ENGINEERING TRIPOS PART IIB

Wednesday 11 May 2011 2.30 to 4

Module 4B14

SOLAR-ELECTRONIC POWER: GENERATION AND DISTRIBUTION

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

Attachment: Sheet of Formulae and Constants (1 page).

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

GA02

1 A p-n junction Si solar cell has the following parameters at 300K in the dark.

(i)	*n*-doping (N_D)	10^{25} m^{-3}
(ii)	*p*-doping (N_A)	10^{23} m^{-3}
(iii)	minority carrier hole life time (τ_h)	1 ns
(iv)	minority carrier electron lifetime (τ_e)	1 μs
(v)	electron diffusion length (L_e)	200 μm
(vi)	hole diffusion length (L_h)	0.5 μm
(vii)	intrinsic carrier concentration (n_i)	10^{16} m^{-3}

Assume that the density of available states at the conduction band (N_c) and valence band edge (N_v) are equal. The junction area is 10^{-3} m^2 and formed such that the n-region penetrates to a depth of 1 μm from the surface, followed by a p-doped Si region of 350 μm.

Calculate the following for the junction.

(a) The reverse saturation current. [15%]

(b) The built-in potential. [25%]

(c) If the transport of electrons outside the depletion region is only due to diffusion, calculate the peak minority electron carrier density when a forward voltage of 0.6 V is applied. [25%]

(d) When the cell is exposed to solar light an open circuit voltage of 0.65 V is measured. Estimate the corresponding short circuit current which would be expected from the cell. Hence also estimate the optical generation rate under these conditions. [35%]

Clearly state all assumptions made.

2 (a) Why are amorphous Si (a-Si:H) solar cells typically 1 μm thick thin films, whereas crystalline Si cells are typically 200 – 300 μm thick? [20%]

(b) Sketch the structure of a p-i-n amorphous Si solar cell marking clearly the main features. [15%]

(c) Why is an intrinsic (i) region essential for the functioning of an a-Si:H solar cell? [15%]

(d) How can the solar light coming into an a-Si:H solar cell be optimised through addition of a transparent thin film on the surface? [20%]

(e) If the relative permittivity of a-Si:H is 9, calculate the optimum thickness for the additional transparent film in (d) above. [30%]

3 A multi-crystalline Si solar cell has a short circuit current (I_{sc}) of 1.5 A under AM1.5 (1kW m^{-2}) solar irradiation. The cell area is 4 x 10^{-3} m^2.

The ideality factor and reverse saturation current measured under dark conditions at 300K are 1.1 and 1nA, respectively.

(a) What is the open circuit voltage expected from the cell? State all assumptions made. [20%]

(b) Estimate the power conversion efficiency of the cell. [20%]

(c) More detailed measurements under dark conditions reveal that the cell has a contact resistance of 50 mΩ. What would be the operational efficiency of the cell? [30%]

(d) Draw an equivalent circuit for the multi-crystalline solar cell making clear the significance of each circuit element. [30%]

4 (a) Why do solar cells have to be connected in series within a solar module? [10%]

(b) Show that if two solar modules have different short circuit currents, I_{SC1} and I_{SC2}, power can be dissipated within one of them when connected in series, providing power to a load. [25%]

(c) How is the dissipation condition in (b) above overcome in practical solar modules? [15%]

(d) What are the advantages and disadvantages of a microinverter on each module compared to a string inverter for grid connection of a solar installation? [20%]

(e) Write a commentary on the following topic. "A Domestic DC grid is ideal for solar power backed lighting and electric vehicle charging". [30%]

END OF PAPER

D14 SOLAR CELL ELECTRONIC POWER: GENERATION AND DISTRIBUTION

Formulae and Constants

Reflection coefficient from the third layer of a 3 layer system comprising of a thin film sandwiched between two bulk materials extending away from their interfaces with the thin film is given as:

$$R = \frac{n_2^2 (n_1 - n_3)^2 \cos^2 \vartheta + (n_1 n_3 - n_2^2)^2 \sin^2 \vartheta}{n_2^2 (n_1 + n_3)^2 \cos^2 \vartheta + (n_1 n_3 + n_2^2)^2 \sin^2 \vartheta}$$

where $$\vartheta = \frac{2\pi\, n_2\, d}{\lambda}$$

n_1, n_2 and n_3 are the refractive indices of 3 materials m_1, m_2 and m_3, respectively; d is the thickness of the thin film m_2 sandwiched between materials m_1 and m_3. Direction of light incidence is taken to be from m_1 to m_3.

Fill Factor for a solar cell

$$FF_o = \frac{\frac{qV_{oc}}{kT} - 1n\left(\frac{qV_{oc}}{kT} + 0.72\right)}{\frac{qV_{oc}}{kT} + 1}$$

where V_{oc} is the open circuit voltage for the cell.

Constants

Electronic charge unit	**q: 1.602 × 10^{-19} C**
Boltzmann's Constant	**k: 1.38 × 10^{-23} J K^{-1}**
Speed of light	**c: 3 × 10^{8} m s^{-1}**
Planck's Constant	**h: 6.626 × 10^{-34} J s**

Dielectric permittivity free space ε_0: **8.85 × 10^{-12} F m^{-1}**

Relative permittivity of **Si** ε_r: **11.9**

Refractive index (for weakly and non-absorbing wavelengths) **$n = \varepsilon_r^{0.5}$**

Band-gap energy of **Si: 1.12 qV J**