EEE105 Tutorial Questions & Review Topics – W10

Fundamental Constants
Boltzman Constant, $k = 1.381\text{x}10^{-23}\ JK^{-1} = 8.62\times10^{-5}\ eVK^{-1}$
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 $n_i=2.5\times 10^{19}\ m^{-3}$ at room temperature (This was the p-n junction last time!). The minority carrier lifetimes of the p and n-type material of the junction are 150 and 75 μs respectively, and the sample has a cross-sectional area of $1\times10^{-6}\ m^2$. Assuming that there is a large thickness of semiconductor on each side of the junction, calculate the saturation current.

a) What is the saturation current?
b) What proportion of the saturation current is carried by holes?
c) Calculate the hole density at the interface between the depletion layer and the n-type material when forward voltages of 25, 50 and 100 mV are applied to the junction.
d) Calculate the hole density at the interface between the depletion layer and the n-type material when reverse voltages of 25, 50 and 100 mV are applied to the junction.

2) The current flowing in a certain p-n junction at room temperature is 1 μA when a reasonably large reverse bias voltage is applied.
Find the applied voltage corresponding to a forward current of 10 mA.
This diode is constructed with p-type material of conductivity 2000 Sm^{-1} and n-type of 500 Sm^{-1}. Each region is l mm long and 1 x 0.5 mm in cross-section. Calculate the total voltage drop across the terminals of the diode when 10 mA flows. Comment on the result.

3) In what wavelength range will a GaAs photodiode respond to incident light?
Note that the energy of a photon is hc/λ, where h is Planck's constant and c is the speed of light. E_g for GaAs is 1.42 eV.
What happens if light outside this wavelength range is incident?
What wavelength would you expect a GaAs LED to operate at?

Review
Rectification in p-n junctions, photodiodes and photocurrent generation, LEDs,

Solutions

a) The saturation current can be expressed in many ways. They should all give the same result, but the most direct is-

$$J_0 = q\left(\left(\frac{D_h p_n}{L_h}\right) + \left(\frac{D_e n_p}{L_e}\right)\right)$$

Care needs to be taken !. The electron minority carrier lifetime is in the p-material (where the electrons are minority carriers) and is 150 μs. The hole minority carrier lifetime in the n material is 75 μs.

We can get the diffusion coefficients and minority carrier diffusion lengths from the data provided by

$$D = \frac{kT}{q}\mu \Rightarrow D_e = 7.6x10^{-3}\,\mathrm{m^2s^{-1}}\ \&\ D_h = 3.8x10^{-3}\,\mathrm{m^2s^{-1}}$$

$$L = \sqrt{D\tau} \Rightarrow L_e = 1.07x10^{-3}\,\mathrm{m}\ \&\ L_h = 5.3x10^{-4}\,\mathrm{m}$$

We calculated p_n last time – it was $p_n = 6.25\mathrm{x}10^{17}\mathrm{m}^{-3}$
We can use the same method here

As $\quad n_i^2 = n_p n_n$

We know n_i and n_n ($n=1.0(0)\mathrm{x}10^{21}\ \mathrm{m}^{-3}$)

So $n_p = 6.3\mathrm{x}10^{15}\ \mathrm{m}^{-3}$

Substituting all these values into the equation for J_0 gives $J_0 = 0.72\ \mathrm{Am}^{-2}$

However the question actually asks for the saturation current, *not* the current density. As we are told the area it is easy to get **I_0 = 7.2x10^{-7} A (or 0.72 μA)**

b) The saturation current is made up from contributions due to holes and electrons. The proportion due to holes is just

$$\frac{D_h p_n / L_h}{\left(\frac{D_h p_n}{L_h} + \frac{D_e n_p}{L_e}\right)} \approx 0.99$$

i.e. almost all the current is carried by holes. This is what we would expect because the p-side is much more heavily doped than the n-side.

c) As we push the junction into forward bias, holes are injected from the p to n side of the junction. (Electrons are also injected from the n to p side, but we aren't asked about that here). The concentration of these excess holes decays exponentially as we move away from the junction, but the question asks us about the hole density at the interface. We referred to this as p_{no} in the lecture notes. We can find this hole density from the equation.

$$p_{n_0} = p_n \exp\left(\frac{qV}{kT}\right)$$

Using this equation we can easily get p_{no} as a function of V. You can do this for +ve and –ve voltage to answer part (d).

Forward voltages of 25, 50 and 100 mV give 1.7×10^{18}, 4.52×10^{18}, 3.27×10^{19} m^{-3}.
Reverse voltages of 25, 50 and 100 mV give 2.3×10^{17}, 8.64×10^{16}, 1.19×10^{16} m^{-3}.

Don't worry if your calculated value is a little different to these. It's very sensitive to the value you took for kT.

2) We know that at a reasonable large reverse bias the current flowing is $-I_0$ (assuming we are nowhere near breakdown. So we can easily get the forward current from

$$I = I_0 \exp\left(\frac{qV}{kT}\right)$$

$$\therefore V = \frac{kT}{q}\ln\left(\frac{I}{I_0}\right) = 0.025\ln\left(\frac{10x10^{-3}}{10^{-6}}\right) = 0.025x9.2 = 0.23\text{V}$$

The next part merely says that the 10mA has to flow through p and n-type slabs of material on the way to the junction. Hence we need to calculate the resistance of them and then get the voltage dropped across them.

$$V = IR = \frac{Il}{\sigma A}$$

From this we can calculate that the voltage across the p-material should be 10 mV, and that across the n-material should be 40 mV. So the total voltage drop across the whole diode will be 0.01+0.04+0.23=0.28 V.

In an ideal diode negligible current flows until V reaches a certain value. Then once the diode is properly on the voltage rises very little with increasing current. However, since real diodes have a parasitic series resistance, the voltage does rise (almost linearly) with current.

3). The wavelength corresponding to the bandgap energy of the GaAs will be:

$$\lambda = \frac{hc}{E} = \frac{6.6x10^{-34}x3x10^{8}}{1.42x1.6x10^{-19}} = 884\text{nm}$$

Now you need to ask whether a photon of lower or higher wavelength would be absorbed. A higher energy photon be absorbed, exciting an electron across the bandgap to create an electron-hole pair. Lower energy photons will be transmitted through the material having no effect.

We would expect a GaAs LED to emit light at the band-gap energy. The LED will therefore emitlight at 884nm.