4.3 |

HW-7

Si doped 2×10^{15} donors/cm^3

4×10^{14} EHP/cm^3 @ $t=0$

$\tau_n = \tau_p = 5ns$

$$\delta n(t) = \Delta n\, e^{-t/\tau_n}$$

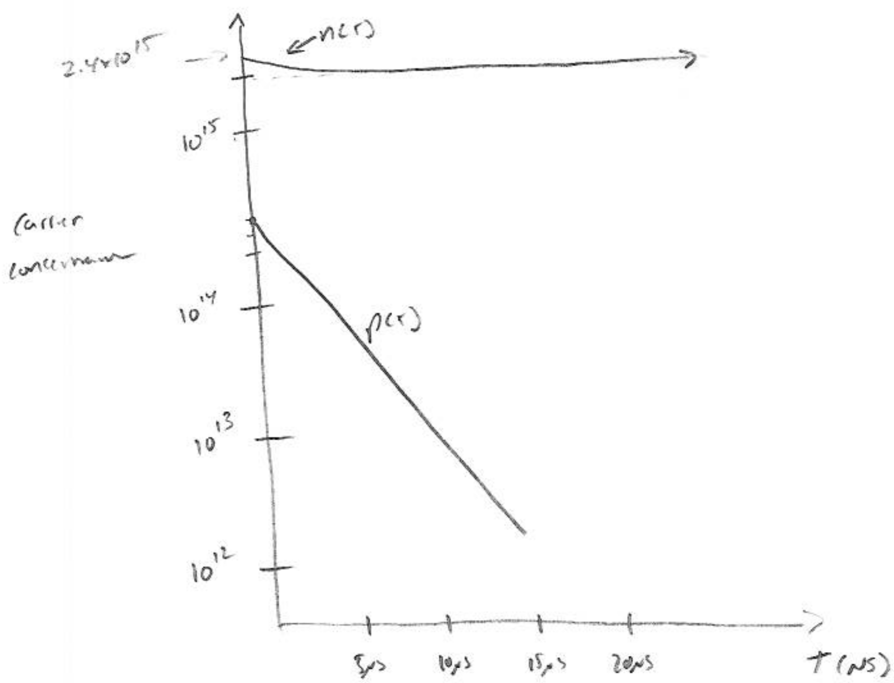
$$= 4\times10^{14} \cdot e^{-t/5ns}$$

$$\boxed{n(t) = 2\times10^{15} + 4\times10^{14}\, e^{-t/5ns}}$$

$$p(t) = p_0 + \Delta p\, e^{-t/5ns}$$

$$p_0 = \frac{n_i^2}{n} = \frac{2.25\times10^{20}}{2\times10^{15}} = 1.125\times10^{5}$$

$$p(t) = 1.125\times10^{5} + 4\times10^{14}\, e^{-t/5ns}$$



4.5

$$N_d = N_0 e^{-ax}$$

a) Find expression for $\mathcal{E}$ at equilibrium for $N_d \gg n_i$

In equilibrium, E_F constant

$$n = n_i e^{(E_F - E_i)/kT}$$

$$N_0 e^{-ax} = n_i e^{(E_F - E_i)/kT}$$

$$\ln \frac{N_0}{n_i} - ax = (E_F - E_i)/kT$$

$$E_i = E_F - kT \ln \frac{N_0}{n_i} + kTax$$

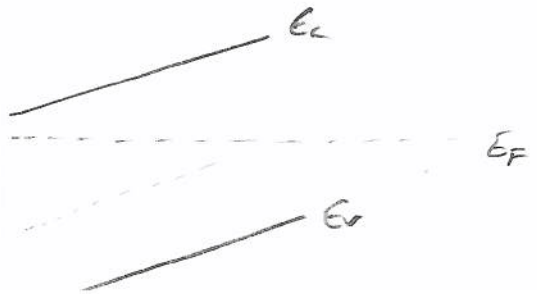
$$\mathcal{E}(x) = \frac{1}{q} \frac{\partial E_i}{\partial x}$$

$$\boxed{\mathcal{E}(x) = \frac{kT}{q} a}$$

b) $a = 1\ \mu m^{-1}$ $\qquad \mathcal{E}(x) = 26\,mV/\mu m = \frac{.026\ V}{1 \times 10^{-4}\ cm} = .026 \times 10^{4}\ V/cm$

$$\boxed{\mathcal{E} = 260\ V/cm = .26\ kV/cm}$$

c)



4.6)

Si, w/ $N_d = 10^{15}\ cm^{-3}$ @ RT

$g_{op} = 10^{19}$ EHP/cm^{-3} /s

$\tau_n = \tau_p = 10\,ns$ $D_p = 12\ cm^2/s$

Find ΔE_F's $\Rightarrow F_n - F_p$

for $g_{op} = 0$

$N_d = n = 10^{15}$

$n_o = n_i e^{(E_F - E_i)/kT}$

$kT \ln \frac{n}{n_i} = E_F - E_i$

$kT \ln \frac{10^{15}}{1.5\times10^{10}} = E_F - E_i$

$p_o = \frac{n_i^2}{n_o} = \frac{2.25\times10^{20}}{10^{15}} = 2.25\times10^5\ cm^{-3}$

for $g_{op} = 10^{19}$ EHP/$cm^3 \cdot s$

$\Delta p = \Delta n = 10^{19} \cdot 10\times10^{-6} = 10^{19} \cdot 1\times10^{-5} = 10^{14}\ cm^{-3}$

$p = p_o + \Delta p$

$= 2.25\times10^5 + 10^{14}\ cm^{-3}$

$\simeq 10^{14}\ cm^{-3}$

$n = n_o + \Delta n$

$= 10^{15} + 10^{14}\ cm^{-3}$

$= 1.1\times10^{14}\ cm^{-3}$

$p = n_i e^{(E_i - F_p)/kT}$

$n = n_i e^{(F_n - E_i)/kT}$

$E_i - F_p = kT \ln \frac{p}{n_i} = 0.228\,eV$

$F_n - E_i = kT \ln \frac{n}{n_i} = 0.2898\,eV$

$\boxed{F_n - F_p = 0.517\,eV}$

4.10

100mW laser $\lambda = 6328\,\text{Å}$

100μm GaAs $\alpha = 3\times10^4\ cm^{-1}$

NEED TO KNOW TEMP!!

ASSUME 300 K.

@ 300K, $E_g(GaAs) = 1.42 eV$

$$E_{laser} = \frac{12390}{6328} = 1.957 eV$$

$$E_{laser} - E_{gGaAs} = 0.538 eV$$

0.538 eV/photon goes to heat

How many photons is 100mW?

$$100 m J/s = 0.1 J/s = \frac{0.1}{1.6\times10^{-19}} eV/s = 6.25\times10^{17} eV/s$$

$$= 3.194 \text{ photons/s}$$

How many photons absorbed?

$$I = I_0 e^{-\alpha x} = 100mW\, e^{-3\times10^4 /cm \cdot .01 cm}$$

$$= 100mW\, e^{-300} \Rightarrow \text{All photons absorbed}$$

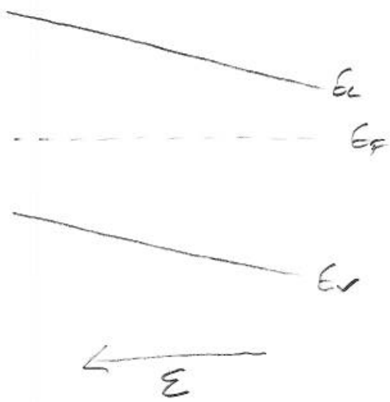
power absorbed = $\frac{0.538 eV}{1.957 eV} \cdot 100mW$

$= 27.5 mW$

power remained = 72.5 mW

4.13

n-type semiconductor



$J_n(\text{drift}) \Rightarrow \longrightarrow$

$J_n(\text{diff}) \Rightarrow \longleftarrow$

Double electrons

$J_n(\text{drift}) \propto n \rightarrow J_n$ doubles

$J_n(\text{diff}) \propto \partial n / \partial x$

i.e. $\Rightarrow$ if $n = n_0 \cdot x$

$\partial n / \partial x = n_0$

if $n = 2n_0 x$

$\partial n / \partial x = 2n_0$

$J_n(\text{diff}) \Rightarrow$ doubles

If you add constant n concentration

$J_n(\text{drift}) = q\mu_n n_0(x)\, \mathcal{E}_x \qquad J_n = q D_n \, \partial n(x) / \partial x$

$J_n'(\text{drift}) = q\mu_n (n_0(x) + \Delta n)\, \mathcal{E}_x \qquad J_n = q D_n \frac{d}{dx}(n(x) + \Delta n)$

$= \underbrace{q\mu_n n_0 \mathcal{E}_x + q\mu_n \Delta n \mathcal{E}_x}_{\text{changes by } q\mu_n \Delta n \mathcal{E}_x} \qquad \underbrace{J_n = q D_n \, \partial n(x) / \partial x}_{\text{no change}}$

If sample still in Equilibrium, then

$\mathcal{E}(x)$ must change!

4.17)

Want τ_p

$t_{d1} = 200\mu s$ $\quad$ $t_{d2} = 50\mu s$

$V_{p1} = 20mV$ $\quad$ $V_{p2} = 80mV$

In book (4-44)

$$\delta p(x,t) = \left[\frac{\Delta P}{2\sqrt{\pi D_p t}}\right] e^{-x^2/4D_p t}$$

But this does <u>NOT</u> include recombination

If you include recombination

$$\delta p(x,t) = \left[\frac{\Delta P}{2\sqrt{\pi D_p t}}\right] e^{-x^2/4D_p t} e^{-t/\tau_p}$$

$x = 0 \rightarrow$ b/c we are measuring at peak V, where $x = 0$

$$\delta p(x,t) = \left[\frac{\Delta P}{2\sqrt{\pi D_p t}}\right] e^{-t/\tau_p}$$

(1)
$$20mV = \frac{\Delta P}{2\sqrt{\pi D_p t_{d1}}} e^{-t_{d1}/\tau_p}$$

(2)
$$80mV = \frac{\Delta P}{2\sqrt{\pi D_p t_{d2}}} e^{-t_{d2}/\tau_p}$$

$$\frac{(2)}{(1)} = 4 = \frac{\Delta P / 2\sqrt{\pi D_p t_{d2}}}{\Delta P / 2\sqrt{\pi D_p t_{d1}}} \frac{e^{-t_{d2}/\tau_p}}{e^{-t_{d1}/\tau_p}}$$

$$4 = \sqrt{\frac{t_{d1}}{t_{d2}}} e^{-(t_{d1} - t_{d2})/\tau_p}$$

$$4 = \sqrt{4} e^{-(200-50)/\tau_p}$$

$\rightarrow \ln 2 = +150/\tau_p$

$\tau_p = +150/\ln 2$

$\boxed{\tau_p = 216.4 \mu s}$

5-9

$N_a = 10^{17}\ cm^{-3}$ → p-side

$N_d = 10^{16}\ cm^{-3}$ → n-side

300K a) Find E_F's, band diagram, V_o

p-side

$$10^{17} = n_i e^{(E_{Fi} - E_{Fp})/kT}$$

$$E_{Fi} - E_{Fp} = kT \ln\left(\frac{10^{17}}{1.5\times10^{10}}\right)$$

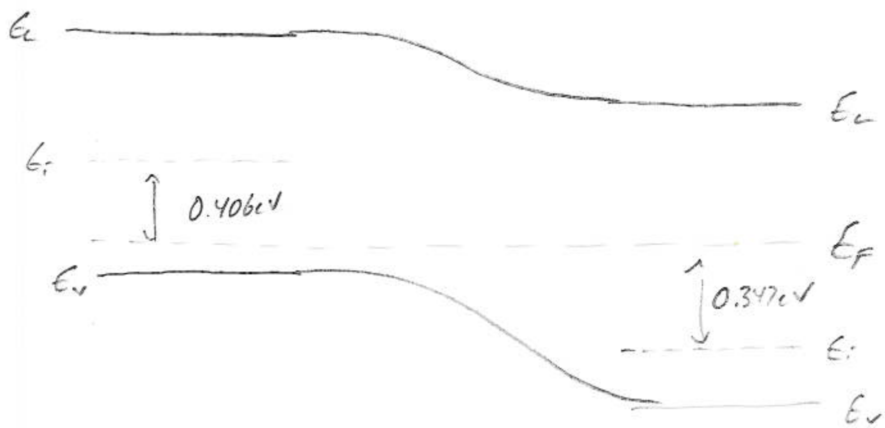
$$\boxed{E_i - E_{Fp} = 0.406\ eV}$$

n-side

$$10^{16} = n_i e^{(E_{Fn} - E_i)/kT}$$

$$E_{Fn} - E_i = kT \ln \frac{10^{16}}{1.5\times10^{10}}$$

$$\boxed{E_{Fn} - E_i = 0.347\ eV}$$



$$V_o = 0.406 + 0.347\ eV$$

$$\boxed{V_o = 0.753\ eV}$$

b)

$$V_o = \frac{kT}{q} \ln \frac{N_a N_d}{n_i^2}$$

$$\boxed{V_o = 0.7535\ eV}$$

8)

n-type Si substrate $1\times10^{18}\ cm^{-3}$

$W = 60\ nm$

What is N_a of p-type Si?

$$W = \left[\frac{2\epsilon V_0}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)\right]^{1/2}$$

$$60\,nm = \left[\frac{2\epsilon KT}{q^2}\left(\ln\frac{N_a N_d}{n_i^2}\right)\left(\frac{1}{N_a}+\frac{1}{N_d}\right)\right]^{1/2}$$

$$(6\times10^{-8})^2 = \frac{2\epsilon KT}{q^2}\left(\ln\frac{N_a N_d}{n_i^2}\right)\left(\frac{1}{N_a}+\frac{1}{N_d}\right)$$

$\epsilon_{Si} = 11.8\times8.85\times10^{-14}$

$$\frac{(6\times10^{-6})^2 q^2}{2\epsilon KT} = 1.0658\times10^{-16} = \left(\ln\frac{N_a N_d}{n_i^2}\right)\left(\frac{1}{N_a}+\frac{1}{N_d}\right)$$

$N_a \approx 5\times10^{17}$ solved numerically

Does this work?

$$V_0 = \frac{KT}{q}\ln\frac{N_a N_d}{n_i^2} = 0.915$$

$$W = \left[\frac{2\epsilon V_0}{q}\left(\frac{N_a+N_d}{N_a N_d}\right)\right]^{1/2}$$

$$W = 6\times10^{-6}\ cm = 60\,nm$$

9]

GaAs pn junction

$$N_d = 1\times10^{17}\ cm^{-3}$$

$$N_a = 5\times10^{16}\ cm^{-3}$$

What is V_0 @ 4K, 77K, 300K?

$$V_0 = \frac{kT}{q}\ln\frac{N_a N_d}{n_i^2}$$

assume 100% ionization

$$n_i(T) = 2\left(\frac{2\pi kT}{h^2}\right)^{3/2}(m_n^* m_p^*)^{3/4} e^{-E_g/2kT}$$

$$E_g = 1.519 - 5.4\times10^{-4}\, T^2/(T+204)$$

$m_n^* = .067 m_0$ $m_p^* = .074, 0.5$ (lh, hh)

$$m_p^* = \left[m_{hh}^{*\,3/2} + m_{lh}^{3/2}\right]^{2/3}$$

$V_0(4K) \rightarrow$ N/A

$V_0(77K) \rightarrow 1.49$ eV

$V_0(300K) \rightarrow 1.249$ eV