EEE105 Tutorial Question Set 7
Solutions

1. a) The procedure to solve the first part of this question is very similar to what was done in self test 6, part 1. Following the same arguments you should be able to find

$$p_p = 3.7x10^{23}\,\mathrm{m}^{-3}, n_{n=}1.7x10^{21}\,\mathrm{m}^{-3}, p_n = 3.3x10^{17}\,\mathrm{m}^{-3}$$
$$V_0 = 0.35\mathrm{V}$$

b) This part follows a similar logic to self test 6 part 3 and you should be able to calculate that for a forward bias of 0.1V

$$p_{n_0} = 1.8x10^{19}\,\mathrm{m}^{-3}$$

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

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

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.

The voltage across the p-material should be 10 mV, 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:

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

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.

4. a) The first part of this question should be simple bookwork from the lecture notes.

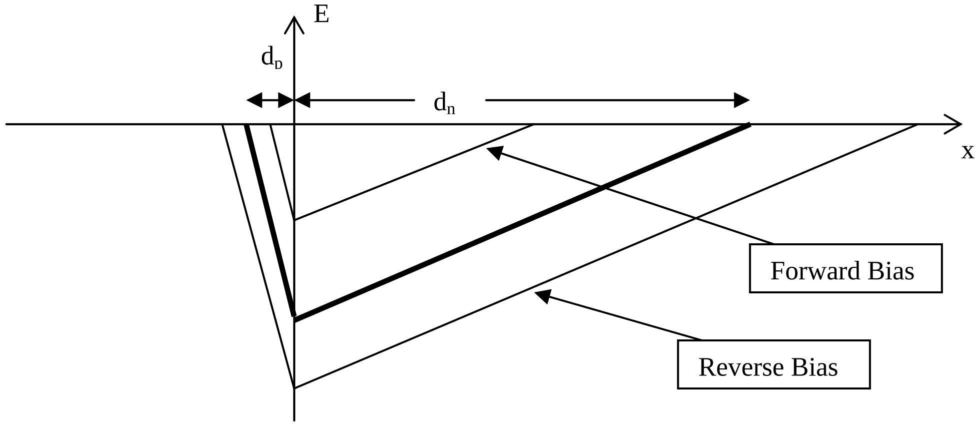
Charge balance relates to the exposed (ionised) donor and acceptor atoms in the n- and p-type materials in the depletion regions on either side of the junction. In order to maintain charge neutrality across the device the number of each must be equal. Hence if the density of acceptors is higher then the thickness will be thinner on the p-side of the junction. It can be beneficial to your answer to illustrate this with a figure.

For a junction of constant cross-sectional area, A, this can be written as: $\mathbf{d_pN_A=d_nN_D}$, where d_p, d_n are the depletion region thicknesses on either side of the junction and N_A and N_D the dopant densities.

Hence: $\dfrac{d_p}{d_n} = \dfrac{N_D}{N_A}$

You should draw a picture of the field in the form below, illustrating the that slope is steeper on the p-side as $d_p < d_n$. It should also show that reverse bias reinforces the built-in field making the depletion region thicker, whereas forward bias opposes the built-in field, reducing the depletion layer thickness.

Strictly speaking the field should have negative slope on the p-side with distance, x, as the exposed acceptor atoms are negatively charged.



(10 marks: 3 marks for the zero bias explanation and diagram, 2 marks for the equation and 5 marks for forward / reverse bias explanation and diagram)

b) In the next part you are asked about the capacitance per unit area. For the parallel plate capacitor we know:

$C = \frac{\varepsilon A}{d}$, which for the diode capacitance per unit area becomes: $\frac{C}{A} = \frac{\varepsilon}{d_j}$

using the information in the question we can therefore write: $\frac{C}{A} = \left(\frac{\varepsilon e N_d}{2V_j}\right)^{1/2}$ ①

Note that e was used rather than q for the charge on the electron in this example.

(3 marks)

c) In the final part of the question you need to apply the above in the first half. Clearly $C \propto V_j^{-1/2}$

We need to compare the situation for V=3.7V and V=0.7V (including the built-in voltage):

$\frac{C_{3.7}}{C_{0.7}} = \left(\frac{V_{j(0.7)}}{V_{j(3.7)}}\right)^{1/2} = 0.43$. Hence we can reduce the capacitance to just below half using this supply voltage on the diode.

(4 marks)

The capacitance is highest when V is smallest, and the units are in Fm^{-2}, corresponding to capacitance per unit area. Rewriting equation ① above and solving for N_d with V_j=0.7 V the we obtain:

$N_d = 3.29 \times 10^{17}$ m^{-3}

(3 marks)