ECE 340 Homework VII Spring 2003

Due: Wednesday, February 26, 2003

1. *A bar of silicon has a donor doping profile of $n(x) = N_o exp\{-Ax^2\}$ where A is a constant. Derive an expressing for the built-in electric field as a function of x. If A = 5.6 x $10^7/cm^2$, determine the position at which the electric field is 10^4 V/cm. Why is the electric field zero at x=0?*

Solutions:
Use Quasi-neutral approximation to solve this problem. Quasi-neutral means that even there is carrier redistribution due to the diffusion or drift, we assume the redistribution is small and space charge-neutrality holds everywhere. Hence we can approximate the carrier profile by the doping profile.

At equilibrium, J = 0; Hole diffusion current can be neglected (why?), therefore Jp = 0;

$$J_n = qm_n n\mathrm{E} + qD_n \frac{dn}{dx} = 0 \text{, therefore: } \mathrm{E} = -\frac{D_n}{m_n n}\frac{dn}{dx}$$

By using Einstein relation (Equation. 4-29), $\frac{D}{m} = \frac{kT}{q}$

$$\mathrm{E} = -\frac{kT}{qn}\frac{dn}{dx} = -0.0259\frac{1}{n}\frac{dn}{dx} = -0.0259\frac{1}{N_0 e^{-Ax^2}}\frac{dN_0 e^{-Ax^2}}{dx} = 0.0259(2Ax) = 0.0518Ax$$

If A = 5.6 x $10^7/cm^2$, electric field is 10^4 V/cm, then

$$x = E/0.0518A = 10^4/(0.0518\times 5.6\times 10^7) = 3.45\times 10^{-3}cm$$

Electric field is zero at x=0 because there is no the doping profile is symmetric around x=0, and the slope at x=0 is zero.

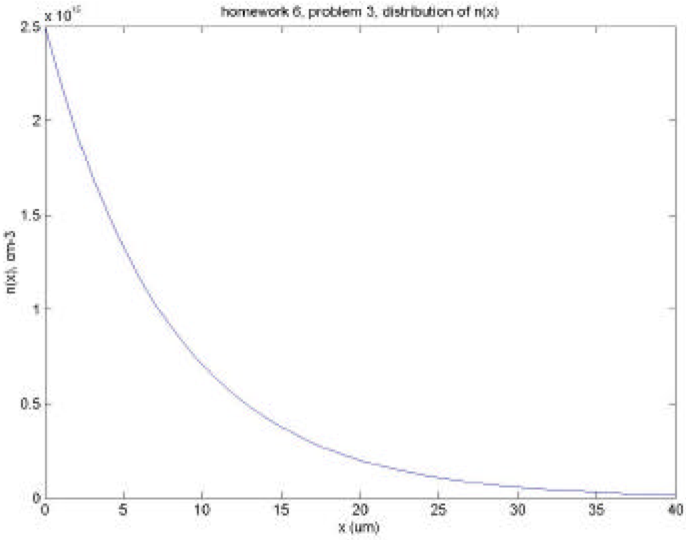
2. *An p-type germanium sample doped with N_a = 5x10^{16} /cm^3 is in steady state with an excess electron concentration Dn = 2.5 x 10^{15} /cm^3 injected at x=0. Assume T = 300K and the sample cross-sectional area is 5 x 10^{-4} cm^2.*
   - *(a) Determine the mobility and diffusion coefficient for electron.*
   - *(b) If the excess electron concentration at x = 20 mm is 2 x 10^{14} /cm^3, find an expression of and plot the excess electron concentration as a function of position x.*
   - *(c) Determine the electron lifetime t_n. What is the maximum electron diffusion current and at which position is it taking place?*
   - *(d) Derive the relationship between the maximum electron diffusion current and the total excess electron, Q_n in the sample, assuming the sample is infinite in the x-direction.*

(a) From Fig 3-23, $m_n = 3200cm^2/Vs$, $D_n = \frac{KT}{q}m_n = 82.8cm^2/s$

(b) At steady state, $d\,n(x) = \Delta n e^{-x(mm)/L_n}$, Δn = 2.5 x 10^{15} /cm^3

for x = 20 μm, $d\,n(x)$ =2 x 10^{14} /cm^3, therefore, L_h = 7.92μm, i.e.,

$$d\,n(x(mm)) = 2.5\times10^{15}e^{-x(mm)/7.92}cm^{-3}, or, d\,n(x(mm)) = 2.5\times10^{15}e^{-0.126x(mm)}cm^{-3}$$



(c) $t_n = \dfrac{L_n^2}{D_n} = \dfrac{\left(7.918\times10^{-4}\right)^2}{82.8} = 7.58\times10^{-9}\,\text{sec}$

The maximum diffusion current happens at x=0

$$I_n = AqD_n\frac{dn(x)}{dx} = AqD_n\frac{d\;2.5\times10^{15}e^{-x/7.918}}{dx}\xrightarrow{x=0} = -1.6\times10^{-19}\times82.8\times2.5\times10^{15}\times\frac{5\times10^{-4}}{7.92\times10^{-4}} = -20.92mA$$

(d) $I_{\max} = \dfrac{Q}{t_n}$

(i.e., the diffusion current at x=0 supplies all the carrier that lost due to recombination in the x>0 region).

A more rigorous calculation is:

$$Q_{total} = qA\int_0^\infty d\,n(x)dx = q\int_0^\infty \Delta n e^{-x/L_n}dx = qL_n\Delta n$$

$$I_{\max} = I_{x=0} = qA\Delta nD_n / L_n$$

$$\frac{Q_n}{I_{\max}} = \frac{L_n^2}{D_n} = t_n$$