A

Section 3.10 in Anderson book discusses quasi-fermi levels.

Using equation 3.89 from Anderson, we can write the current densities J_n and J_p in terms of the carrier mobility, carrier concentration, and the first derivative of the quasi-fermi levels. This relationship is valid for any combination of drift and diffusion, so there is no need to find drift and diffusion separately.

$$J_n(x) = \mu_n(x)\, n(x) \frac{dE_{fn}}{dx}$$
$$J_p(x) = \mu_p(x)\, p(x) \frac{dE_{fp}}{dx} \qquad \text{equation 3.89}$$

Shortcut $\rightarrow$ at $x = 10\ \mu m$, E_{fn} and E_{fp} are both flat, so $\frac{dE_{fn}}{dx} = \frac{dE_{fp}}{dx} = 0$. So,

$$\boxed{\begin{aligned} J_n(x = 10\ \mu m) &= 0\ A/cm^2 \\ J_p(x = 10\ \mu m) &= 0\ A/cm^2 \end{aligned}}$$

1B At $x = 20\,\mu m$, we can use the equations 3.89 again.

$$J_n(x) = \mu_n(x)\, n(x) \frac{dE_{fn}}{dx}$$
$$J_p(x) = \mu_p(x)\, p(x) \frac{dE_{fp}}{dx}$$

at $x = 20\,\mu m$, none of these terms are zero, so we will need to calculate all three.

At $x = 20\,\mu m$, $E_{fn} = E_{fp} = E_i$. We can use equation 3.86 from Anderson to find n and p.

$E_{fn} = E_i + kT \ln\left(\frac{n}{n_i}\right)$ This implies that $kT \ln\left(\frac{n}{n_i}\right) = 0$

$E_{fp} = E_i - kT \ln\left(\frac{p}{n_i}\right)$ " " " $kT \ln\left(\frac{p}{n_i}\right) = 0$.

$n = n_i \quad (\ln(1) = 0)$
$p = n_i = 1 \times 10^{10}\ cm^{-3}$

Using equation 3.42 from Anderson

$$\mu_n = \frac{q D_n}{kT} \qquad \mu_p = \frac{q D_p}{kT}$$

$$\mu_n = \frac{33.625\ cm^2/sec}{.0259\ V} = 1298\ cm^2/V\text{-}sec$$

$$\mu_p = \frac{11.86\ cm^2/sec}{.0259\ V} = 458\ cm^2/V\cdot sec$$

$$\frac{dE_{fn}}{dx} = -10\ eV/\mu m \qquad \frac{dE_{fp}}{dx} = 2\ eV/\mu m$$

These units don't match our other terms, so conversion is needed.

$$\frac{-10\ eV}{\mu m}\left(\frac{1\ \mu m}{1\times 10^{-4}\ cm}\right)\left(\frac{1.6\times 10^{-19}\ J}{1\ eV}\right) = -1.6\times 10^{-14}\ J/cm$$

similarly,

$$\frac{2\ eV}{\mu m}\left(\frac{1\ \mu m}{1\times 10^{-4}\ cm}\right)\left(\frac{1.6\times 10^{-19}\ J}{1\ eV}\right) = 3.2\times 10^{-15}\ J/cm$$

Finally,

$$J_n = (\mu_n)(n)\left(\frac{dE_{fn}}{dx}\right) = -.208\left(\frac{J}{V}\right)\left(\frac{1}{sec}\right)\left(\frac{1}{cm^2}\right)$$

$$\frac{J}{V} = \text{coulomb}$$

$$\frac{\text{coulombs}}{sec} = \text{Amps}$$

$$\boxed{= -.208\ A/cm^2}$$

$$J_p = (\mu_p)(p)\left(\frac{dE_{fp}}{dx}\right) \boxed{= .0146\ A/cm^2}$$

2A] Use the minority carrier diffusion equation in lecture 10

$$\frac{\partial \Delta n_p}{\partial t} = D_N \frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G_L$$

The electron beam has been on for a long time, so it is safe to say that steady-state conditions apply up to when the beam is switched off.

We want to find the excess carrier concentration after the beam has been turned off, and in order to do that we need to know Δn_p at the moment the beam is switched off ~~as~~ in order to construct the exponentially decaying solution.

When the beam is on, absorption is uniform, so there is no concentration gradient $\frac{\partial^2 \Delta n_p}{\partial x^2} = 0$

This leaves $0 = -\frac{\Delta n_p}{\tau_n} + G_L$, which has general solution of $\Delta n_p = G_L \tau_n$. τ_n is known ($.1\mu S$) and G_L can be calculated.

G_L = hole/electron pair generation rate caused by electron bombardment.

$1\ nA/cm^2$ electrons $= \frac{\#\text{ electrons}}{cm^2/sec} = \frac{1nA}{1.6\times10^{-19}} = 6.25\times10^{9}$ electrons/$cm^2 \cdot sec$

2 um thick slab of semiconductor

$$\#\text{electrons}/_{cm^2 \cdot sec} = \frac{6.25 \times 10^9}{2 \times 10^{-4}} = 3.125 \times 10^{13}\ cm^{-3}/_{sec}$$

each of these electrons has 10,000 eV of energy. 1/3 of this energy goes towards electron-hole pair generation. Each electron-hole pair requires approx. 3.2 eV to form. $\frac{10000\ eV}{3 \cdot 3.2 eV} = 1042$ electron-hole pairs per bombarding electron.

$$G_L \approx 3.26 \times 10^{16}\ cm^{-3}/_{sec}$$

$$\Delta n_p = G_L \tau_n = 3.26 \times 10^9\ cm^{-3}$$

This is the concentration of excess electrons up to when the beam turns off

Once beam shuts down,

$$G_L = 0 \qquad \frac{\partial^2 \Delta n_p}{\partial x^2} = 0$$

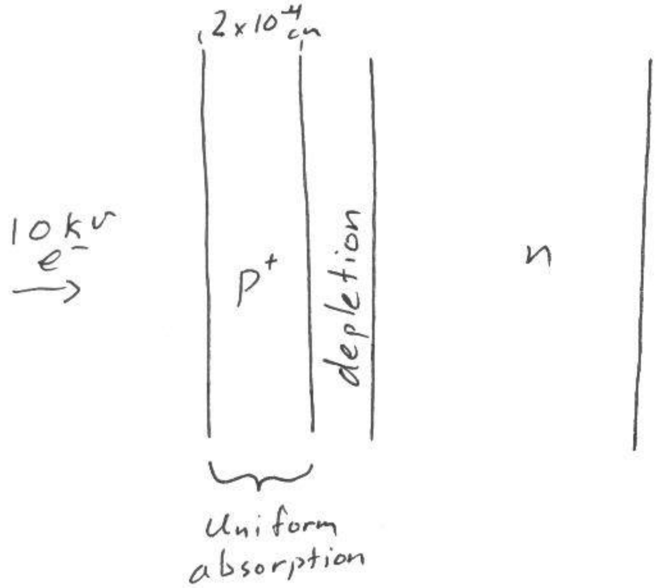
$$\frac{\partial \Delta n_p}{\partial t} = -\frac{\Delta n_p}{\tau_n}$$

which has solution

$$\Delta n_p(t) = \Delta n_p(x=0)\, e^{-t/\tau_n}$$

$$\boxed{\Delta n_p(t) = [3.26 \times 10^9 cm^{-3}]\, e^{-t/.1us}}$$

2B1 Device looks like this:



We're measuring the open-circuit voltage of this ~~photodiode~~ beta-voltaic diode, so we need to know carrier concentration and use law of the junction.

known: Steady-State $\rightarrow \dfrac{\partial \Delta n_p}{\partial t} = 0$

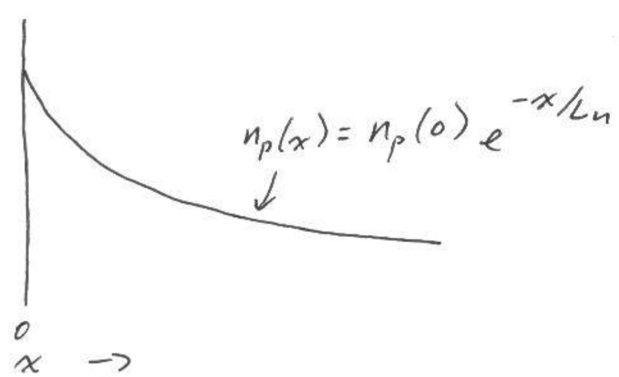
$G_{T_2} \rightarrow 3.26 \times 10^{16}\ cm^{-3}/sec$

$\dfrac{m^*_n}{m_0} = .355 \qquad \dfrac{m^*_p}{m_0} = .8 \qquad \tau_n = .1 \mu S$

$D_n = \dfrac{kT}{q}\mu_n \qquad \mu_n = 30\, cm^2/v \cdot sec \qquad D_n = .777$

$L_n = \sqrt{D_n \tau_n} = 2.78 \times 10^{-4}\ cm$

Normally, the concentration of excess carriers near a depletion region looks like this:



However, $L_n > 2 \times 10^{-4}\ cm$, the size of our p-region. So, over the width of the region absorbing the beta radiation n_p is fairly constant.

Treating Δn_p as constant over the absorbing region,

$\frac{\partial^2 \Delta n_p}{\partial x^2} = 0$ leaving us with

$0 = -\frac{\Delta n_p}{\tau_n} + G_L$ which has solution

$\Delta n_p = G_L \tau_n = 3.26 \times 10^9 \text{ cm}^{-3}$ Found in part A.

Voltage across the junction can now be found using equation 5.68 from Anderson.

$\Delta n_p = n_{po}(e^{qV_a/kT} - 1)$ V_a is the voltage across the device.

n_{po} can be found using the $n \cdot p = n_i^2$ relationship

~~due to low-level~~ $p = N_A = 10^{18} \text{ cm}^{-3}$

the trick now is to find n_i for SiC.

Equations 2.63 and 2.64 in Anderson and 2.85

$N_c = 2.54 \times 10^{19} \left(\frac{m_n^*}{m_0}\right)^{3/2} \left(\frac{T}{300K}\right)^{3/2} \text{cm}^{-3} = 5.37 \times 10^{18} \text{ cm}^{-3}$

$N_v = 2.54 \times 10^{19} \left(\frac{m_p^*}{m_0}\right)^{3/2} \left(\frac{T}{300K}\right)^{3/2} \text{cm}^{-3} = 1.82 \times 10^{19} \text{ cm}^{-3}$

$\cancel{n_i = \sqrt{N_c N_v}\, e^{-E_g/2kT}}$ $n_i = \sqrt{N_c N_v}\, e^{-E_g/2kT}$

$kT = .0259 \text{ eV}$ $n_i = 1.465 \times 10^{-8} \text{ cm}^{-3}$

$n_{po} = 2.146 \times 10^{-34}$

$\Delta n_p = 3.26 \times 10^9 \text{ cm}^{-3} = 2.146 \times 10^{-34}(e^{qV_A/kT} - 1)$

$\frac{qV_A}{kT} = 99$ $V_A = 2.5641$ $\boxed{V_A = 2.56 \text{ Volts}}$