ME4252 – NANOMATERIALS FOR ENERGY ENGINEERING

(Semester 1: AY2022/23)

Assignment solutions

Question 1

(a) Consider two physically separated semiconductors as shown below in the Figure 1.

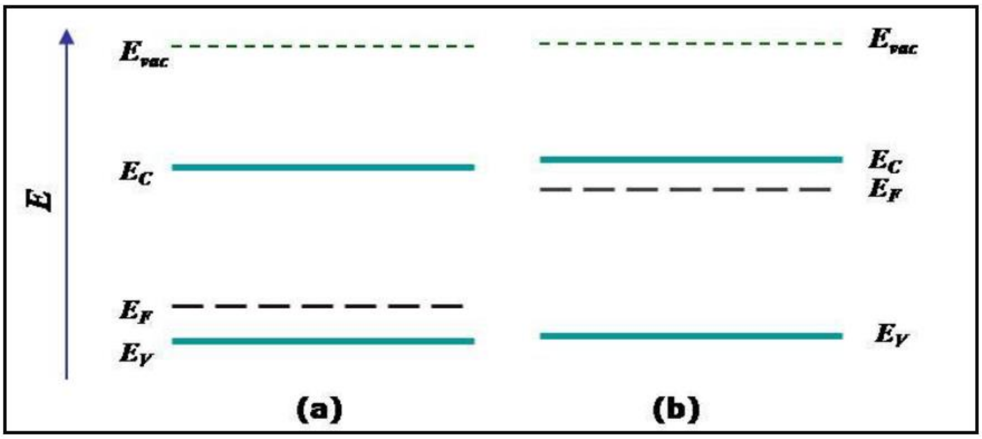


Figure 1

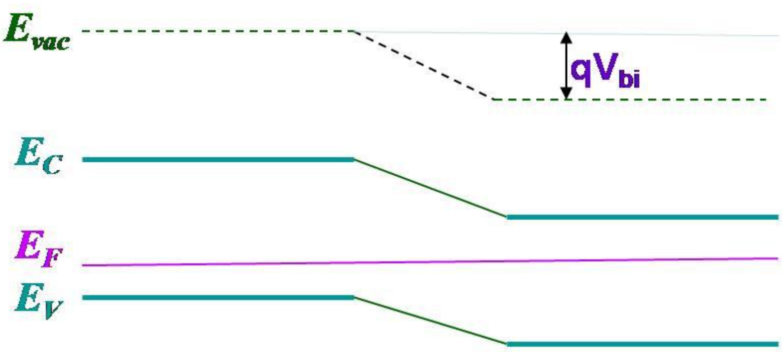
(i) Draw the band diagram if these two semiconductors are placed in direct contact in dark condition. Label the Fermi level, the conduction band, the valance band and the vacuum level. Show the built-in potential.

(ii) Assume that these two semiconductors which are in contact are illuminated by light. Draw the band diagram highlighting the changes in the energy levels. Show the open circuit voltage.

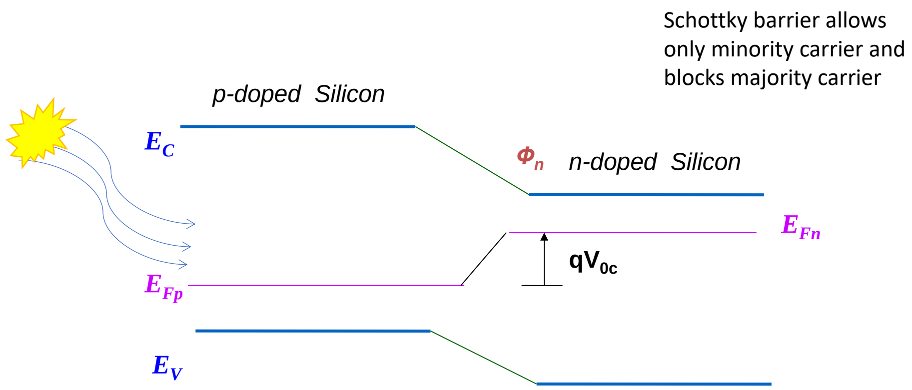
[5 *marks*]

Solution:

(i)



(ii)



Band profile of Illuminated *p-n* homojunction cell

<u>Question 2</u>

Figure 2 below shows I-V curves of a solar panel at 25°C under various irradiance levels.

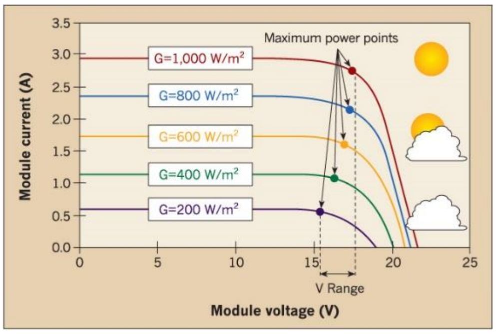


Figure 2

(i) Why the short circuit current increases largely with increase in solar irradiance?

(ii) Why the open circuit voltage increases only slightly with increase in light intensity?

[*4 marks*]

Solution:

(i) The short-circuit current ($I_{sc}=I_L$) is proportional to the irradiance, hence it increases largely with solar irradiance

(ii) The open-circuit voltage increases logarithmically (slightly) with the irradiance considering that I_L is proportional to the irradiance as given below:

$$\boxed{V_{OC} = \frac{kT}{q}\ln\left(\frac{I_L}{I_0}+1\right)}$$

Question 3

Identify three recombination processes in a dye-sensitized solar cell (use a schematic energy level diagram)

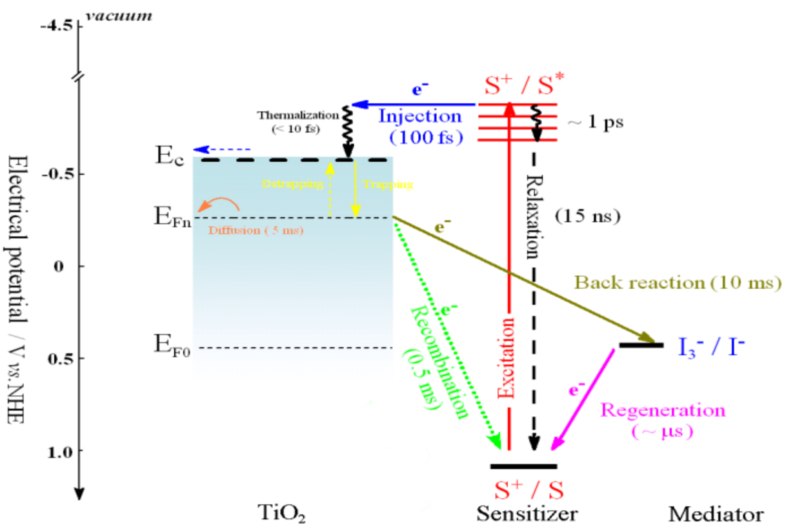
[*5 marks*]

Solution:

(i) Recombination processes in a dye-sensitized solar cell

Back transfer reaction, where injected electrons into TiO_2 combines with the holes in the HOMO level of dye molecules

Back transfer reaction, where injected electrons into TiO_2 combines with the redox couples in the electrolytes.



Question 4

Calculate the density of the donor atoms which we wish to add to change the intrinsic germanium to *n – type* material with resistivity $0.19\times10^{-2}\ \Omega m$. The mobility of electrons in the *n – type* semiconductor is 0.325 $m^2V^{-1}s^{-1}$.

[*5 marks*]

Solution:

$$Resistivity\ \rho = \frac{1}{\sigma} = \frac{1}{qN_D\mu_e}$$

Given,

$\rho = 0.19\times10^{-2}\ \Omega m$
$\mu_e = 0.325\ \ m^2V^{-1}s^{-1}$
$N_D = ?$

$$=> 0.19\times10^{-2} = \frac{1}{N_D\times0.325\times1.6\times10^{-19}}$$

$$=> N_D = \frac{1}{0.19\times10^{-2}\times0.325\times1.6\times10^{-19}}$$

$$= 1.01\times10^{22}\ /\ m^3$$

Question 5

A 5 cm^2 Ge solar cell with a dark saturation current of 2 *nA* has AM1.5 radiation incident upon it producing $4\text{x}10^{17}$ EHP *per* cm^3 *per second*. The electron and hole diffusion lengths may be assumed to be 5 μm. Neglecting the photo generated currents within the junction, calculate the I_{SC} and V_{OC} of the cell at room temperature (300K).

[*5 marks*]

Solution:

Given A = 5 cm^2; I_o = 2 nA = 2 x 10^{-9} A; g = 4 x $10^{17}/cm^3$-sec

$L_n = L_h = 5\ \mu m = 5 \times 10^{-4}$ cm

$I_{SC} = q\ A\ g\ (L_n + L_h)$

$= 1.6 \times 10^{-19} \times 5 \times 4 \times 10^{17} \times 10 \times 10^{-4}$

$= 320\ \mu A$

$V_{OC} = (kT/q) \ln (1 + I_{SC} / I_o)$

$= 0.026 \ln (1+(320 \times 10^{-6} / 2 \times 10^{-9}))$

$= 0.310\ V$

Question 6

Provide three ways of increasing conductivity of an ionic solid.

[*3 marks*]

1) Raise the temperature and so increase the number of intrinsic defects

2) Add an impurity to create vacancies or defects in the structure (extrinsic defects)

3) Lower the activation energy of the jump, perhaps by creating more space in the structure.

Question 7

(a) Provide possible defects in KCl upon doping by $CdCl_2$ and write down the equilibrium defect equation.

Creation of an extra vacancy in K site to compensate excess positive charge of Cd siting in K site.

$$KCl + CdCl_2 \rightleftarrows Cd_K^{\circ} + V_K'$$

(b) Provide two possible defect reactions in TiO_2.

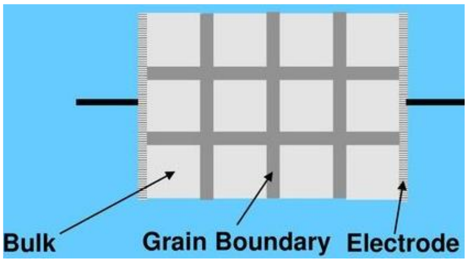
(i) $O_o^x \rightleftarrows V_o^{\cdot\cdot} + O_i^{''}$

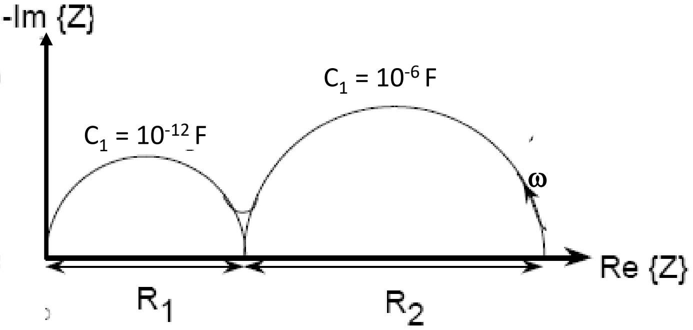
(ii) $Ti_{Ti}^x \rightleftarrows Ti_i^{\cdot\cdot\cdot\cdot} + V_{Ti}^{''''}$

[*5 marks*]

Question 8

Figure below shows a model of a polycrystalline AgI sample of 5mm thick kept between two Ag electrodes, along with its impedance spectrum recorded at 1Hz – 10 MHz. The capacitance of these two semicircles derived from the equivalent circuit diagram are also shown.





Identify the semicircle that belongs to the bulk and the grain boundaries of the polycrystalline AgI sample. Justify your answer.

[*4 marks*]

Solution:

Low frequency semicircle refers to the grain boundaries while the high frequency semicircle belongs to the bulk of AgI.

The micro Farad capacitance of the grain boundary is due to its nanometer thickness, while the picofarad capacitance of the bulk is due to the thick bulk layers of 5 mm.