\delta(\omega-2\pi k)$$

Therefore in the range $-\pi < \omega \le \pi$.

$$\sum_{k=-\infty}^{n} x_1[k] \xleftrightarrow{DTFT} \frac{1}{1-e^{-j\omega}}X_1(e^{j\omega}) + 3\pi\delta(\omega)$$

Also, in the range $-\pi < \omega \le \pi$

$$1 \xleftrightarrow{FT} 2\pi\delta(\omega)$$

$\therefore$ In the range of $-\pi < \omega \le \pi$

$$x[n] = 1 + \sum_{k=-\infty}^{n} x_1[k] \xleftrightarrow{DTFT} \frac{1}{1-e^{-j\omega}}X_1(e^{j\omega}) + 5\pi\delta(\omega)$$

$\therefore$ The discrete signal $x[n]$ may be expressed as,

$$x[n] = 1 + \sum_{k=-\infty}^{n} x_1[k] = \begin{cases} 1, & n \le -2 \\ n+3, & -1 \le n \le 1 \\ 4, & n \ge 2 \end{cases}$$

$\therefore$ $x[n]$ at $n = 3$ is $x[3] = 4$.

200. **(b, c)**

Majority charge carrier concentation of a compensated semiconductor is

$$3 \times 10^{16} - 2.5 \times 10^{15} = 2.75 \times 10^{16}/\text{cm}^3$$

$$\text{Minority charge carrier concentration} = \frac{n_i^2}{N_D - N_A} = \frac{(1.5\times10^{13})^2}{2.75\times10^{16}}$$

$$= 0.818 \times 10^{10}/\text{cm}^3$$

■■■■