

EE566 Solid State Devices

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Dept of Electrical Engineering

University of Notre Dame

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Assignment 6 SOLUTIONS

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EE 566

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1. 5.12 MKC.

The net flux of e^- entering the p-region of the diode $\phi_n = \frac{\Delta n \Delta x}{\tau_0}$

The net flux of e^- & h^+ entering the space charge region $\phi_{n+p} = \frac{\Delta n \Delta x}{2\tau_0}$

The net flux of h^+ entering the n-region of the diode $\phi_p = \frac{2(\Delta n \Delta x)}{\tau_0}$

with currents

$$J_T = J_n + J_p + 2J_r$$

$$J_T = J_n \left(\frac{7}{2} \right)$$

recombination current.

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2.5.14.

$$I = qA \left(\frac{D_n n_i^2}{L_n N_A} + \frac{D_p n_i^2}{L_p N_D} \right) (e^{qV_a/KT} - 1)$$

$$I = qA \exp(-E_g/KT) \left(\frac{D_n N_c N_v}{L_n N_A} + \frac{D_p N_c N_v}{L_p N_D} \right) (e^{qV_a/KT} - 1)$$

$$\left| \frac{I_F}{I_R} \right| = (e^{qV_a/KT} - 1) = 10^4 \quad \checkmark$$

$$T = \frac{q}{k \ln(10^4 + 1)} = 1259 \text{ K}$$

$$I_0 = qA \exp(-E_g/KT) \left(\frac{D_n N_c N_v}{L_n N_A} + \frac{D_p N_c N_v}{L_p N_D} \right)$$

$$T = \frac{-E_g}{k \ln \left[\frac{I_0}{qA N_c N_v \left[\frac{D_n}{L_n N_A} + \frac{D_p}{L_p N_D} \right]} \right]} = 518 \text{ K}$$

$$A = 10^{-5} \text{ cm}^2$$

$$N_c = 2.8 \times 10^{19} \text{ cm}^{-3}$$

$$N_v = 1.0 \times 10^{19} \text{ cm}^{-3}$$

$$D_n = 39 \text{ cm}^2/\text{sec}$$

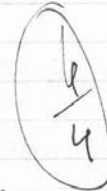
$$D_p = 12 \text{ cm}^2/\text{sec}$$

$$N_A = 5 \times 10^{18} \text{ cm}^{-3}$$

$$N_D = 10^{15} \text{ cm}^{-3}$$

$$L_n = \sqrt{D_n \tau_n} = 0.00197 \text{ cm}$$

$$L_p = \sqrt{D_p \tau_p} = 0.00110 \text{ cm}$$



3.

5.18 Using Charge Control Analysis we know

$$a. Q_p = \frac{(W_B - x_p)^2 J_0}{2 D_n} \quad W_B = 3 \text{ mm}$$

Since $N_D \gg N_A$ we can assume that the current is carried predominately by e^- 's. We can expect W_B to be much greater than x_p \therefore

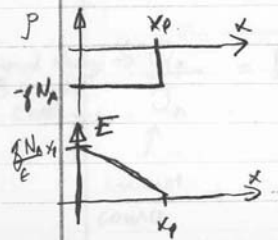
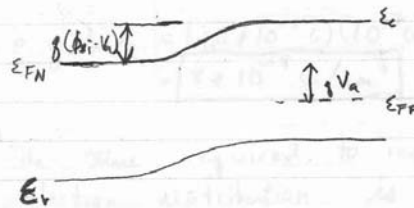
$$Q_p = \frac{(W_B)^2}{2 D_n} \frac{I}{A} = 5.77 \times 10^{-9} \text{ C/cm}^2 \quad \leftarrow \text{refer to buck for more exact}$$

We will justify the assumption in part (b.) of this problem.

$$b. I_n = \left(\frac{q A D_n n_i^2}{W N_A} \right) \left(e^{q V_a / K T} - 1 \right)$$

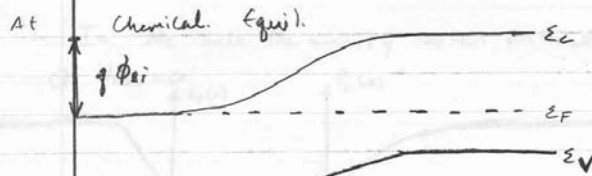
$$V_a = \frac{K T}{q} \ln \left(\frac{I_n W N_A}{q A D_n n_i^2} + 1 \right)$$

$$V_a = .741 \text{ V}$$



$$\frac{q N_A x_p^2}{2 \epsilon} = \phi_{Bi} - V_a$$

$$x_p = \sqrt{\frac{2 \epsilon (\phi_{Bi} - V_a)}{q N_A}}$$



By Inspection

$$\phi_{bi} = \frac{kT}{q} \ln \left(\frac{N_A N_D}{n_i^2} \right) = 0.985 \text{ V.}$$

$$\phi_{bi} - V_a = 0.19 \text{ V.}$$

$$x_p = \sqrt{\frac{2(11.9)(8.854 \times 10^{-12} \text{ F/m})(0.19 \text{ V})}{(1.602 \times 10^{-19} \text{ C})(10^{17} \text{ cm}^{-3})(100 \text{ cm})^3 / \text{m}^3}}$$

$$= 50 \text{ nm} \approx 0.05 \mu\text{m}$$

$$Q_p = \frac{(W_B - x_p)^2}{2D_n} \frac{I}{A} = \boxed{5.6 \times 10^{-8} \text{ C/cm}^2} \approx 2.5\% \text{ diff. in part (a)}$$

$$Q_{sc} = q N_A x_p = (1.6 \times 10^{-19} \text{ C})(10^{17} \text{ cm}^{-3})(5 \times 10^{-6} \text{ cm})$$

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

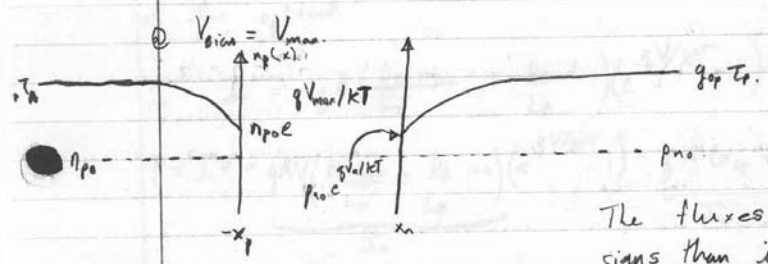
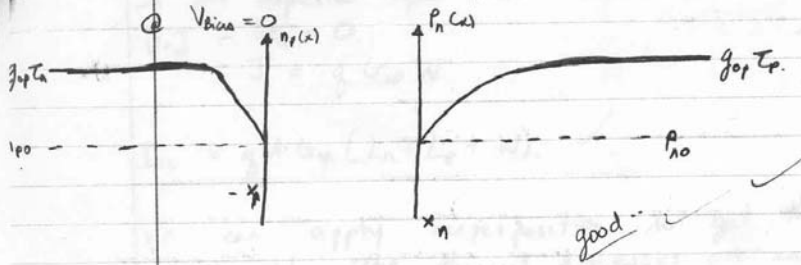
∴ The time required to reach the steady-state electron distribution is

stored charge → $\frac{Q_p}{J_n} = \frac{(W_B - x_p)^2}{2D_n} = \frac{(3 \times 10^{-4} \text{ cm} - 0.05 \times 10^{-4} \text{ cm})^2}{2(39 \text{ cm}^2/\text{sec})} = \boxed{1.2 \text{ ns}}$

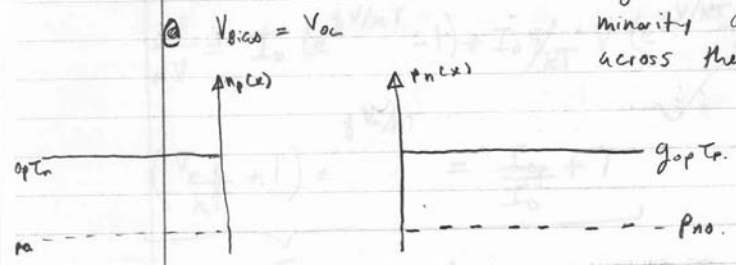
↑
current source

(b)

4. In the bulk the minority carrier distribution will be:



The fluxes have different signs than in the case where minority carriers are injected across the depletion region.



In the $V_{bias} = 0$, obviously @ the edges of the depletion region the dominant current mechanism for minority carriers is diffusion $\therefore J_{diff} = q D_n \frac{G_{op} I_n}{L_n} = q G_{op} L_n$.

$$J_{p, diff} = q D_p \frac{G_{op} I_p}{L_p} = q G_{op} L_p$$

In the depletion region we know

$$\nabla \cdot \mathbf{J} - G_{\text{opt}} = 0.$$

$$\mathbf{J} = q G_{\text{opt}} \mathbf{W}.$$

$$I_{\text{sc}} = q A G_{\text{opt}} (L_n + L_p + W).$$

We can apply superposition to get the net current b/c the thermal processes are independent of the optical.

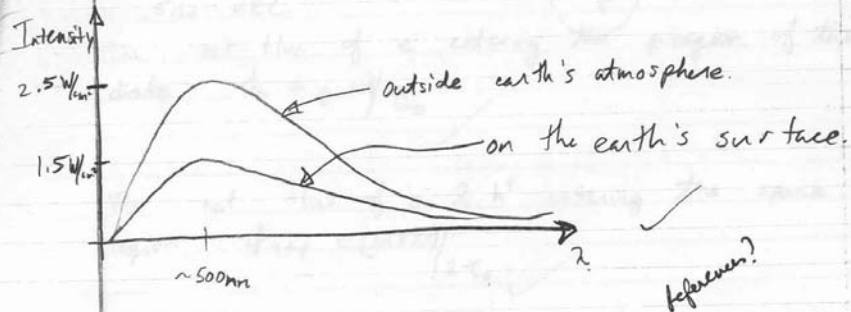
$$\therefore I = q A \left(\frac{D_n n_{\text{po}}}{L_n} + \frac{D_p p_{\text{po}}}{L_p} \right) (e^{qV/kT} - 1) - q A G_{\text{opt}} (L_n + L_p + W)$$

$$P = IV = \underbrace{qAV \left(\frac{D_n n_{\text{po}}}{L_n} + \frac{D_p p_{\text{po}}}{L_p} \right)}_{I_0} (e^{qV/kT} - 1) - \underbrace{q A G_{\text{opt}} V (L_n + L_p + W)}_{I_{\text{op}}}$$

$$\frac{dP}{dV} = I_0 (e^{qV/kT} - 1) + I_0 \frac{q}{kT} V (e^{qV/kT}) - I_{\text{op}} = 0.$$

$$\left(\frac{V q}{kT} + 1 \right) e^{qV/kT} = \frac{I_{\text{op}}}{I_0} + 1$$

Transcendental.



Highest reported efficiency is 36.9%.

Multi-junction cells exhibit the highest efficiency because the spectrum has a bandwidth in which most of the power is contained. Solar cells consisting of only one semi-conducting may not be able to create EHP from the photon of longer wavelength. However, if the energy of photon is much greater than the photon energy quickly recombine @ the surface. One way to mitigate the problem of the spectrum not being monochromatic is to employ cells which contain multiple bandgaps.

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