EEE118 Problem Class Questions – Sheet 4

Fundamental Constants

Boltzman Constant, $k = 1.381 \times 10^{-23}$ JK^{-1}
Charge on Electron, $q = 1.602 \times 10^{-19}$ C

1. A germanium p-n junction has a bulk resistivity of 4.2×10^{-4} and 2.08×10^{-2} Ωm for the p- and n-type material respectively. For germanium $\mu_e = 0.3$, $\mu_h = 0.15$ $m^2V^{-1}s^{-1}$, and $n_i = 2.5\times 10^{19}$ m^{-3} at room temperature. Stating all assumptions;

   a) Show the free electron carrier density in the n-type material is 1×10^{21} m^{-3}.

   b) Show that the free hole carrier density in the p-type material is 9.9×10^{22} m^{-3}

   c) Sketch the extent of the depletion region into the p-type and n-type material.

   d) Calculate the hole (minority) carrier density in the n-type material.

   e) Show the height of the potential barrier at the junction is 0.3V.

   f) Can you estimate the band-gap of Ge ?

   g) Calculate the diffusion coefficients for the electrons and holes.

   h) Is the saturation current mainly due to electrons or holes? (Assume the minority carrier lifetimes are identical).

EEE118 Solutions Sheet 4

1.

a) From notes, assuming minority carrier contribution is negligible

Rearranging and substituting $\quad n = (\rho_e q \mu_e)^{-1} = (2.08x10^{-2}.1.6x10^{-19}.\ 0.3)^{-1}$

So n=1.0(0)x10^{21} m^{-3}

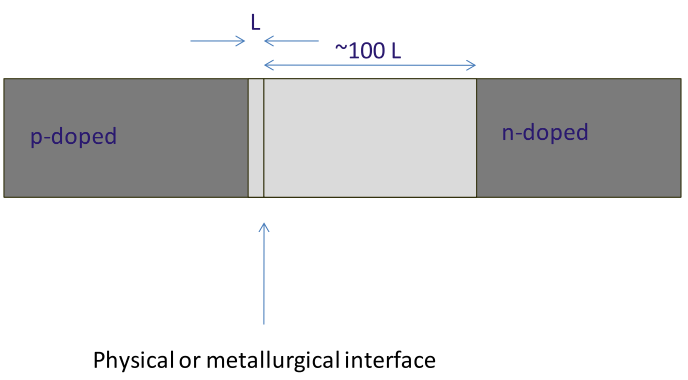
b) From notes, assuming minority carrier contribution is negligible $\quad \rho_h = (pq\mu_h)^{-1}$

Rearranging and substituting $\quad p = (\rho_h q \mu_h)^{-1} = (4.2x10^{-4}.1.6x10^{-19}.\ 0.15)^{-1}$

So p=9.9(2)x10^{22} m^{-3}

c) If we assume that all donors and acceptors are ionized, we can say that the donor density is 1.0x10^{21} m^{-3} and the acceptor density is 9.9x10^{22} m$^{-3.}$

The ratio of space charge (ionized acceptors to donors) in a given length is in the ratio ~1:100. The depletion region is therefore 100 times thicker in the n-type compared to the p-type.



d) As $\quad n_i^{\,2} = n_n p_n$

Plugging values in

$$\left(2.5x10^{19}\right)^2 = 1x10^{21}.p_n$$

So p_n = 6.25x10^{17}m^{-3}

e) In order to calculate the potential height we use the relation:

$$V_0 = \frac{k_B T}{q}\ln\left(\frac{p_{(p)}}{p_n}\right)$$

Plugging in these values should give V_0.= 0.3 V.

f) We know that V_0 is usually quite close to the band-gap. So we can guess at a band-gap of 0.3 ~ 0.5 eV

g) To remind you, the Einstein relation relates diffusion coefficient to mobility and the thermal energy by

$$D_{e,h} = \frac{kT}{q}\mu_{e,h}$$

All that is required is to plug in the values - be careful to make sure kT is in Joules so choose your Boltzmann constant carefully (or remember to use the charge on the electron if you use eV……)…

$$D_e = \frac{kT}{q}\mu_e = \frac{1.38x10^{-23}x300}{1.6x10^{-19}}x0.3 = 0.0078$$

For electrons $\mathbf{D_e = 0.0078\ m^2s^{-1}}$

$$D_h = \frac{kT}{q}\mu_h = \frac{1.38x10^{-23}x300}{1.6x10^{-19}}x0.15 = 0.0039$$

For electrons $\mathbf{D_e = 0.0039\ m^2s^{-1}}$

h) $$\mathrm{I_0 = I_e + I_h = qAn_i^2\left[\frac{D_e}{L_eN_A} + \frac{D_h}{L_hN_d}\right]}$$

The saturation current is determined essentially by the ratio of doping concentrations (D differ by ~2, minority carrier lifetime identical). However – the electron diffusion current is inversely proportional to the *acceptor* doping density (and vice versa for holes)

For this asymmetrically doped junction, the diffusion current is mainly due to holes.