

6.012 Fall 1997 - Answers to Exam #1

Problem 1 (a) n-type, $N_D = 5 \times 10^{15} \frac{1}{cm^3}$, Can be As, P, or Sb.

(b) $\rho = \frac{1}{\sigma} = \frac{1}{q(\mu_e n + \mu_h p)} = 1.04 \Omega \cdot cm$

(c) Since the excitation is uniform, the number of excess carriers is determined by the expression:

$$n' = G \cdot \tau_{min} = 10^{14} cm^{-3} = p'$$

(d)

$$n'(t) = 10^{14} e^{-\frac{t}{\tau_{min}}} cm^{-3}$$

(e)

$$g_l(t) = -D_e \frac{d^2 n'}{dx^2} = G$$

Since n' must be a quadratic, and must also go to zero at the ends,

$$n'(x) = Ax(x - 10\mu m) cm^{-3}$$

Substituting n' into the continuity equation, we find:

$$\begin{aligned} G &= -2D_e A \\ A &= 1.25 \times 10^{17} cm^{-4} \\ n'(x) &= 1.25 \times 10^{17} x(x - 10\mu m) cm^{-3} \end{aligned}$$

(f) Faster, since the carriers are able to diffuse out of the sides through the ohmic contacts.

Problem 2 (a)

$$\begin{aligned} \phi_n &= \frac{kT}{q} \ln\left(\frac{n_o}{n_i}\right) \\ \phi_p &= -\frac{kT}{q} \ln\left(\frac{p_o}{n_i}\right) \end{aligned}$$

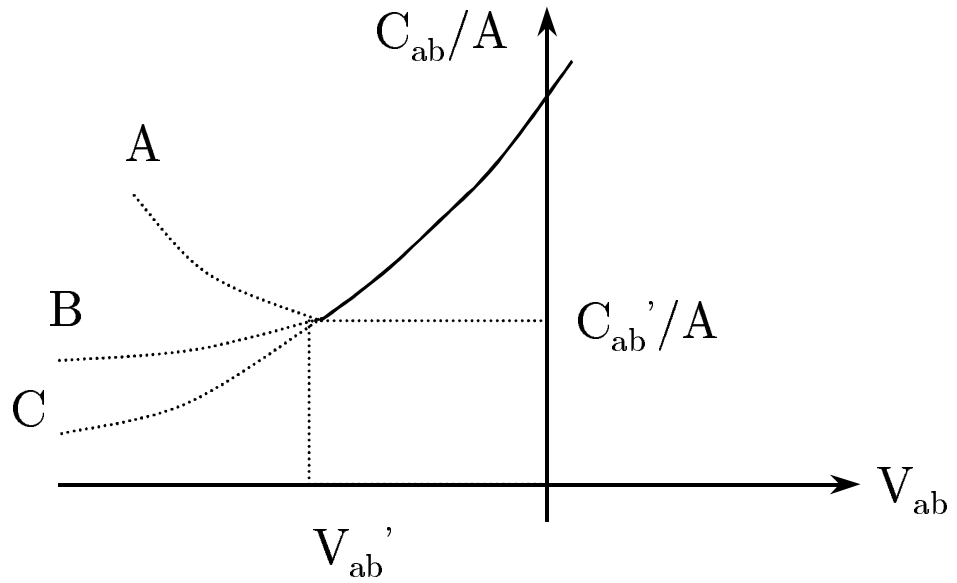
1. $\phi_n = -420mV$
2. $\phi_{b,p-n} = 780mV$
3. $\phi_{b,n-n^+} = 60mV$
4. $\phi_{b,m-n^+} = 340mV$

(b)

$$\begin{aligned} x_{n_o} N_{Dn} &= x_{p_o} N_{Ap} \\ x_{n_o} &= \frac{N_{Dn}}{N_{Ap}} x_{p_o} = 10x_p \end{aligned}$$

1. $x_n = 1.5\mu m$
2. $x_n = 2.1\mu m$

(c)



1. B, since the capacitance is given by:

$$C'_{ab} \propto \sqrt{\frac{N_D}{\phi_b - v_{ab}}}$$

Since the doping increases at V'_{ab} , the capacitance must also increase, so it cannot be C. However, C'_{ab} remains a decreasing function versus V_{ab} , so it cannot be A.

- 2.

$$C'_{ab} = \frac{\epsilon}{w} = \frac{10^{-12}}{x_n + x_p} = \frac{10^{-12}}{x_n + \frac{N_{Dn}}{N_{Ap}} x_n} = \frac{10^{-12}}{x_n \left(1 + \frac{N_{Dn}}{N_{Ap}}\right)} = \frac{10^{-12}}{2 \times 10^{-4} \left(1 + \frac{1}{10}\right)} = 4.54 \times 10^{-9} \frac{F}{cm^2}$$

- 3.

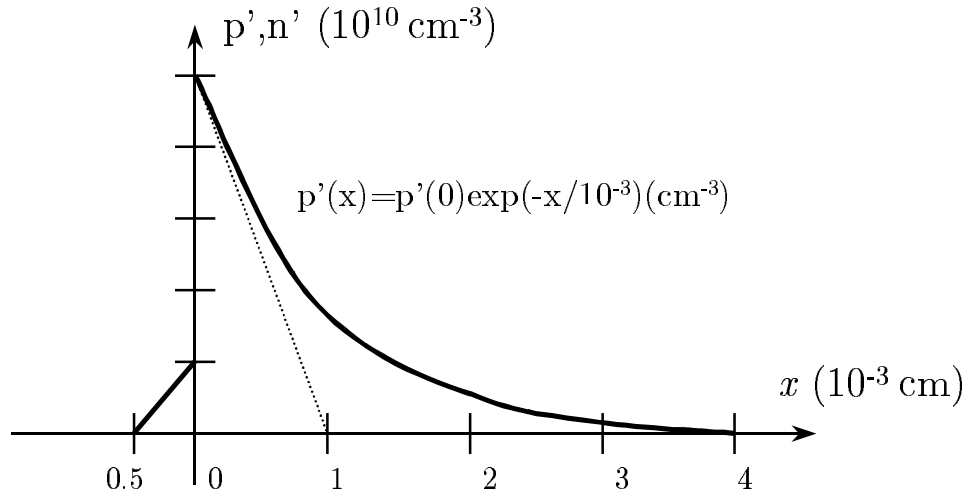
$$x_n = \sqrt{\frac{2\epsilon(\phi_b - v_{ab})N_A}{N_D(N_D + N_A)}} \cong \sqrt{\frac{2\epsilon(\phi_b - v_{ab})}{N_D}}$$

$$v_{ab} = \phi_b - q \frac{N_{D1} x_n^2}{2\epsilon} = -31.22 \text{ Volts}$$

4. The peak field occurs at $x = 0\mu m$, since that is where the depletion charge goes from negative to positive.

$$\xi_{peak} = -\frac{q}{\epsilon} (N_{D1} \cdot 2\mu m + N_{D2} \cdot 0.2\mu m) = -6.4 \times 10^5 \frac{Volts}{cm}$$

Problem 3



(a)

$$n_{po} = \frac{n_i^2}{p_{po}} = 10^2 \text{ cm}^{-3}$$

(b)

$$n'(-x_n) = n_{po} \left(e^{\frac{q v_{ab}}{kT}} - 1 \right)$$

$$v_{ab} = \frac{kT}{q} \ln \left(\frac{n'(-x_p)}{n_{po}} + 1 \right) = 480 \text{ mV}$$

(c)

$$p'(x_n) = p_{no} \left(e^{\frac{q v_{ab}}{kT}} - 1 \right)$$

$$n'(-x_p) = n_{po} \left(e^{\frac{q v_{ab}}{kT}} - 1 \right)$$

$$\frac{p'(x_n)}{n'(-x_p)} = \frac{p_{no}}{n_{po}} = \frac{\frac{n_i^2}{N_{Dn}}}{\frac{n_i^2}{N_{Ap}}} = \frac{N_{Ap}}{N_{Dn}}$$

$$N_{Dn} = \frac{p'(x_n)}{n'(-x_p)} N_{Ap} = 2 \times 10^{17} \text{ cm}^{-3}$$

(d)

$$J_e(x) = q D_e \frac{dn'}{dx} = q \frac{kT}{q} \mu_e \frac{n'(-x_p)}{w_p} = 9.6 \times 10^{-5} \frac{\text{Amp}}{\text{cm}^2}$$

(e)

$$J_h(x) = -q D_h \frac{dp'}{dx} = -q \frac{kT}{q} \mu_h \frac{d}{dx} \left(p'(0) e^{-\frac{x}{L_h}} \right) = -q \frac{kT}{q} \mu_h \frac{p'(0)}{L_h} e^{-\frac{x}{L_h}} = 8 \times 10^{-5} e^{-\frac{x}{10^{-3}}} \frac{\text{Amp}}{\text{cm}^2}$$

(f)

$$J_{TOT} = J_e(-x_p) + J_h(x_n) = 1.76 \times 10^{-4} \frac{\text{Amp}}{\text{cm}^2}$$

(g) 1. about 0%

$$\frac{F_h(40 \mu\text{m})}{F_h(0 \mu\text{m})} = \frac{-D_h \frac{dp'}{dx} \Big|_{x=40 \mu\text{m}}}{-D_h \frac{dp'}{dx} \Big|_{x=0 \mu\text{m}}} = \frac{e^{-\frac{x}{L_h}} \Big|_{x=40 \mu\text{m}}}{e^{-\frac{x}{L_h}} \Big|_{x=0 \mu\text{m}}} = e^{-4} = 1.83\%$$

2. about 100%

$$\frac{F_e(-0.5\mu m)}{F_e(0\mu m)} = \frac{|F_e(0\mu m)| - F_R}{|F_e(0\mu m)|} = \frac{D_e \frac{dn'}{dx} \Big|_{x=0} - \int_{-0.5\mu m}^{0\mu m} \frac{n'}{\tau} dx}{D_e \frac{dn'}{dx} \Big|_{x=0}} = 95.8\%$$

3.

$$F_R = \int_{-5\mu m}^{0\mu m} \frac{n'}{\tau} dx = 2.5 \times 10^{15} \frac{pairs}{cm^2 sec}$$