6.012 Fall 1996 - Answers to Exam #1

Problem 1 (a)
1. n-type, $N_D = 10^{16} \frac{1}{cm^3}$
2. p-type, $N_A = 9 \times 10^{16} \frac{1}{cm^3}$
3. n-type, $N_D = 9.1 \times 10^{17} \frac{1}{cm^3}$

(b) It will create a large change in conductance. Since the excitation is uniform, the number of excess carriers is determined by the expression:

$$n' = G \cdot \tau_{min} = 10^{23} \cdot 10^{-6} = 10^{17} cm^{-3}$$

This is one order of magnitude larger than the equilibrium concentration. Since the conductivity is defined as:

$$\sigma = q \left(\mu_e n + \mu_h p\right)$$

the conductivity will also increase by at least an order of magnitude.

(c) At 300 K, the concentrations of electrons and holes are n_{o1} and p_{o1}, and the intrinsic concentration is $n_{i1} = n_{o1} p_{o1}$. The thermal excitation will thermally excite an equal amount of free electrons and holes. Lets call these amounts Δn_o and Δp_o. Since the number of each is equal, $\Delta n_o = \Delta p_o$. The new thermal equilibrium ($T = 350K$) concentrations are n_o, p_o, and n_i:

$$\begin{aligned} n_o &= n_{o1} + \Delta n_o \\ p_o &= p_{o1} + \Delta p_o \\ n_i &= \sqrt{n_o p_o} = \sqrt{\left(n_{o1} + \Delta n_o\right)\left(p_{o1} + \Delta p_o\right)} = \sqrt{n_{o1} p_{o1} + \left(p_{o1} + n_{o1}\right) \Delta p_{o1} + \Delta p_{o1}^2} \end{aligned}$$

1. The least changed will be p_o. p_{o1} is a large number since the sample is p-type, so the change is given by:

$$\% = \frac{p_{o1}}{p_o} = \frac{p_{o1}}{p_{o1} + \Delta p_o} = \frac{1}{1 + \frac{\Delta p_o}{p_{o1}}}$$

2. The most changed will be n_o. n_{o1} is a small number since the sample is p-type, so the change is given by:

$$\% = \frac{n_{o1}}{n_o} = \frac{n_{o1}}{n_{o1} + \Delta n_o} = \frac{1}{1 + \frac{\Delta n_o}{n_{o1}}}$$

As an aside, n_i should not change too much, since $n_i = \sqrt{\left(n_{o1} + \Delta n_o\right)\left(p_{o1} + \Delta p_o\right)} \cong \sqrt{p_{o1}(n_{o1} + \Delta n_o)}$. So it should change more than p_o, but not as much as n_o.

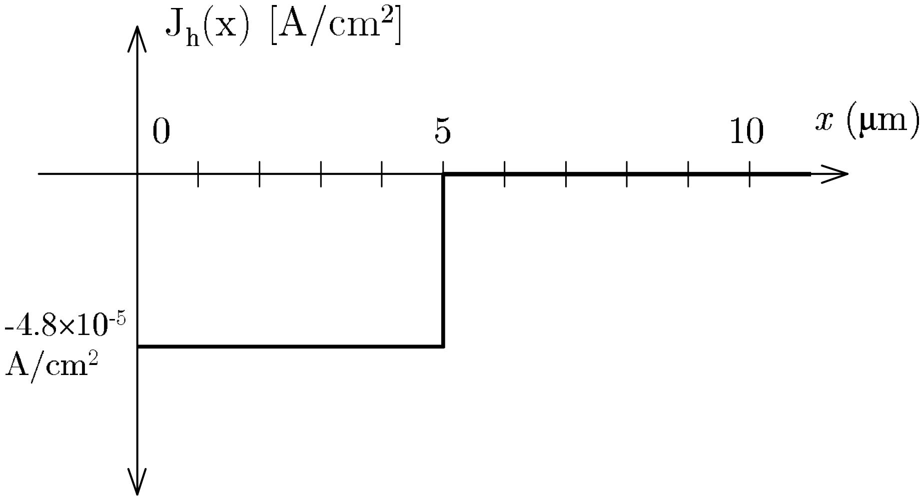
(d) The semiconductor with the larger energy gap is sample A, since a larger bandgap will translate to no photon absorption. Since material A is transparent, the photon is not absorbed (the photon does not create an electron/hole pair), it must have the larger energy gap.

Problem 2 (a)

$$\begin{aligned} L_h &= \sqrt{D_h \tau_{\min}} \\ \tau_{\min} &= \frac{L_h^2}{D_h} = \frac{q}{kT} \cdot \frac{L_D^2}{\mu_h} = 1.667 \times 10^{-6} \ seconds \end{aligned}$$

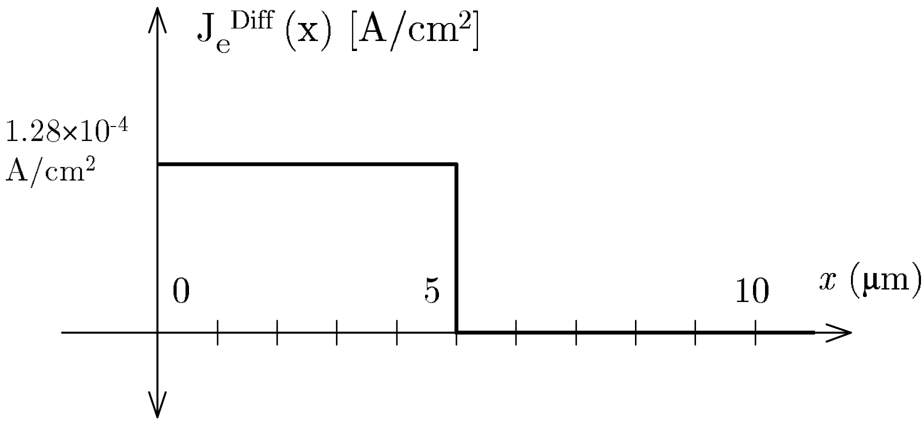
(b) 1.

$$J_h\left(x\right) = -q D_h \frac{dp'}{dx} = -4.8 \times 10^{-5} \left(u(x) - u(x - 5\mu m)\right) \ \frac{Amp}{cm^2}$$



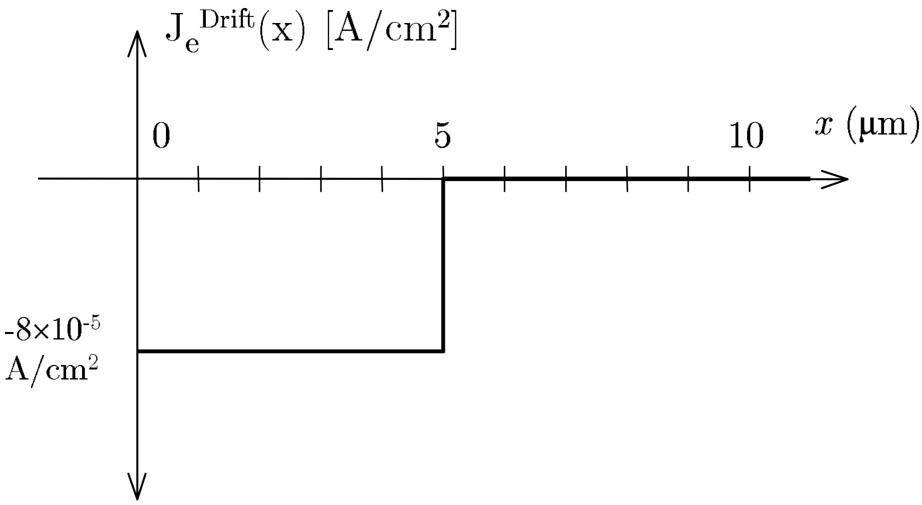
2.

$$J_e^{diff}(x) = qD_e\frac{dn'}{dx} = q\frac{D_e}{D_h}D_h\frac{dp'}{dx} = -\frac{D_e}{D_h}J_h^{diff}(x) = 1.28\times10^{-4}\left(u(x)-u(x-5\mu m)\right)\ \frac{Amp}{cm^2}$$



3.

$$\begin{aligned} J_T &= 0 = J_e + J_h = J_e^{diff} + J_e^{drift} + J_h^{diff} \\ J_e^{drift} &= -J_e^{diff} - J_h^{diff} = -8\times 10^{-5-4}\left(u(x)-u(x-5\mu m)\right)\ \frac{Amp}{cm^2} \end{aligned}$$



(c)

$$F_G = -F_h(L) = D_h \frac{dp'}{dx}\bigg|_{x=0^+} = 3\times10^{14}\frac{1}{cm^2 sec}$$
$$g_l(x) = 3\times10^{14}\delta(x-5\mu m)\ \frac{1}{cm^2 sec}$$

(d) 1.

$$F_r = \int_{0\mu m}^{10\mu m}\frac{n'(x)}{\tau}dx = 4.5\times10^{12}\frac{1}{cm^2 sec}$$

2. Location = 0 μm, Fraction ≅ 100% (98.5%)

(e) 1. The value of $p'\,(5\mu m)$ should be smaller than in the earlier situation.

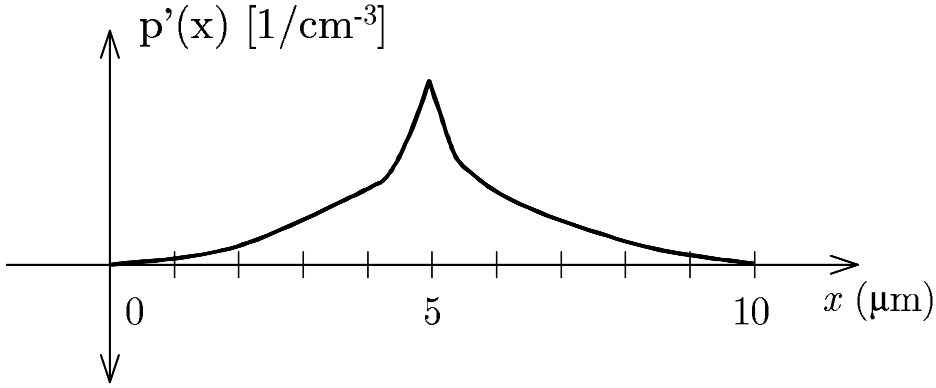
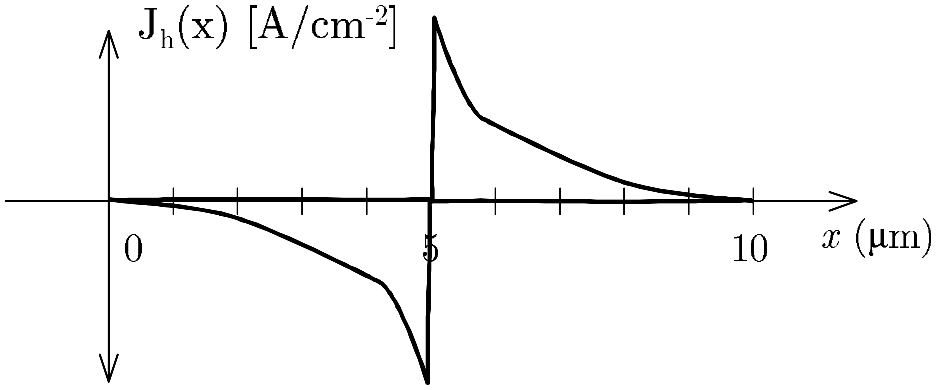


Figure 1:

2.



Problem 3 (a)

$$\phi_n = \frac{kT}{q} ln(\frac{n_o}{n_i})$$
$$\phi_p = -\frac{kT}{q} ln(\frac{p_o}{n_i})$$

1. $\phi_n = 420mV$
2. $\phi_p = -360mV$
3. $\phi_b = 780mV$

(b)

$$x_{po}N_{Ap} = x_{no}N_{Dn}$$
$$x_{po} = \frac{N_{Ap}}{N_{Dn}} x_{no} = 0.03\mu m$$

(c) 1.

$$p'(x_n) = p_{no}\left(e^{\frac{qv_{ab}}{kT}} - 1\right)$$
$$n'(-x_p) = n_{po}\left(e^{\frac{qv_{ab}}{kT}} - 1\right)$$
$$\frac{p'(x_n)}{n'(-x_p)} = \frac{p_{no}}{n_{po}}$$
$$p'(x_n) = \frac{p_{no}}{n_{po}} n'(-x_p) = 10^{13} cm^{-3}$$

2.

$$J_e(-x_p) = qD_e \left.\frac{dn'}{dx}\right|_{x=-x_p} = 6.4 \times 10^{-1} \frac{A}{cm^2}$$

3.

$$J_h(x_n) = -qD_h \left.\frac{dp'}{dx}\right|_{x=x_n} = 2.4 \times 10^{-2} \frac{A}{cm^2}$$

4. Since there is no generation or recombination in the depletion region:

$$J_e(-x_p) = J_e(x_n) = 6.4 \times 10^{-1} \frac{A}{cm^2}$$

(d)

$$p'(x_n) = p_{no}\left(e^{\frac{qv_{ab}}{kT}} - 1\right)$$
$$v_{ab} = \frac{kT}{q} ln\left(\frac{p'(x_n)}{p_{no}} + 1\right) = 600mV$$
$$v_b = \phi_{bi} - v_r = 180mV$$
$$v_r = v_{ab} = 600mV$$

(e) 1. p-side. $\rho = 1.04\Omega \cdot cm$

2. The total current times the resistance,

$$V = AJ_{tot}R_p$$

A potential drop will form across the P region due to the fact that all current is impeded due to the resistance in the region.