EEE105 Tutorial Questions & Review Topics – W9

Fundamental Constants

Boltzman Constant, $k = 1.381\text{x}10^{-23}$ JK^{-1}
Charge on Electron, $q = 1.602\text{x}10^{-19}$ 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× 10^{19} m^{-3} at room temperature. Stating all assumptions;

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

   b) Show that the free hole carrier density in the p-type material is $9.9\text{x}10^{22}$ 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).

Review Topics

Derivations of p-n junction equations.
Origin of drift current in p-n junctions.
Space charge.

Solutions

1.

a) From notes, assuming minority carrier contribution is negligible

Rearranging and substituting $n = (\rho_e q\mu_e)^{-1} = (2.08\text{x}10^{-2}.1.6\text{x}10^{-19}.\ 0.3)^{-1}$

So $n=1.0(0)\text{x}10^{21}\ \text{m}^{-3}$

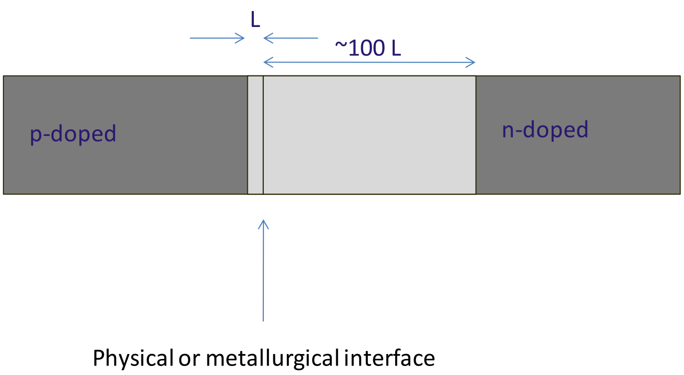
b) From notes, assuming minority carrier contribution is negligible $\rho_h = (pq\mu_h)^{-1}$

Rearranging and substituting $p = (\rho_h q\mu_h)^{-1} = (4.2\text{x}10^{-4}.1.6\text{x}10^{-19}.\ 0.15)^{-1}$

So $p=9.9(2)\text{x}10^{22}\ \text{m}^{-3}$

c) If we assume that all donors and acceptors are ionized, we can say that the donor density is $1.0\text{x}10^{21}\ \text{m}^{-3}$ and the acceptor density is $9.9\text{x}10^{22}\ \text{m}^{-3}$.

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 $n_i^2 = n_n p_n$

Plugging values in

$$\left(2.5\text{x}10^{19}\right)^2 = 1x10^{21}.p_n$$

So $p_n = 6.25\text{x}10^{17}\text{m}^{-3}$

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……)…

$$D_e = \frac{kT}{q}\mu_e = \frac{1.38x10^{-23}x300}{1.6x10^{-19}}x0.3 = 0.026$$

For electrons $\mathbf{D_e}$ = **0.026 $\mathbf{m^2s^{-1}}$**

$$D_h = \frac{kT}{q}\mu_h = \frac{1.38x10^{-23}x300}{1.6x10^{-19}}x0.15 = 0.013$$

For electrons $\mathbf{D_e}$ = **0.013 $\mathbf{m^2s^{-1}}$**

h)

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

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.