EEE105 Tutorial Question Set 6
Solutions

1. In order to calculate the potential height we use the relation we have for potential barrier height:

$$V_0 = \frac{kT}{q} \ln\left(\frac{p_p}{p_n}\right)$$

In order to use this relationship we need to know the background hole concentration on both sides of the junction. Much of this just reproduces work dealt with in detail in earlier self test sheets, so in brief:

Getting hole concentration on the p-type side of the junction is trivial since we are given the resistivity and mobility. The value is $9.9 \text{x} 10^{22}$ m^{-3}

Obtaining the hole concentration on the n-type side is very slightly more complex. First we have to find the electron concentration (it should be $1\text{x}10^{21}$ m^{-3}) and from this, and n_I, we get p_n (= $6.2\text{x}10^{17}$ m^{-3})

Simply plugging in these values should give $\mathbf{V_0}$**.= 0.3 V**.

This low value is as expected since we know that V_0 is not too far from W_g and Ge has relatively low W_g. It is this small W_g that leads to Ge having high n_i (which leads to very leaky p-n junctions since J_0 will also be high)

2. NOTE: It is common for students to mix up the minority carrier lifetimes in this question. Hence care needs to be taken not to get confused. 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.

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

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

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

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

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

We calculated p_n is part 1. Using the same method we calculate $n_p = 6.3\text{x}10^{15}$ m^{-3}

Substituting all these values into the equation for J_0 gives $J_0 = 0.72$ 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 $\mathbf{I_0 = 7.2x10^{-7}}$ **A (or 0.72 μA)**

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.

3. For this question we just need to realise that 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, and in any case we have just shown in part 2 that the dominant effect is due to hole injection). The concentration of these excess holes decays exponentially as we move away

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

from the junction, but the question asks us about the hole density at the interface. We can find this hole density from the equation.

Note that if the applied voltage V is zero the hole concentration is just equal to the background concentration, which fits our intuition.

Using this equation we can easily get p_{no} as a function of V

You should find that the value exponentially follows V. As an example, for a forward bias of 100 mV the hole conc at the interface is $3.27x10^{19}$ m^{-3}.

Don't worry if you value is a little different to this. It's very sensitive to the value you took for kT (see comments on question sheet for Self Test 4).

Similarly in reverse bias we are driving any holes generated in the junction into the p-type region where they will form the leakage current in the device. Hence we would expect the hole density to decrease as you will find if you substitute negative values of V into the equation above.

Just to check that you can manipulate the equations I asked you to work out the forward voltage where the hole conc at the interface is 10^{20} m^{-3} (the normal electron density was calculated to be 10^{21} m^{-3} in part 1)

The voltage will be around 128mV

The very last part is just another test of your ability to calculate conductivity. At the interface just inside the n material we have conductivity due the electrons ***and*** the injected holes. Since n and p are known we can calculate conductivity.

$$\sigma = q\left(n\mu_e + p\mu_p\right) = 1.6x10^{-19}\left(10^{21}x0.3 + 10^{20}x0.15\right) = 50.4Sm^{-1}$$

Note that in this case I didn't neglect the conductivity due to holes because a lot of holes are being injected and they may contribute significantly to conductivity.

Actually this conductivity isn't very important since the current flow is not due to drift, but rather due to diffusion. However it is useful practice!