CLASS TEST

Sl. : 01JPEC_EDC_16102023

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ELECTRONICS ENGINEERING

ELECTRONIC DEVICES

Duration : 1:00 hr. **Maximum Marks : 50**

Read the following instructions carefully

1. This question paper contains **30** objective questions. **Q.1-10** carry one mark each and **Q.11-30** carry two marks each.
2. Answer all the questions.
3. Questions must be answered on Objective Response Sheet (**ORS**) by darkening the appropriate bubble (marked **A**, **B**, **C**, **D**) using HB pencil against the question number. Each question has only one correct answer. In case you wish to change an answer, erase the old answer completely using a good soft eraser.
4. There will be **NEGATIVE** marking. For each wrong answer **1/3rd** of the full marks of the question will be deducted. More than one answer marked against a question will be deemed as an incorrect response and will be negatively marked.
5. Write your name & Roll No. at the specified locations on the right half of the **ORS**.
6. No charts or tables will be provided in the examination hall.
7. Choose the **Closest** numerical answer among the choices given.
8. If a candidate gives more than one answer, it will be treated as a **wrong answer** even if one of the given answers happens to be correct and there will be same penalty as above to that questions.
9. If a question is left blank, i.e., no answer is given by the candidate, there will be **no penalty** for that question.

DO NOT OPEN THIS TEST BOOKLET UNTIL YOU ARE ASKED TO DO SO

Q.No. 1 to Q.No. 10 carry 1 mark each

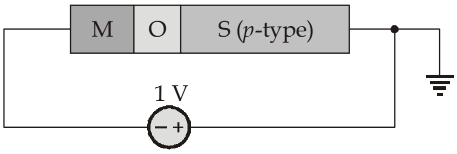
Q.1 Which of the following are the advantages of Silicon over Insulator (SOI) technology?

1. Lower diffusion capacitance
2. Smaller parasitic delay
3. Lower dynamic power consumption

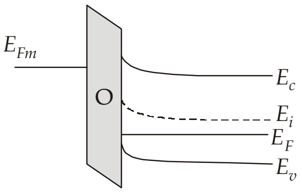
Select the correct answer using the code given below.

(a) 1 and 2 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3

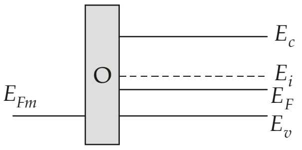
Q.2 Which of the following figures correctly depicts band bending phenomenon for the ideal MOS capacitor setup shown below?



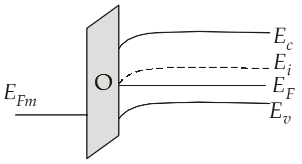
(a)



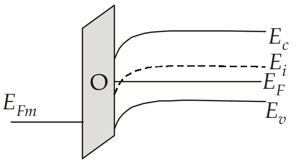
(b)



(c)



(d)



Q.3 For a *p-n* junction LED, the radiative recombination efficiency is 20%. If the radiative recombination life time of the material is 10 ns, then the non-radiative recombination life time will be equal to

(a) 2.5 ns (b) 2 ns
(c) 2.25 ns (d) 1.5 ns

Q.4 Which of the following equation correctly represents the fermi level in intrinsic semiconductor?

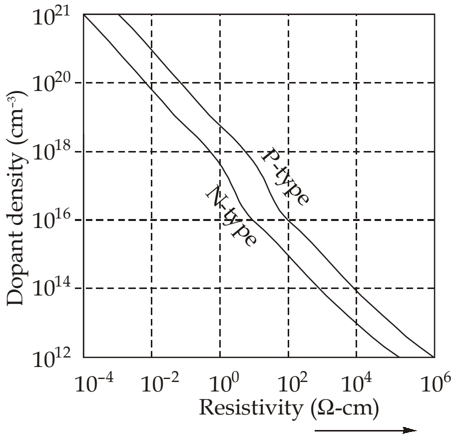
(a) $E_i = E_c - \frac{E_g}{2} - \text{kT} \ln\left(\sqrt{N_C N_V}\right)$

(b) $E_i = E_c - \frac{E_g}{2} - \text{kT} \ln\left(\sqrt{\frac{N_C}{N_V}}\right)$

(c) $E_i = E_c + \frac{E_g}{2} - \text{kT} \ln\left(\sqrt{\frac{N_V}{N_C}}\right)$

(d) $E_i = E_c - \frac{E_g}{2} + \text{kT} \ln\left(\sqrt{N_C N_V}\right)$

Q.5 Consider the below graph between resistivity versus dopant density of silicon at room temperature.



The resistance (R) of silicon sample doped with 10^{16} cm^{-3} of boron atoms is (Assume Si sample has 1 μm long and 0.1 μm^2 cross-sectional area)

(a) 10^5 Ω (b) 10^6 Ω
(c) 10^7 Ω (d) 10^9 Ω

Q.6 Which of the following statements are correct regarding the diffusion capacitance (C_D) of a *p-n* junction diode?

(a) Increases inversaly proportional to the forward bias current.
(b) Increases exponentially with forward bias voltage.
(c) Decreases exponentially with forward bias voltage.
(d) Increases linearly with forward bias voltage.

Q.7 Consider a p^+n junction has doping concentrations $N_a = 10^{20}$ cm^{-3} and $N_d = 10^{17}$ cm^{-3}. Then the built-in potential at the junction is
(Assume, $n_i = 10^{10}$ cm^{-3}, KT/q = 26 mV)

(a) 0.8 V
(b) 0.9 V
(c) 1.0 V
(d) 1.8 V

Q.8 With the introduction of donor dopant atoms in a semiconductor, the electrons spreads out by diffusion and disappears by recombination in semiconductor. Then which of the following equation represents diffusion equation for electrons in semiconductor?

(a) $\dfrac{\partial \delta n}{\partial t} = D_n \dfrac{\partial^2 \delta n}{\partial x^2} - \dfrac{\delta n}{\tau_n}$

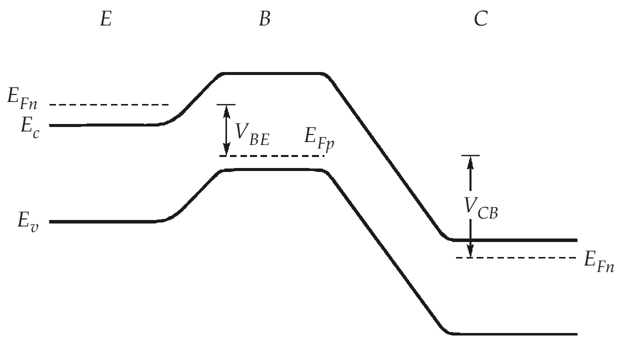
(b) $\dfrac{\partial \delta n}{\partial t} = D_n \dfrac{\partial \delta n}{\partial x} - \dfrac{\delta n}{\tau_n}$

(c) $\dfrac{\partial^2 \delta n}{\partial t^2} = D_n \dfrac{\partial \delta n}{\partial x} - \dfrac{\delta n}{\tau_n}$

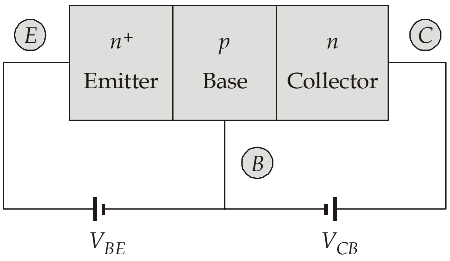
(d) $\dfrac{\partial^2 \delta n}{\partial t^2} = D_n \dfrac{\partial^2 \delta n}{\partial x^2} - \dfrac{\delta n}{\tau_n}$

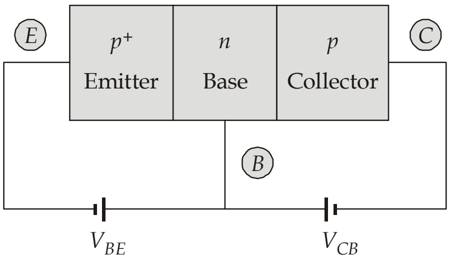
δ_n : excess electron concentration
τ_n : carrier life time
D_n : Diffusion coefficient of electrons

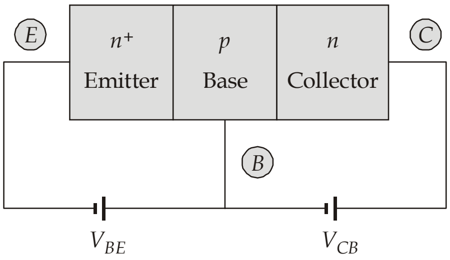
Q.9 Consider the energy band diagram of a certain transistor configuration shown below:

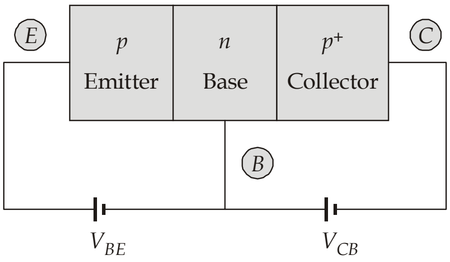


Then, which of the following biased transistor is equivalent to the given energy band diagram?

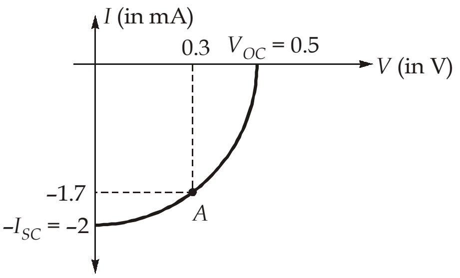
(a)


(b)


(c)


(d)


Q.10 Consider a solar cell is operating at the point A on its I-V characteristics shown below:

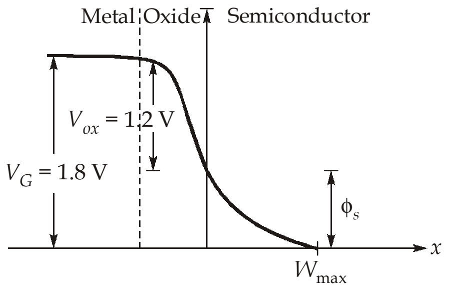


Then the fill factor (FF) is equal to ________.

(a) 0.54
(b) 0.41
(c) 0.55
(d) 0.51

Q. No. 11 to Q. No. 30 carry 2 marks each

Q.11 Consider an approximate distribution of electrostatic potential in the ideal MOS capacitor in strong inversion mode of operation. The semiconductor is doped with 1.5×10^{15} cm^{-3} dopant atoms.



Then the maximum width of the depletion region which is extended into semiconductor is ________ $\times 10^{-6}$ m (Assume, $\in_{Si} = 1.04 \times 10^{-12}$ F/cm).

(a) 0.82 (b) 0.72
(c) 0.62 (d) 0.52

Q.12 Consider a MOSFET operating with drain to source current of 1 mA, has transconductance (g_m) equal to 2 mA/V. Assume the MOSFET operating in saturation region then the overdrive voltage of MOSFET is

(a) 0.5 V (b) 1 V
(c) 1.5 V (d) 2 V

Q.13 A photodiode has responsivity of 0.5 A/W at a wavelength of 850 nm. Then the efficiency of photodiode is

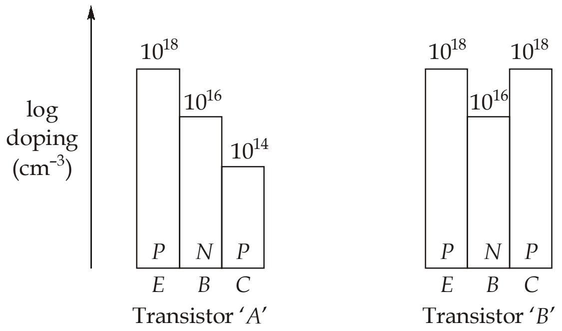
(Assume, planck's constant $h = 6.626 \times 10^{-34}$ J-sec, $c = 3 \times 10^8$ m/sec)

(a) 0.56 (b) 0.65
(c) 0.73 (d) 0.84

Q.14 A silicon p^+-n-p transistor has impurity concentration of 5×10^{18}, 10^{16} and 10^{15} cm^{-3} in the emitter, base and collector regions respectively. The base width is 1 µm and the device cross sectional area is 3 mm^2. The width of depletion region of EB junction and CB junction is 0.22 µm and 2.86 µm respectively. If steady state conditions prevail, then the neutral base width is

(a) 0.52 µm (b) 0.42 µm
(c) 0.62 µm (d) 0.56 µm

Q.15 Two pnp BJTs are similar except $N_B >> N_C$ in transistor 'A' while $N_B << N_C$ in transistor 'B'. The doping profiles in the two transistors are graphed below:



Which transistor is expected to have the larger punch through voltage and by which limiting phenomenon respectively under active mode biasing?

(a) Transistor 'B' and Avalanche Breakdown
(b) Transistor 'A' and Avalanche Breakdown
(c) Transistor 'B' and Zener Breakdown
(d) Transistor 'A' and Zener Breakdown

Q.16 Consider the following statements. Which of the below statements is/are incorrect?

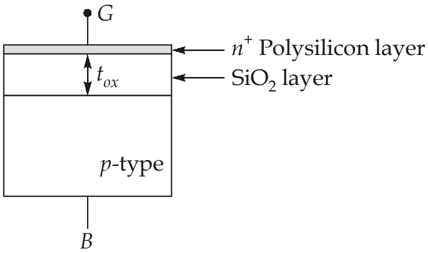
(a) Due to body effect, Latchup occurs in CMOS circuits.
(b) Due to body effect threshold voltage of a MOS device increases.
(c) The increase in the threshold voltage due to body effect becomes zero if source and body (substrate) are short circuited but latchup occurs.
(d) Body effect parameter (γ) is directly proportional to the oxide thickness.

Q.17 In a very long p-type Si bar with cross-sectional area = 0.5 cm^2 and $N_a = 10^{17}$ cm^{-3}, we inject holes such that the steady state excess hole concentration is 5×10^{16} cm^{-3} at $x = 0$. The excess stored hole charge (in nC) is __________.

Assume that $\mu_p = 500$ cm^2/V-sec and $\tau_p = 10^{-10}$ sec $= \tau_n$.

(a) 144 µC (b) 1.44 nC
(c) 14.4 nC (d) 144 nC

Q.18 Consider the MOS structure shown below with t_{ox} = 50 nm, the doping concentration in the substrate $N_a = 10^{16}$ cm^{-3}, $\in_{ox} = 3.45 \times 10^{-13}$ F/cm and $\in_{Si} = 1.05 \times 10^{-12}$ F/cm.
(Assume intrinsic carrier concentration, $n_i = 1 \times 10^{10}$ cm^{-3})



The value of hole concentration at the oxide semiconductor junction at flatband voltage and at threshold voltage is respectively

(a) 10^{16} cm^{-3}, 10^{20} cm^{-3} (b) 10^4 cm^{-3}, 10^{16} cm^{-3}
(c) 10^{16} cm^{-3}, 10^4 cm^{-3} (d) 10^{20} cm^{-3}, 10^{16} cm^{-3}

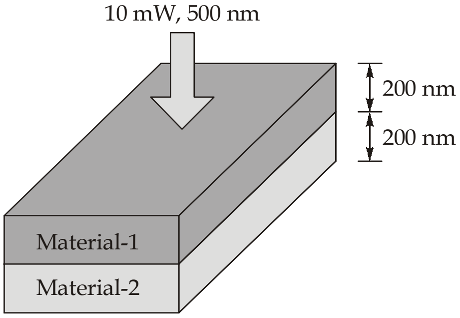
Q.19 Assume a p-type silicon at room temperature uniformly doped with $N_A = 10^{17}$ cm^{-3}, μ_n = 300 cm^2/V-sec and $\tau_n = 10^{-6}$ s. The sample has been uniformly illuminated with light for a long time with the optical generation rate, $G_L = 10^{20}$ cm^{-3} sec^{-1}. At $t = 0$, the light is switched off. Assuming spatially uniform conditions, the excess minority carrier concentration at t = 10 μs is

(a) 45.4×10^7 cm^{-3} (b) 45.4×10^8 m^{-3}
(c) 45.4×10^8 cm^{-3} (d) 55.4×10^8 cm^{-3}

Q.20 Consider a MOS device with an oxide thickness of 25 mm. A pulse of ionizing radiation creates 10^{18} electron-hole pairs per cm^3 in the oxide ($\in_{ox} = 3.9\in_0$). Assume that the electrons are swept through the gate terminal with zero recombination, and that 20 percent of the generated holes are trapped at the oxide-semiconductor interface. The magnitude of shift in the threshold voltage due to radiation induced oxide charge trapping is

(a) 0.486 V (b) 0.579 V
(c) 0.526 V (d) 0.625 V

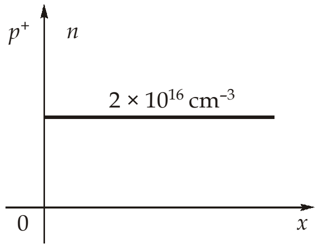
Q.21 Two different semiconductor materials, with identical dimensions, are fabricated one upon another as shown in the figure below.



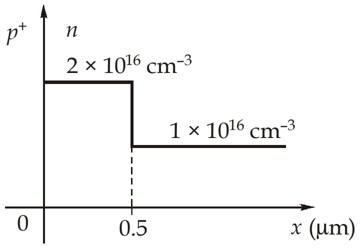
A monochromatic light of 10 mW is incident on the top surface of the composite block as shown. The wavelength of the light is less than the cut-off wavelength of both the materials. Assume that the surface of incidence and the interface between the materials are ideal such that no power will be reflected from them. If the light absorption coefficient of material-1 is 5×10^4 cm^{-1} and that of material-2 is 10^5 cm^{-1} at the given wavelength of the light, then the light power that will come out from the bottom surface of the composite block will be approximately equal to

(a) 0.37 mW (b) 0.50 mW
(c) 0.63 mW (d) 1.35 mW

Q.22 The donor concentrations in n-side of two p^+–n junction diodes are shown in the figure below.



For diode-1

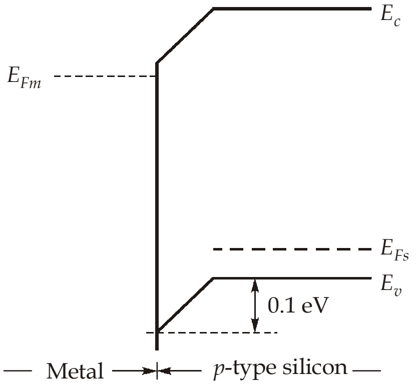


For diode-2

Both the diodes are made up of same type of material and both have identical doping profile in p^+ regions. Assume that, the width of the depletion region extended into p^+ region is negligible and the built-in potential is negligible compared to the breakdown voltage. It is known that the critical electric field at the junction for breakdown is 4×10^5 V/cm. If the breakdown voltage of diode–1 is 30 V, then the breakdown voltage of diode-2 will be approximately equal to

(a) 43.33 V (b) 66.67 V
(c) 86.67 V (d) 100 V

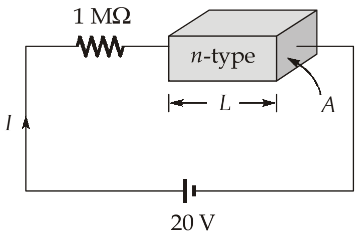
Q.23 A Schottky barrier is formed between a metal having a work function of 4.7 eV and a p-type silicon having electron affinity of 4 eV. The acceptor doping concentration in the p-type silicon is 10^{17} cm^{-3}. The device is operating at 300 K, where $kT = 0.026$ eV and intrinsic carrier concentration 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 given figure.

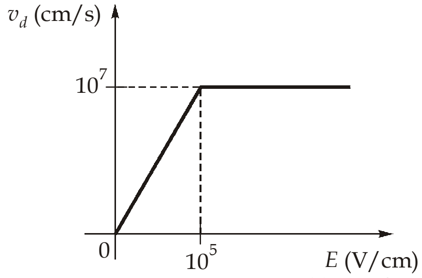


If the energy gap of silicon is 1.1 eV, then the magnitude of the forward biasing voltage is equal to

(a) 0.2 V (b) 0.1 V
(c) 0.17 V (d) 0.27 V

Q.24 A uniformly doped n-type semiconductor bar is connected in a circuit as shown in the following figure. The variation of drift velocity (v_d) of electrons with the electric field (E) across the semiconductor bar is also given in the figure.





The doping concentration used in the semiconductor bar is $N_d = 10^{16}$ cm^{-3} and assume that the minority carrier concentration is negligible. Dimensions of the semiconductor bar are: $L = 1$ μm and cross-sectional area A = (0.5 μm × 0.5 μm). The current (I) flowing through the circuit is approximately equal to

(a) 8 μA (b) 16 μA
(c) 20 μA (d) 40 μA

Q.25 A Si wafer, doped with 10^{15} cm^{-3} donar atoms, is uniformly illuminated with light which generates 10^{18} e-h pairs/cm^3/sec. Minority carrier life time in the wafer is 1 μs. In steady state, the position of quasi-Fermi levels for the two carrier times with respect to intrinsic Fermi level i.e., the values of ($E_{FN} - E_i$) and ($E_i - E_{FP}$) will be respectively equal to

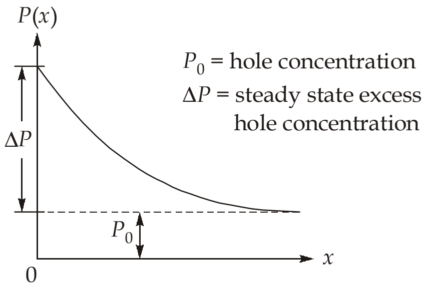
[Assume that, intrinsic carrier concentration $(n_i) = 10^{10}$ cm^{-3} and $kT = 0.026$ eV]

(a) 0.3 eV and 0.12 eV
(b) 0.12 eV and 0.3 eV
(c) 0.12 eV and 0.43 eV
(d) 0.43 eV and 0.67 eV

Q.26 An ideal MOS capacitor with p-type substrate has substrate doping concentration of $N_A = 1.2 \times 10^{15}$ cm^{-3}, oxide capacitance $C_{ox} = 2 \times 10^{-9}$ F/cm^2, $\varepsilon_{si} = 1.04 \times 10^{-12}$ F/cm. If the body terminal is grounded, then the gate voltage required to produce a surface potential of 0.026 V at the semiconductor-oxide layer interface will be

(a) 1.64 V (b) 0.82 V
(c) 3.28 V (d) 4.2 V

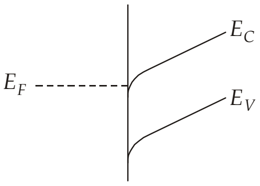
Q.27 Consider a p-type Si bar where injection of holes into Si bar gives a steady state hole distribution $P(x)$ shown in below figure.

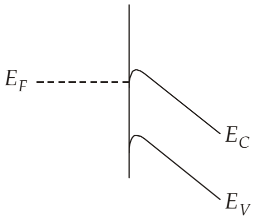


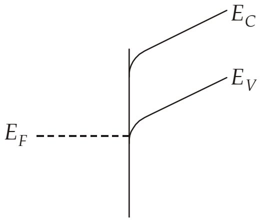
After injection, the steady state excess hole concentration is 5×10^{16} cm^{-3} at $x = 0$. Then the current density resulting by diffusion process at $x = 0$ is equal to (Assume $\tau_p = 10^{-10}$ sec, $\mu_p = 500$ cm^2/V-sec, $V_T = 26$ mV)

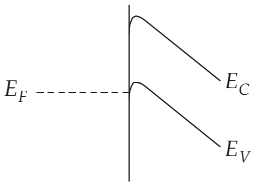
(a) 1.42×10^3 A/cm^2 (b) 2.88×10^3 A/cm^2
(c) 3.12×10^3 A/cm^2 (d) 3.63×10^4 A/cm^2

Q.28 Consider a metal n-type semiconductor junction with $\phi_m < \phi_s$. Which of the following represents the energy band diagram of the ohmic contact when a positive voltage is applied to the semiconductor?

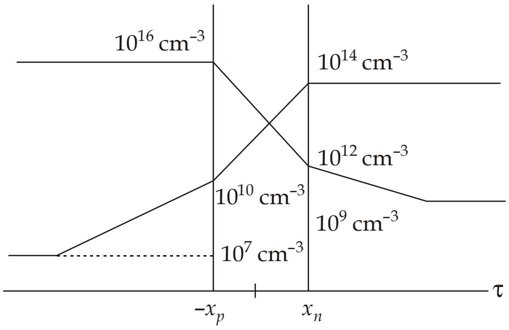
(a)


(b)


(c)


(d)


Q.29 The sketch below shows the carrier concentrations in a PN junction at room temperature.



The bias voltage applied to the diode is

(a) 0.28 V (b) 0.38 V
(c) 0.48 V (d) 0.18 V

Q.30 For a semiconductor material following parameters are observed:

$\mu_n = 1000$ cm^2/V-s
$\mu_p = 600$ cm^2/V-s
$N_C = N_V = 10^{19}$ cm^{-3}

Consider these parameters are independent of temperature. The measured conductivity of the intrinsic material is $\sigma = 10^{-6}$ $(\Omega\text{-cm})^{-1}$ at $T = 300$ K. The conductivity at $T = 500$ K will be

(in ℧/cm, assume that E_g is independent of temperature)

(a) 10^{-6} (b) 2.29×10^{-5}
(c) 3.91×10^{-4} (d) 5.63×10^{-3}

■■■■

CLASS TEST

Sl. : 01JPEC_EDC_16102023

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ELECTRONIC DEVICES

ELECTRONICS ENGINEERING

Date of Test : 16/10/2023

ANSWER KEY ➤

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

Detailed Explanations

2. (a)

In the given connection, V_G is negative. So, the MOS capacitor is in accumulation mode.

The energy band diagram given in option (a) is in accumulation mode.

3. (a)

$$\eta_r = \frac{\tau_{nr}}{\tau_r + \tau_{nr}} = \frac{1}{1 + \left(\dfrac{\tau_r}{\tau_{nr}}\right)} = \frac{20}{100} = \frac{1}{5}$$

So,
$$\frac{\tau_r}{\tau_{nr}} = 5 - 1 = 4$$

$$\tau_{nr} = \frac{\tau_r}{4} = \frac{10}{4} = 2.5 \text{ ns}$$

4. (b)

We know that, for intrinsic semiconductor,

$$n_i = \sqrt{N_C N_V}\, e^{-E_g/2\text{kT}}$$

$$\ln n_i = \ln\left(\sqrt{N_C N_V}\right) - \frac{E_g}{2\text{ kT}} \quad \text{...(i)}$$

but for intrinsic semiconductor, $n = n_i$

$$n_i = n = N_C e^{-(E_C - E_i)/\text{kT}}$$

$$\therefore \quad e^{-(E_C - E_i)/\text{kT}} = \frac{n_i}{N_C}$$

$$-(E_C - E_i)/\text{kT} = \ln\left(\frac{n_i}{N_C}\right)$$

$$E_i = E_C - \text{kT}\ln\left(\frac{N_C}{n_i}\right)$$

$$= E_C - \text{kT}[\ln(N_C) - \ln(n_i)]$$

From equation (i), substituting $\ln(n_i)$

$$E_i = E_C - \text{kT} \ln N_C + \text{kT} \ln(n_i)$$

$$= E_C - \text{kT}\ln N_C + \text{kT}\ln\sqrt{N_C N_V} - \frac{E_g}{2}$$

$$\therefore \quad E_i = E_C - \frac{E_g}{2} - \text{kT} \ln\sqrt{\frac{N_C}{N_V}}$$

5. (c)

We know that, when we dope silicon with boron atoms, it becomes p-type silicon semiconductor.

Given,dopant concentration, $N_a = 10^{16}$ cm^{-3}.

From the given graph, the resistivity of *p*-type silicon at 10^{16} cm^{-3} dopant density is equal to 10^2 Ω-cm.

$$\therefore \qquad \text{Resistance, } R = \frac{\rho l}{A}; \quad l = 1\ \mu\text{m};\ A = 0.1\ \mu\text{m}^2$$

$$= \frac{10^2 \times 1}{0.1 \times 10^{-4}}$$

$$\therefore \qquad R = 10^7\ \Omega$$

6. **(b)**

We know that,

$$\text{Diffusion capacitance, } C_D = \frac{\tau I_f}{\eta V_T}$$

$$\text{But, forward current, } I_f = I_0\, e^{\frac{V_F}{\eta V_T}}$$

$$\therefore \qquad C_D = \frac{\tau}{\eta V_T} I_0 \cdot e^{\frac{V_F}{\eta V_T}}$$

$$\text{Hence} \qquad C_D \propto e^{\frac{V_F}{\eta V_T}}$$

7. **(c)**

Given, doping concentrations, $N_a = 10^{20}\ \text{cm}^{-3};\ N_d = 10^{17}\ \text{cm}^{-3}$

We know that, the built-in potential,

$$V_{bi} = \frac{KT}{q} \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$$= 26 \times 10^{-3} \ln\left(\frac{10^{20} \times 10^{17}}{(10^{10})^2}\right)$$

$$= 0.026 \ln\left(\frac{10^{37}}{10^{20}}\right)$$

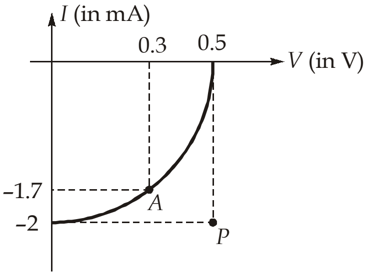
$$\therefore \qquad V_{bi} \simeq 1.0\ \text{V}$$

9. **(c)**

From the given energy band diagram, Emitter-Base junction is forward bias and collector-base junction is reverse bias. So, option (c) will satisfy.

10. **(d)**

Given I-V characteristics of solar cell,



At the operating point A, maximum output power, $P_{\max} = V_A \cdot I_A$

Input power of solar cell at point P,

$$P_{\text{in}} = V_P I_P$$

Fill factor (FF) of solar cell,

$$\text{FF} = \frac{P_{\max'}}{P_{in}} = \frac{V_A \cdot I_A}{V_P \cdot I_P} = \frac{0.3 \times (-1.7)}{0.5 \times (-2)}$$

$$\text{FF} = 0.51$$

11. **(b)**

Clearly from the given graph,

Semiconductor potential, $\phi_s = V_G - V_{ox} = 1.8 - 1.2 = 0.6$ V

The width of depletion region, under the strong inversion,

$$W_{\max} = \left[\frac{2\epsilon_{Si}(\phi_s)}{qN_a}\right]^{1/2}$$

$$W_{\max} = \left[\frac{2 \times 1.04 \times 10^{-12} \times 0.6}{1.6 \times 10^{-19} \times 1.5 \times 10^{15}}\right]^{1/2}$$

$$W_{\max} = 0.72 \times 10^{-4} \text{ cm} = 0.72 \ \mu\text{m}$$

12. **(b)**

Given that MOSFET operating in saturation region,

$$I_{DS} = \mu_n C_{ox} \frac{W}{2L}(V_{GS} - V_{th})^2 \quad \text{...(i)}$$

The transconductance of MOSFET (g_m) is

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{th}) \quad \text{...(ii)}$$

where (V_{GS} – V_{th}) is called overdrive voltage (V_{OV})

Dividing equation (i) to (ii)

$$\therefore \quad \frac{I_{DS}}{g_m} = \frac{V_{GS} - V_{th}}{2} = \frac{V_{OV}}{2}$$

$$\therefore \quad V_{OV} = \frac{2 \times 1 \times 10^{-3}}{2 \times 10^{-3}} = 1 \text{ V}$$

13. **(c)**

Given, Responsivity, $R = 0.5$ A/W

$$\text{Efficiency, } \eta = \frac{I_{ph} \times hc}{P_{op} \times q\lambda}$$

$$= R \cdot \frac{hc}{q\lambda}$$

$$\eta = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{0.5 \times 1.6 \times 10^{-19} \times 850 \times 10^{-9}} = 0.73$$

$$\eta = 0.73$$

14. (a)

$N_E = 5 \times 10^{18}$ cm^{-3}, $N_B = 10^{16}/\text{cm}^3$, $N_C = 10^{15}/\text{cm}^3$, Base width = 1 μm

Now, depletion width of *EB* junction extended into Base region.

$$W_1 = \left(\frac{N_E}{N_E + N_B}\right) \times 0.22\ \mu\text{m}$$

$$= \left[\frac{5 \times 10^{18}}{5 \times 10^{18} + 10^{16}}\right] \times 0.22$$

$$W_1 = 0.22\ \mu\text{m}$$

Similarly, depletion width of *CB* junction extended into base region

$$W_2 = \left(\frac{N_C}{N_C + N_B}\right) \times 2.86 = \left[\frac{10^{15}}{10^{16} + 10^{15}}\right] \times 2.86$$

$$W_2 = 0.26\ \mu\text{m}$$

$$\therefore \text{Neutral base width, } W_B = 1 - W_1 - W_2 = 1 - 0.22 - 0.26$$

$$= 0.52\ \mu\text{m}$$

15. (a)

Under active mode biasing

Collector base junction is reverse bias. The punch through voltage,

$$V_{CB} \propto \left[\frac{N_C N_B}{N_C + N_B}\right]$$

Clearly $[V_{CB}]_{Tr\cdot A} < [V_{CB}]_{Tr\cdot B}$

and it is limited by Avalanche Breakdown.

16. (a)

(a) Body effect prevents latch up condition

(b) $\Delta V_T \propto \sqrt{V_{SB}}$

(c) $\Delta V_T \propto \sqrt{V_{SB}}$, if $V_{SB} = 0$ then increase in threshold voltage is zero.

(d) $\gamma = \dfrac{\sqrt{2 \in_{Si} eN_A}}{C_{ox}} = \dfrac{t_{ox}}{\in_{ox}}\sqrt{2 \in_{Si} eN_A}$

17. (d)

$$D_p = \mu_p V_T = 0.0259 \times 500 = 12.95\ \text{cm}^2/\text{sec}$$

$$L_p = \sqrt{D_p \tau_p} = \sqrt{12.95 \times 10^{-10}} = 3.6 \times 10^{-5}\ \text{cm}$$

Excess stored hole charge $Q_P = qA(\Delta p)L_p$

$$= 1.6 \times 10^{-19} \times 0.5 \times 5 \times 10^{16} \times 3.6 \times 10^{-5}$$

$$= 14.4 \times 10^{-8}$$

$$Q_p = 144\ \text{nC}$$

18. **(c)**

At flatband voltage, hole concentration is equal to doping concentration.

∴ At the junction, $p = N_a = 10^{16}\text{ cm}^{-3}$

At threshold voltage, e^- concentration is equal to doping concentration.

∴ At the junction, $n = N_a = 10^{16}\text{ cm}^{-3}$

$$\therefore \qquad p(x=0) = \frac{n_i^2}{n} = \frac{10^{20}}{10^{16}}$$

$$p = 10^4\text{ cm}^{-3}$$

19. **(c)**

The minority carrier diffusion equation is given as

$$\frac{\partial \Delta n}{\partial t} = D_n\frac{d^2\Delta n}{dx^2} - \frac{\Delta n}{\tau_n} + G_L$$

When the sample is illuminated before $t = 0$, at steady state and assuming spatially uniform conditions, we have,

$$0 = -\frac{\Delta n}{\tau_n} + G_L$$

$$\Rightarrow \qquad \Delta n = G_L\,\tau_n = 10^{20} \times 10^{-6} = 10^{14}\text{ cm}^{-3}$$

When the light is switched off at $t = 0$, the equation is modified as

$$\frac{\partial \Delta n}{\partial t} = -\frac{\Delta n}{\tau_n}$$

The solution is, $\Delta n(t) = Ae^{-t/\tau_n}$

At $t = 0$, $\Delta n(0) = A = 10^{14}\text{ cm}^{-3}$

Hence, $\Delta n(t) = 10^{14}e^{-10^6 t}\text{ cm}^{-3}$

At t = 10 μs, $\Delta n(10\ \mu\text{s}) = 10^{14}\,e^{-10} = 45.4 \times 10^8\text{ cm}^{-3}$

20. **(b)**

The areal density of holes generated in the oxide is

$$N_h = 10^{18} \times 25 \times 10^{-7} = 25 \times 10^{11}\text{ cm}^{-2}$$

The equivalent trapped surface charge is

$$Q'_{ss} = 0.2 \times 25 \times 10^{11} \times 1.6 \times 10^{-19}$$

$$Q'_{ss} = 8 \times 10^{-8}\text{ C/cm}^2$$

The shift in threshold voltage is,

$$\Delta V_T = \frac{-Q'_{ss}}{C_{ox}} = \frac{-Q'_{ss}\,t_{ox}}{\epsilon_{ox}}$$

$$\Delta V_T = \frac{-8\times10^{-8}\times25\times10^{-7}}{3.9\times8.85\times10^{-14}}$$

$$\Delta V_T = -0.579\text{ V}$$

$$\Rightarrow \qquad |\Delta V_T| = 0.579\text{ V}$$

21. **(b)**

Let the absorption coefficients of materials as α_1 and α_2, and respective thickness of the material blocks are L_1 and L_2.

Given that, $\alpha_1 = 5 \times 10^4\ \text{cm}^{-1}$ and $\alpha_2 = 10^5\ \text{cm}^{-1}$

$L_1 = L_2 = 200\ \text{nm} = 2 \times 10^{-5}\ \text{cm}$

The relation between the incident power (P_i) and the power come out from the bottom surface (P_o) can be given by,

$$P_o = P_i\, e^{-\alpha_1 L_1} e^{-\alpha_2 L_2}$$

$$\alpha_1 L_1 = 5 \times 10^4 \times 2 \times 10^{-5} = 1$$

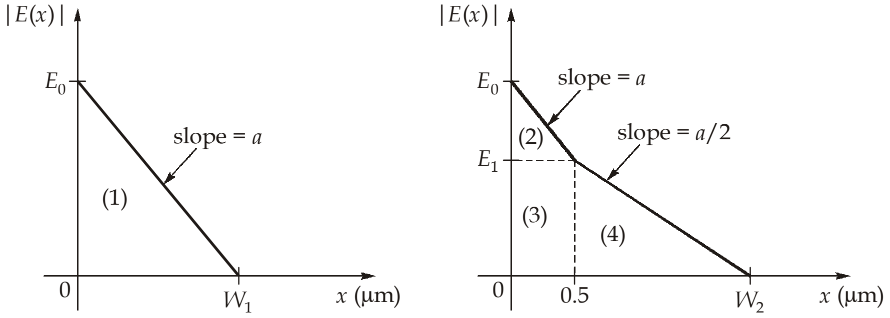
$$\alpha_2 L_2 = 10^5 \times 2 \times 10^{-5} = 2$$

Given that, $P_i = 10\ \text{mW}$

So, $P_o = 10(e^{-1})(e^{-2}) = 10e^{-3} \simeq 0.50\ \text{mW}$

22. **(a)**

The magnitude of electric field distributed in n-side for both the diodes can be plotted as shown below.



When E_0 = critical electric field = 4×10^5 V/cm, the area under the plot of $|E(x)|$ is equal to the breakdown voltage.

$$\text{Area (1)} = \frac{1}{2}E_0 W_1 = V_{BR(1)} = 30\ \text{V}$$

$$W_1 = \frac{2 \times 30}{4 \times 10^5}\text{cm} = \frac{60}{40}\mu\text{m} = 1.5\ \mu\text{m}$$

Observe clearly the above plots, the slope of the curve $|E(x)|$ is same in both the plots till $x = 0.5\ \mu$m, but it becomes half in the second plot from $x = 0.5\ \mu$m.

So, $W_2 = 0.5\ \mu\text{m} + 2(W_1 - 0.5\ \mu\text{m}) = 0.5 + 2(1.5 - 0.5) = 2.5\ \mu\text{m}$

$$E_1 = E_0 - \frac{0.5\ \mu\text{m}}{W_1}E_0 = \frac{2E_0}{3}$$

$$V_{BR(2)} = \text{Area (2)} + \text{Area (3)} + \text{Area (4)}$$

$$\text{Area (2)} = \left(\frac{1}{2} \times 0.5 \times 10^{-4} \times \frac{4 \times 10^5}{3}\right) = \frac{10}{3}\text{V}$$

$$\text{Area (3)} = \frac{2 \times 4 \times 10^5}{3} \times 0.5 \times 10^{-4} = \frac{40}{3}\text{V}$$

$$\text{Arae (4)} = \frac{1}{2} \times \frac{2 \times 4 \times 10^5}{3} \times (W_2 - 0.5\mu)$$

$$= \frac{1}{2} \times \frac{2 \times 4 \times 10^5}{3} \times 2 \times 10^{-4} = \frac{80}{3} \text{ V}$$

So, $$V_{BR(2)} = \frac{10 + 40 + 80}{3} = \frac{130}{3} = 43.33 \text{ V}$$

23. **(c)**

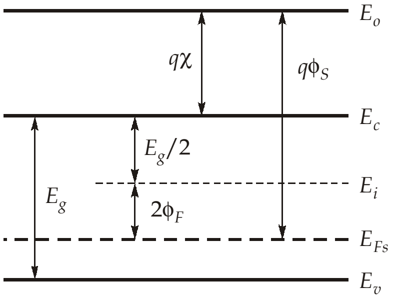
From the given energy band diagram, it is clear that,

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

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

Given that, $\phi_m = 4.7$ V

To calculate ϕ_s :



$$q\phi_s = q\chi + \frac{E_g}{2} + q\phi_F$$

$$\phi_s = \chi + \frac{E_g}{2q} + \phi_F$$

$$= (4 + 0.55) + \frac{kT}{q} \ln\left(\frac{N_a}{n_i}\right)$$

$$= 4.55 + 0.026 \ln (10^7) \simeq 4.97 \text{ V}$$

$$V_o = \phi_s - \phi_m = 4.97 - 4.7 = 0.27 \text{ V}$$

$$V_o - V = 0.1 \text{ V}$$

$$V = V_o - 0.1 = 0.27 - 0.1 = 0.17 \text{ V}$$

24. **(b)**

From the given graph of v_d, we get,

Electron mobility, $$\mu_n = \frac{10^7}{10^5} = 100 \text{ cm}^2/\text{V-s}$$

Assuming that the v_d is in linear region for the given supply voltage,

$$I = nqA\mu_n E = nqA\mu_n \frac{V_s}{L}$$

$$V_s = (20 \text{ V} - IR) = (20 - 10^6 I) \quad [\because R = 1 \text{ M}\Omega]$$

So,
$$I = 10^{16}\times1.6\times10^{-19}\times0.25\times10^{-8}\times100\times\frac{(20-10^{6}I)}{10^{-4}}$$
$$I = (4\times10^{-6})(20-10^{6}I) = (80\times10^{-6}) - 4I$$
$$5I = 80\times10^{-6}$$
$$I = 16\ \mu\text{A}$$

Verifying the validity of the assumption:

At $I = 16\ \mu$A, the voltage across the semiconductor bar will be,

$$V_s = 20\text{ V} - IR = 20 - 16 = 4\text{ V}$$
$$E = \frac{V_s}{L} = \frac{4\text{ V}}{1\ \mu\text{m}} = 4\times10^{4}\text{ V/cm}$$
$$E = 4\times10^{4}\text{ V/cm} < 10^{5}\text{ V/cm} \Rightarrow v_d \text{ is in linear region.}$$

So, our initial assumption is correct and hence $I = 16\ \mu$A.

25. **(a)**

The concentration of excess electrons and holes generated are,

$$\delta p = \delta n = \text{Generation rate }(G_{op})\times\tau_p$$
$$= 10^{18}\times10^{-6} = 10^{12}\text{ cm}^{-3}$$

In steady state

Concentration of holes $(p') = p_0 + \delta p$

where $p_0 = \dfrac{n_i^2}{n_0} = 10^{5}\text{ cm}^{-3}$

$\therefore \quad p' = 10^{5} + 10^{12} \cong 10^{12}\text{ cm}^{-3}$

concentration of electrons $(n') = n_0 + \delta n = 10^{15} + 10^{12} \simeq 1\times10^{15}\text{ cm}^{-3}$

So,
$$E_{Fn} - E_i = kT\ln\left(\frac{n'}{n_i}\right) = 0.026\ln\left(\frac{10^{15}}{10^{10}}\right) \simeq 0.3\text{ eV}$$
$$E_i - E_{FP} = kT\ln\left(\frac{p'}{n_i}\right) = 0.026\ln\left(\frac{10^{12}}{10^{10}}\right) \simeq 0.12\text{ eV}$$

26. **(a)**

Substrate doping concentration,

$N_A = 1.2\times10^{15}\text{ cm}^{-3}$

Oxide capacitance, $C_{ox} = 2\times10^{-9}\text{ F/cm}^2$

Surface potential, $\phi_s = 0.026$ V

gate voltage, $V_G = \phi_s + V_{ox}$

but,
$$V_{ox} = \frac{\sqrt{2qN_A\varepsilon_{si}\phi_s}}{C_{ox}}$$
$$V_{ox} = \frac{\sqrt{2\times1.6\times10^{-19}\times1.2\times10^{15}\times1.04\times10^{-12}\times0.026}}{2\times10^{-9}}$$

$\therefore \quad V_{ox} = 1.611$ V

$\therefore$ Gate voltage, $V_G = \phi_s + V_{ox} = 0.026 + 1.611$

$\therefore \quad V_G = 1.637\text{ V} \approx 1.64\text{ V}$

27. (b)

We know that, diffusion current density due to injection of holes,

$$J_n(x) = -qD_p \frac{dP(x)}{dx}$$

where, $D_p = V_T \mu_P$

$D_p = 26 \times 10^{-3} \times 500 = 13 \text{ cm}^2/\text{sec}$

diffusion length, $L_p = \sqrt{D_p \tau_p}$

$$L_p = \sqrt{13 \times 10^{-10}} = 3.6 \times 10^{-5} \text{cm}$$

and $P(x) = P_0 + \Delta P e^{-x/L_p}$ due to injection of holes

∴ $P(x) = P_0 + 5 \times 10^{16}\, e^{-x/L_p}$

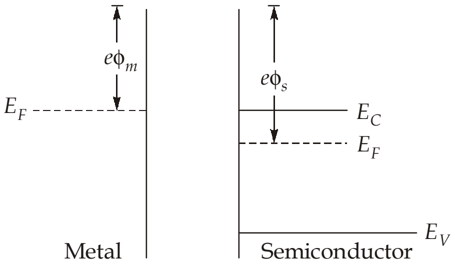
$$\therefore \quad J_n(x) = -qD_p \frac{d}{dx}\left[P_0 + 5 \times 10^{16} e^{-x/L_p}\right]$$

at $x = 0$; $$J_n(0) = q\frac{D_p}{L_p} 5 \times 10^{16} = 1.6 \times 10^{-19} \times \frac{13}{3.6 \times 10^{-5}} \times 5 \times 10^{16}$$

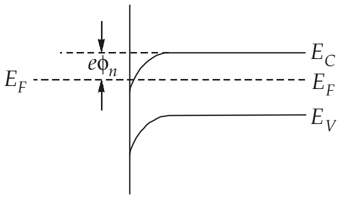
∴ $J_n(0) = 2.88 \times 10^3 \text{ A/cm}^2$

28. (b)

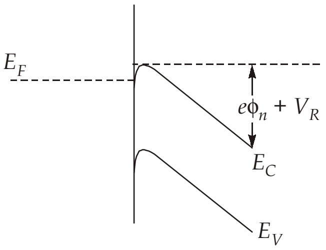
If $\phi_m < \phi_s$, the energy levels before the contact are shown below:



When they come in contact, to achieve thermal equilibrium in the junction, electrons flow from the metal into the lower energy states in the semiconductor, which makes the surface of the semiconductor more *n*-type. The excess charge in the *n*-type semiconductor exists essentially as a surface charge density.



When a positive voltage is applied to the semiconductor, (i.e., reverse bias), the energy band diagram is as below:



29. (d)

We have,

$$N_A = 10^{16}\text{ cm}^{-3},\ N_D = 10^{14}\text{ cm}^{-3}$$

$$n_i^2 = n_o p_o = 10^{16} \times 10^{7} = 10^{14} \times 10^{9}$$

$$n_i^2 = 10^{23} \Rightarrow n_i = 3.16 \times 10^{11}\text{ cm}^{-3},$$

According to the law of the junction,

$$\Delta n(-x_p) = n_{po} \exp\left(\frac{qV_A}{kT}\right)$$

$$\Rightarrow \qquad V_A = \frac{kT}{q} ln\left[\frac{\Delta n(-x_p)}{\eta_{po}}\right]$$

$$V_A = 0.026\, ln\left(\frac{10^{10}}{10^{7}}\right) = 0.18\, V$$

30. (d)

Given: σ = 10^{-6}/cm at $T = 300$ K

$$\sigma = q\, n_i(\mu_n + \mu_p)$$

$$10^{-6} = 1.6 \times 10^{-19}\, n_i(1600)$$

$$n_i = 3.91 \times 10^{9}\text{ cm}^{-3}$$

$$E_g = kT \ln\left(\frac{N_C N_V}{n_i^2}\right)$$

$$= 26 \times 10^{-3} \ln\left[\frac{10^{19} \times 10^{19}}{(3.91 \times 10^{9})^2}\right]$$

$$= 1.12\text{ eV}$$

at $T = 500$ K, let conductivity is σ′ and intrinsic concentration be n_i'

$$\sigma' = q(n_i')[\mu_n + \mu_p]$$

$$(n_i')^2 = N_C N_V e^{-\left(\frac{1.12}{0.043}\right)}$$

$$n_i' = 2.20 \times 10^{13}\text{ cm}^{-3}$$

$$\therefore \qquad \sigma' = qn_i'(\mu_n + \mu_p) = 1.6 \times 10^{-19} \times 2.20 \times 10^{13}\,(1000 + 600)$$

$$\sigma' = 5.63 \times 10^{-3}\ \text{℧/cm}$$

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