EEE337/348: Tutorial 2

1) Consider a Si pn junction with the following parameters.

   Diode area, A = 1 mm^2
   p-side doping, N_A = 1×10^{16} cm^{-3}
   n-side doping, N_D = 2×10^{16} cm^{-3}
   Electron diffusion coefficients, D_e = 20 cm^2/s
   Hole diffusion coefficients, D_h= 12 cm^2/s
   Electron minority carrier lifetime, τ_e = 100 ns
   Hole minority carrier lifetime, τ_h = 10 ns
   Intrinsic carrier concentration, n_i = 1.5x10^{10} cm^{-3}

   i) Calculate the minority carrier diffusion lengths.

$$L_e = \sqrt{D_e \tau_e} = \sqrt{20\times10^{-4}\times10^{-7}} = 1.41\times10^{-5}m = 14.1\mu m$$
$$L_h = \sqrt{D_h \tau_h} = \sqrt{12\times10^{-4}\times10^{-8}} = 3.46\times10^{-6}m = 3.46\mu m$$

   ii) When used as a solar cell, it is important to have a large depletion width. Calculate the depletion width of this diode at 0 V.

First we need to calculate the built in potential

$$V_{bi} = \frac{kT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right) = 0.026\ln\left(\frac{1\times10^{16}\times2\times10^{16}}{\left(1.5\times10^{10}\right)^2}\right) = 0.715V\ .$$

The depletion width is given by

$$W = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{N_A+N_D}{N_A N_D}\right)V_{bi}} = \sqrt{\frac{2\times11.9\times8.85\times10^{-14}}{1.602\times10^{-19}}\left(\frac{3\times10^{16}}{2\times10^{32}}\right)\times0.715} = 0.38\,\mu\text{m}.$$

   iii) Assuming that when exposed to direct sunlight the electron-hole pair generation rate is constant and is given by 10^{22} cm^{-3}s^{-1}. Calculate the photocurrent produced.

$$I_{ph} = qAG\left(L_e + W + L_h\right) = 1.6\times10^{-19}\times10^{-6}\times10^{22}\times10^{6}\times\left(17.94\times10^{-6}\right) = 0.029A = 29mA$$

   iv) Calculate the saturation current in this diode.

$$I_s = qAN_cN_v\exp\left(-\frac{E_g}{kT}\right)\left[\frac{1}{N_A}\sqrt{\frac{D_e}{\tau_e}} + \frac{1}{N_D}\sqrt{\frac{D_h}{\tau_h}}\right] = qAn_i^2\left[\frac{1}{N_A}\sqrt{\frac{D_e}{\tau_e}} + \frac{1}{N_D}\sqrt{\frac{D_h}{\tau_h}}\right]$$

$$I_s = 1.6\times10^{-19}\times10^{-6}\times\left(1.5\times10^{16}\right)^2\times\left[\frac{1}{1\times10^{22}}\sqrt{\frac{20\times10^{-4}}{10^{-7}}} + \frac{1}{2\times10^{22}}\sqrt{\frac{12\times10^{-4}}{10^{-8}}}\right]$$

$$I_s = 1.13\times10^{-12}A = 1.13pA$$

2) Using values obtained in part (1),

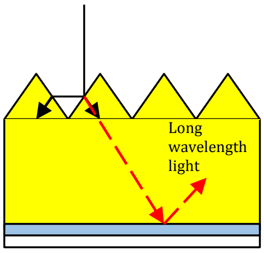
i) calculate the open circuit voltage and the short circuit current of the Si diode in part (2).

$$V_{OC} = \frac{kT}{q}\ln\left(1+\frac{I_{ph}}{I_s}\right) = 0.026\ln\left(1+\frac{29mA}{1.13pA}\right) = 0.623V \, .$$

ii) Consider that the diode described in part (1) is a simple planar diode fabricated with a single implantation step and deposition of metal contacts. Discuss additional fabrication procedures that can be adopted to increase V_{OC}.

Additional fabrication steps that can be performed on a basic solar cell include;

a. We can minimise the light reflected at the surface by using an antireflection coating. A suitable dielectric to be used is SiO_2. In addition to this, we can also include light reflection structure such as “pyramid reflector”, illustrated below. These will maximise the light entering the solar cell and increase the photocurrent.



b. Include a reflector at the substrate. This can be achieved by including a SiO_2/Metal layers at the substrate as shown above. Long wavelength light which is not absorbed close to the surface will be reflected to increase the absorption path length that leads to higher quantum efficiency.

c. Surface should be passivated to reduce surface recombination. This can be done using SiO_2 as passivation layer. Hydrogen has also been introduced to terminte dangling bonds in Si.

3) Consider a solar cell that produces short circuit current I_{SC} = 25 mA and an open circuit voltage, V_{OC} = 0.53 V.

i) Calculate the maximum power produced by this solar cell if its fill factor is 0.81.

$$F_{fill} = \frac{I_m V_m}{I_{SC} V_{OC}} \, .$$

The maximum power produced is therefore $I_m V_m$ = 0.81x0.53x0.025 = 1.07mW.

ii) Assuming that $V_m = 0.9V_{OC}$ and $I_m = 0.9I_{SC}$ calculate the number of cells (specify how the cells should be connected) required to produce a total power of 10 W at an output voltage of 10 V.

Each cell produces 0.53x0.9=0.477 V. To produce 10 V, we need to connect N cells in series so that N = 10/0.477 ~21 cells.

The power produced by this row of 21 cells is 10 x 0.9x0.025 = 0.225 W. To produce 10 W, we will need to have 10/0.225 = 45 rows. Therefore the total number of cells required is 945 solar cells.

4) Discuss the advantages of using a tandem solar cell over a single junction solar cell.
Multi-junction, with each junction optimised to absorb a defined wavelength range, can be designed to maximise the absorption of solar radiation from UV to infrared. Clearly a single junction is not able to do this due to energy loss as heat, inability to absorb photons with energies smaller than its bandgap and incomplete carrier collection. The tandem solar cell usually incorporates wide bandgap transparent window layers to reduce recombination of photogenerated carriers.

5) Describe the structure of a typical high efficiency 3 junction tandem solar cell.
The bandgap is reduced from the top to the bottom. For example the junctions, from top to bottom, are InGaP, InGaAs and Ge with bandgaps of 1.7, 1.2 and 0.65 eV respectively. Very highly doped pn junctions are inserted between each junction. These pn junctions are designed such that carriers can tunnel through the different bandgap junctions. The current from each junction should be the same as the junctions are connected in series. The triple junction can be designed to achieve high absorption efficiency from UV to 1.9 µm and achieves much higher efficiency than Si