CLASS TEST

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ELECTRONIC DEVICES

ELECTRONICS ENGINEERING

Date of Test : 27/08/2023

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)

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

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.

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

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

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

6. **(b)**

We know that,

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

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

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

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

7. **(c)**

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

We know that, the built-in potential,

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

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

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

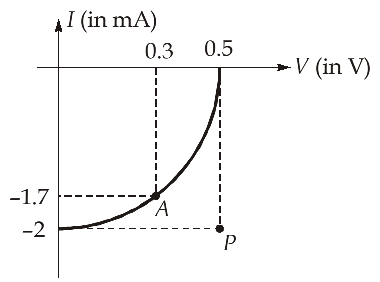
$\therefore$ $V_{bi} \simeq 1.0\ V$

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,

$$P_{in} = V_P I_P$$

Fill factor (FF) of solar cell,

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

$$FF = 0.51$$

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,

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

$$W_{max} = \left[\frac{2\times1.04\times10^{-12}\times0.6}{1.6\times10^{-19}\times1.5\times10^{15}}\right]^{1/2}$$

$$W_{max} = 0.72\times10^{-4}\text{ cm} = 0.72\ \mu\text{m}$$

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)

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

$$\therefore \quad V_{OV} = \frac{2\times1\times10^{-3}}{2\times10^{-3}} = 1\text{ V}$$

13. (c)

Given, Responsivity, R = 0.5 A/W

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

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

$$\eta = \frac{6.626\times10^{-34}\times3\times10^{8}}{0.5\times1.6\times10^{-19}\times850\times10^{-9}} = 0.73$$

$$\eta = 0.73$$

14. (a)

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

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

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

$$= \left[\frac{5\times10^{18}}{5\times10^{18}+10^{16}}\right]\times 0.22$$

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

Similarly, depletion width of CB junction extended into base region

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

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

∴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) $\gamma = \dfrac{\sqrt{2\,\epsilon_{Si}\, eN_A}}{C_{ox}} = \dfrac{t_{ox}}{\epsilon_{ox}}\sqrt{2\,\epsilon_{Si}\, eN_A}$

17. (d)

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

$$L_p = \sqrt{D_p \tau_p} = \sqrt{12.95\times10^{-10}} = 3.6\times10^{-5}\ \text{cm}$$

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.

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

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

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

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

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

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,

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

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

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,

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

$$\Delta V_T = \frac{-8 \times 10^{-8} \times 25 \times 10^{-7}}{3.9 \times 8.85 \times 10^{-14}}$$

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

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

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,
$$\alpha_1 = 5 \times 10^4 \text{ cm}^{-1} \text{ and } \alpha_2 = 10^5 \text{ cm}^{-1}$$
$$L_1 = L_2 = 200 \text{ nm} = 2 \times 10^{-5} \text{ cm}$$

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

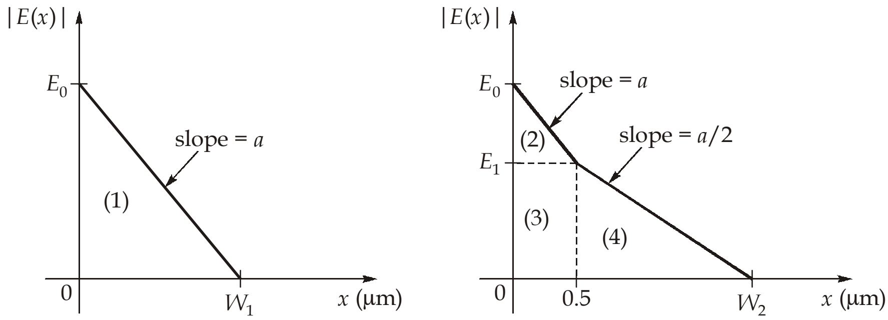
$$P_o = P_i e^{-\alpha_1 L_1} e^{-\alpha_2 L_2}$$
$$\alpha_1 L_1 = 5 \times 10^4 \times 2 \times 10^{-5} = 1$$
$$\alpha_2 L_2 = 10^5 \times 2 \times 10^{-5} = 2$$

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 $x = 0.5$ μm, but it becomes half in the second plot from $x = 0.5$ μm.

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)

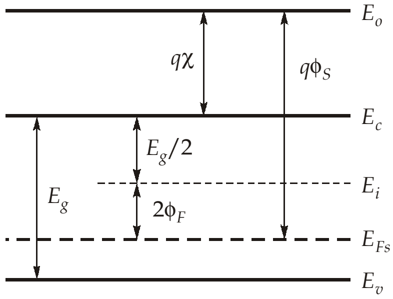
From the given energy band diagram, it is clear that,

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

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,
$$I = 10^{16} \times 1.6 \times 10^{-19} \times 0.25 \times 10^{-8} \times 100 \times \frac{(20 - 10^6 I)}{10^{-4}}$$
$$I = (4 \times 10^{-6})(20 - 10^6 I) = (80 \times 10^{-6}) - 4I$$
$$5I = 80 \times 10^{-6}$$
$$I = 16\ \mu A$$

Verifying the validity of the assumption:

At $I = 16\ \mu A$, the voltage across the semiconductor bar will be,
$$V_s = 20\text{ V} - IR = 20 - 16 = 4\text{ V}$$
$$E = \frac{V_s}{L} = \frac{4\text{ V}}{1\ \mu m} = 4 \times 10^4\text{ V/cm}$$
$$E = 4 \times 10^4\text{ V/cm} < 10^5\text{ V/cm} \Rightarrow v_d \text{ is in linear region.}$$

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

25. (a)

The concentration of excess electrons and holes generated are,
$$\delta p = \delta n = \text{Generation rate } (G_{op}) \times \tau_p$$
$$= 10^{18} \times 10^{-6} = 10^{12}\text{ cm}^{-3}$$

In steady state

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

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

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

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

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,
$$N_A = 1.2 \times 10^{15}\text{ cm}^{-3}$$

Oxide capacitance, $C_{ox} = 2 \times 10^{-9}\text{ F/cm}^2$

Surface potential, $\phi_s = 0.026\text{ V}$

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

but,
$$V_{ox} = \frac{\sqrt{2qN_A \varepsilon_{si} \phi_s}}{C_{ox}}$$
$$V_{ox} = \frac{\sqrt{2 \times 1.6 \times 10^{-19} \times 1.2 \times 10^{15} \times 1.04 \times 10^{-12} \times 0.026}}{2 \times 10^{-9}}$$

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

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

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

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

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

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

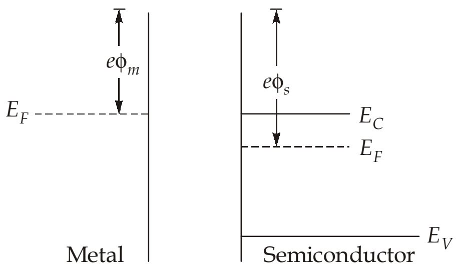
at $x = 0$;

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

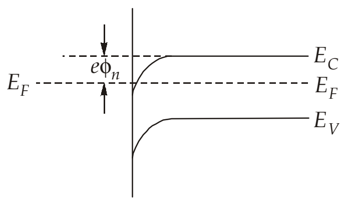
∴ $J_n(0) = 2.88 \times 10^3 \text{ A/cm}^2$

28. (b)

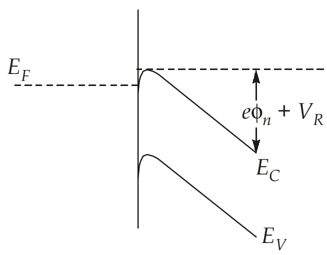
If $\phi_m < \phi_s$, the energy levels before the contact are shown below:



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,
$$\Delta n(-x_p) = n_{po} \exp\left(\frac{qV_A}{kT}\right)$$
$$\Rightarrow \quad V_A = \frac{kT}{q} ln\left[\frac{\Delta n(-x_p)}{\eta_{po}}\right]$$
$$V_A = 0.026\, ln\left(\frac{10^{10}}{10^7}\right) = 0.18\ V$$

30. (d)

Given: $\sigma = 10^{-6}$/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'
$$\sigma' = q(n_i')[\mu_n + \mu_p]$$
$$(n_i')^2 = N_C N_V e^{-\left(\frac{1.12}{0.043}\right)}$$
$$n_i' = 2.20 \times 10^{13}\ \text{cm}^{-3}$$
$$\therefore \quad \sigma' = qn_i'(\mu_n + \mu_p) = 1.6 \times 10^{-19} \times 2.20 \times 10^{13}\ (1000 + 600)$$
$$\sigma' = 5.63 \times 10^{-3}\ \mho/\text{cm}$$

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