Part I : PN Junction Questions (45 points total)

1. A pn junction is uniformly doped with acceptor atoms in the region $x < 0$ and with donor atoms in the region $x > 0$. Under reverse bias, the charge density in the depletion region on the p-side is mainly due to (circle one)

[5 pts]

holes and electrons

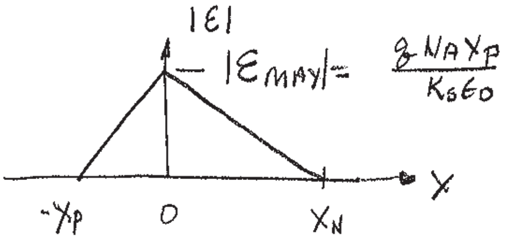
donors

[✓ acceptors]

both holes and acceptors

2. A silicon pn step junction is under reverse bias at room temperature in the dark. The peak electric field in the depletion region is 10^5 V/cm. If $N_D = 7 \times 10^{17}$ cm^{-3} and $N_A = 1 \times 10^{16}$ cm^{-3}, how far does the depletion region extend into the p-type material?

[10 pts]



$$\therefore \quad x_p = \frac{K_s \epsilon_0}{q N_A} |\mathcal{E}_{MAX}| = \frac{11.8\,(8.85 \times 10^{-14}\ F/cm)}{(1.6 \times 10^{-19}\ C)(1 \times 10^{16}\ cm^{-3})} \left(1 \times 10^{5} \frac{V}{cm}\right)$$

$$\boxed{x_p = 6.53 \times 10^{-5}\ cm}$$

4:00

3. (Parts A – C constitute the question for **ABET Outcome #4**)

A silicon pn junction has the following parameters:

$N_D = 1\text{x}10^{17}\ \text{cm}^{-3}$ $\mu_N = 1000\ \text{cm}^2/\text{Vs}$ $\tau_N = 1\ \mu\text{s}$
$N_A = 5\text{x}10^{15}\ \text{cm}^{-3}$ $\mu_P = 500\ \text{cm}^2/\text{Vs}$ $\tau_P = 1\ \mu\text{s}$

A. What is the built-in potential in volts? [5 pts]

$$\phi_{BI} = \frac{kT}{q} \ln\left(\frac{N_D N_A}{n_i^2}\right) = (0.0259\,V) \ln\left[\frac{(1\times10^{17}\,cm^{-3})(5\times10^{15}\,cm^{-3})}{(1\times10^{20}\,cm^{-6})}\right]$$

$$\boxed{\phi_{BI} = 0.757V}$$

B. If the applied voltage $V_A = 0.7$ V, what is the total band bending across the junction in electron-volts?

[5 pts]

$$\phi_J = \phi_{BI} - V_A = 0.757V - 0.7V = \boxed{0.057V}$$

6:00

C. Asuming low-level injection, calculate the "ideal" current density if $V_A = 0.7$ V.

[10 pts]

$$J = q n_i^2 \left[\frac{D_P}{L_P N_D} + \frac{D_N}{L_N N_A} \right] \left(e^{qV_A/kT} - 1 \right)$$

$$D_P = \frac{kT}{q} \mu_P = (0.0259 V)(500\ cm^2/Vs) = 12.95\ cm^2/s$$

$$D_N = \frac{kT}{q} \mu_N = (0.0259 V)(1000\ cm^2/Vs) = 25.9\ cm^2/s$$

$$L_P = \sqrt{D_P \tau_P} = \sqrt{(12.95 \frac{cm^2}{s})(10^{-6} s)} = 3.60 \times 10^{-3}\ cm$$

$$L_N = \sqrt{D_N \tau_N} = \sqrt{(25.9 \frac{cm^2}{s})(10^{-6} s)} = 5.10 \times 10^{-3}\ cm$$

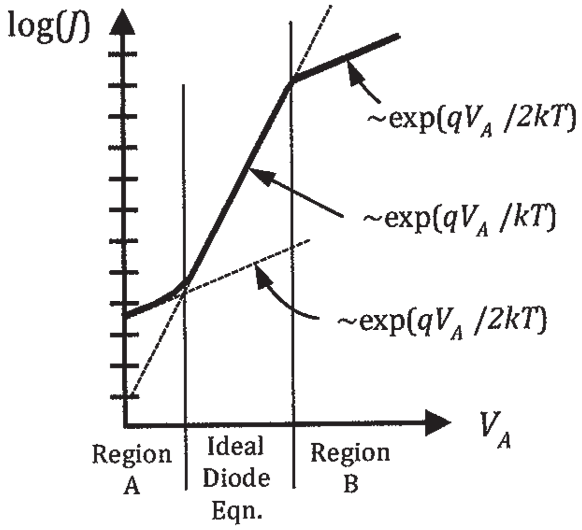
$$\therefore J = (1.6 \times 10^{-19} C)(10^{20} cm^{-6}) \left[\frac{(12.95 \frac{cm^2}{s})}{(3.6 \times 10^{-3} cm)(1 \times 10^{17} cm^{-3})} + \frac{(25.9 \frac{cm^2}{s})}{(5.1 \times 10^{-3} cm)(5 \times 10^{15} cm^{-3})} \right] \left(e^{\frac{0.7V}{0.0259V}} - 1 \right)$$

$$J = \left(16 \frac{C}{cm^6}\right)\left(3.60 \times 10^{-14} \frac{cm^4}{s} + 1.02 \times 10^{-12} \frac{cm^4}{s}\right)\left(e^{27.03} - 1\right)$$

$$\boxed{J = 9.26 \frac{A}{cm^2}}$$

16:00

4. Experimentally, the current in a pn diode is found to deviate from the ideal diode equation at both low and high current, as shown in the plot below.



A. The deviation at low currents (region A) is due to (circle one answer): [5 pts]

generation in the neutral regions

generation in the depletion region

recombination in the neutral regions

[✓ recombination in the depletion region]

none of the above

B. The deviation at high currents (region B) is due to (circle one answer): [5 pts]

recombination in the neutral regions

recombination in the depletion region

[✓ high-level injection]

low-level injection

none of the above

17:00