ELECTRONIC DEVICES
ASSIGNMENT 5

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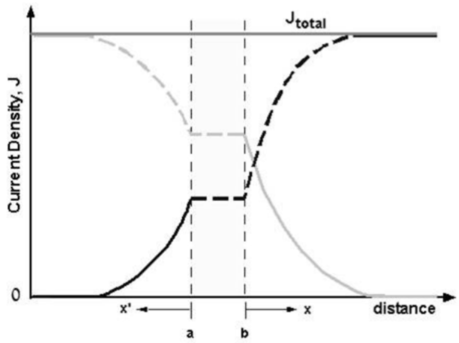
Exercise 1.
Shown below are the electron and hole current densities in an ideal PN junction in forward bias.



(1) Given that the current density J is directed towards the right, which side is N-type and which side is P-type?
(2) If we assume, for this question only, that the diffusion coefficients and minority carrier lifetimes of electrons and holes are equal, what can we say about the doping concentrations?
(3) As shown, the current densities in the depletion region are constant due to which of the following?
   (a) Depletion approximation
   (b) Negligence of recombination in the depletion region
   (c) Strong electric fields in the depletion region
   (d) Boltzmann approximation
(4) If at the edge of the depletion region, the electron current density is equal to the hole density, which of the following conditions must be true?
   (a) $N_A D_p = N_D D_n$
   (b) $\frac{D_p}{N_A L_n} = \frac{D_n}{N_D L_p}$
   (c) $N_A L_p = N_D L_n$
   (d) $\frac{D_n}{N_A L_n} = \frac{D_p}{N_D L_p}$
   (e) $N_A = N_D$

Solution 1.
(1) As the junction is in forward bias, and the current density is directed towards the right, the junction is a PN junction.

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(2) In the depletion region, hole current is greater than the electron current. Therefore, the concentration of holes is greater than that the concentration of electrons. Therefore, $N_A > N_D$.
(3) As the current densities are constant in the depletion region, the concentration of electrons and holes across the depletion region must be constant. Therefore, there is no generation and recombination in the depletion region.
(4)

$$\begin{aligned} J_n &= J_p \\ \therefore \frac{D_p}{L_p} p_{N0} &= \frac{D_n}{L_n} n_{P0} \\ \therefore \frac{D_p}{L_p} \frac{{n_i}^2}{N_D} &= \frac{D_n}{L_n} \frac{{n_i}^2}{N_A} \\ \therefore \frac{D_p}{L_p} N_A &= \frac{D_n}{L_n} N_D \end{aligned}$$

Exercise 2.
Consider a silicon PN step junction diode at 300 K, with

$$\begin{aligned} N_A &= 5 \times 10^{15} \mathrm{cm}^{-3} \\ N_D &= 10^{15} \mathrm{cm}^{-3} \\ A &= 10^{-4} \mathrm{cm}^2 \\ \tau_n &= 0.4 \mathrm{\mu s} \\ \tau_p &= 0.1 \mathrm{\mu s} \\ \mu_n &= 1350 \mathrm{cm}^2\,\mathrm{V}^{-1}\,\mathrm{s}^{-1} \\ \mu_p &= 480 \mathrm{cm}^2\,\mathrm{V}^{-1}\,\mathrm{s}^{-1} \end{aligned}$$

(1) Calculate the reverse hole current, i.e. the hole current when $V_a < 0$.
(2) Calculate the reverse electron current, i.e. the electron current when $V_a < 0$.
(3) Calculate the hole concentration at x_n for $V_a = 0.5 V_{\mathrm{BI}}$.
(4) Calculate the electron current at $x = x_n + \frac{L_p}{2}$ for $V_a = 0.5 V_{\mathrm{BI}}$.

Solution 2.

(1)

$$
\begin{aligned}
J_p(x) &= q\left(\frac{D_p}{L_p}p_{N0}\right)\left(e^{\frac{qV_a}{kT}}-1\right)e^{-\frac{x}{L_p}}\\
&= q\left(\frac{D_p}{\sqrt{D_p\tau_p}}\frac{{n_i}^2}{N_D}\right)\left(e^{\frac{qV_a}{kT}}-1\right)e^{-\frac{x}{\sqrt{D_p\tau_p}}}\\
&= q\left(\frac{\sqrt{D_p}}{\sqrt{\tau_p}}\frac{{n_i}^2}{N_D}\right)\left(e^{\frac{qV_a}{kT}}-1\right)e^{-\frac{x}{D_p\tau_p}}\\
&= q\left(\frac{\sqrt{\frac{\mu_p kT}{q}}}{\sqrt{\tau_p}}\frac{{n_i}^2}{N_D}\right)\left(e^{\frac{qV_a}{kT}}-1\right)e^{-\frac{qx}{\mu_p kT\tau_p}}\\
&= \left(1.6\times10^{-19}\right)\left(\frac{\sqrt{(480)(0.026)}}{\sqrt{(10^{-7})}}\frac{10^{20}}{10^{15}}\right)(-1)e^{-\frac{x}{(480)(0.026)\left(10^{-7}\right)}}\\
&= -\left(1.6\times10^{-19}\right)\left(\frac{12.48}{3.16\times10^{-4}}10^{5}\right)e^{-\frac{x}{1.248\times10^{-6}}}\\
&= -\left(1.6\times10^{-19}\right)\left(3.95\times10^{9}\right)e^{-\left(8\times10^{5}\right)x}\\
&= -6.32e^{-\left(8\times10^{5}\right)x}10^{-10}
\end{aligned}
$$

Therefore,

$$
\begin{aligned}
I_p(x) &= J_p(x)A\\
&= \left(-6.32e^{\left(8\times10^{5}\right)x}10^{-10}\right)\left(10^{-4}\right)\\
&= -6.32e^{\left(8\times10^{5}\right)x}10^{-14}
\end{aligned}
$$

(2)

$$
\begin{aligned}
J_n(x) &= q\left(\frac{D_n}{L_n}n_{P0}\right)\left(e^{\frac{qV_a}{kT}}-1\right)e^{-\frac{x}{L_n}}\\
&= q\left(\frac{D_n}{\sqrt{D_n\tau_n}}\frac{{n_i}^2}{N_A}\right)\left(e^{\frac{qV_a}{kT}}-1\right)e^{-\frac{x}{\sqrt{D_n\tau_n}}}\\
&= q\left(\frac{\sqrt{D_n}}{\sqrt{\tau_n}}\frac{{n_i}^2}{N_A}\right)\left(e^{\frac{qV_a}{kT}}-1\right)e^{-\frac{x}{D_n\tau_n}}\\
&= q\left(\frac{\sqrt{\frac{\mu_n kT}{q}}}{\sqrt{\tau_n}}\frac{{n_i}^2}{N_A}\right)\left(e^{\frac{qV_a}{kT}}-1\right)e^{-\frac{qx}{\mu_n kT\tau_n}}
\end{aligned}
$$

(3)

$$
\begin{aligned}
p(x) &= p_{N0}\left(e^{\frac{qV_a}{kT}}-1\right)e^{-\frac{x}{L_p}}\\
&= \frac{{n_i}^2}{N_D}\left(e^{\frac{qV_{\mathrm{BI}}}{kT}}-1\right)e^{-\frac{x}{L_p}}\\
&= \frac{10^{20}}{10^{15}}\left(e^{\frac{V_{\mathrm{BI}}}{0.026}}-1\right)e^{-\left(8\times10^{5}\right)x}\\
&= 10^{5}\left(e^{\frac{V_{\mathrm{BI}}}{0.026}}-1\right)e^{-\left(8\times10^{5}\right)x}
\end{aligned}
$$

Therefore,

$$p(x_n) = 10^5 \left(e^{\frac{V_{\mathrm{BI}}}{0.026}} - 1\right) e^{-8x_n \times 10^5}$$

(4)

$$\begin{aligned}
J_n(x) &= q \left(\frac{D_n}{L_n} n_{P0}\right) \left(e^{\frac{qV_a}{kT}} - 1\right) e^{-\frac{x}{L_n}} \\
&= q \left(\frac{D_n}{\sqrt{D_n \tau_n}} \frac{{n_i}^2}{N_A}\right) \left(e^{\frac{qV_a}{kT}} - 1\right) e^{-\frac{x}{\sqrt{D_n \tau_n}}} \\
&= q \left(\frac{\sqrt{D_n}}{\sqrt{\tau_n}} \frac{{n_i}^2}{N_A}\right) \left(e^{\frac{qV_a}{kT}} - 1\right) e^{-\frac{x}{D_n \tau_n}} \\
&= q \left(\frac{\sqrt{\frac{\mu_n kT}{q}}}{\sqrt{\tau_n}} \frac{{n_i}^2}{N_A}\right) \left(e^{\frac{qV_a}{kT}} - 1\right) e^{-\frac{qx}{\mu_n kT \tau_n}}
\end{aligned}$$

Therefore,

$$J_n\left(x_n + \frac{L_p}{2}\right) = q \left(\frac{\sqrt{\frac{\mu_n kT}{q}}}{\sqrt{\tau_n}} \frac{{n_i}^2}{N_A}\right) \left(e^{0.013 V_{\mathrm{BI}}} - 1\right) e^{-\frac{x_n + \frac{L_p}{2}}{0.026 \mu_n \tau_n}}$$