EE2003 – SEMICONDUCTOR FUNDAMENTALS (Part III)

Tutorial 13
Photodetectors and solar cells

Q1

What are the differences and similarities between a solar cell and a photodiode?

Both solar cell and photodiode are formed by pn junctions.

When light is illuminated and absorbed by the pn junction, e^{-}–h^{+} pairs are generated in the space charge region. Then the internal field in the space charge region causes the e^{-} and h^{+} to separate.

a) if the pn junction is left on open circuit, an externally measurable potential will appear between the p and n regions.

   This called the photovoltaic mode of operation, which is the basis of solar cell.

b) if the pn junction is operated under a reversed biased voltage.

   This called the photoconductive mode of operation, which is the basis of photodiode.

Q2

A Si photodiode has an active light receiving area of diameter 0.4 mm. When radiation of wavelength 700 nm (red light) and intensity 0.1 mW/cm^2 incidents, it generates a photocurrent of 56.6 nA. What is the responsivity and quantum efficiency (QE) of the photodiode at 700 nm?

Q2:

The incident light intensity I=0.1mW cm^{-2} means that the incident power for conversion is

$$P_0 = AI = \pi\left(0.02cm\right)^2\left(10^{-4}Wcm^{-2}\right) = 1.26\times10^{-7}W = 0.126\mu W$$

The responsivity is

$$R = \frac{I_{ph}}{P_0} = \left(56.6\times10^{-9}A\right)/\left(1.26\times10^{-7}W\right) = 0.45AW^{-1}$$

The QE can be calculated as

$$\eta = R\frac{hc}{e\lambda} = \left(0.45AW^{-1}\right)\frac{\left(6.62\times10^{-34}J\cdot s\right)\left(3\times10^{8}m\cdot s^{-1}\right)}{\left(1.6\times10^{-19}C\right)\left(700\times10^{-9}m\right)}$$

$$= 0.80 = 80\%.$$

Q3

A silicon photodiode has an external quantum efficiency of 70% at 830 nm. If the incident optical power is 10 nW, what is the photocurrent?

$$R = \eta \frac{e\lambda}{hc} = 0.70 \frac{1.6 \times 10^{-19} \times 830 \times 10^{-9}}{6.626 \times 10^{-34} \times 3 \times 10^{8}} = 0.47 A/W$$

Then, $I = RP = 0.47 \times 10 \times 10^{-9} A = 4.7 nA$

Q4

Operating under the room temperature (T=300k), a solar cell under illumination of 600 W·m^{-2} has an open circuit output voltage V_{oc} of 0.485V. What is the open circuit voltage when the light intensity is doubled?

Q4

The general I-V characteristics under light illumination is given by:

$$I = I_0\left[\exp\left(\frac{qV_{oc}}{kT}\right)-1\right]-I_L$$

For open circuit, I=0. Hence, one has

$$I_0\left[\exp\left(\frac{qV_{oc}}{kT}\right)-1\right]-I_L=0$$

As $V_{oc} \gg \frac{kT}{q}$, $\exp\left(\frac{qV_{oc}}{kT}\right) \gg 1$, So rearrange above equation

One has $V_{oc} = \frac{kT}{q}\ln\left(\frac{I_L}{I_0}\right)$

Because I_L is proportional to the light intensity, therefore, at a given temperature, the change in V_{oc} is

$$V_{oc2} - V_{oc1} = \frac{kT}{q}\ln\left(\frac{I_{L2}}{I_0}\right) - \frac{kT}{q}\ln\left(\frac{I_{L1}}{I_0}\right) = \frac{kT}{q}\ln\left(\frac{I_{L2}}{I_{L1}}\right)$$

$$= \frac{kT}{q}\ln\left(\frac{I_{light2}}{I_{light1}}\right)$$

Therefore, the new open circuit voltage is

$$V_{oc2} = V_{oc1} + \frac{kT}{q}\ln\left(\frac{I_{light2}}{I_{light1}}\right)$$

$$= 0.485 + 0.0259\ln(2) = 0.503V$$