EGT3
ENGINEERING TRIPOS PART IIB

Monday 25 April 2016 9.30 to 11

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.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book
Attachment: Sheet of Formulae and Constants (1 page).

10 minutes reading time is allowed for this paper.

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

1 A pn^+ junction Si solar cell has the parameters given below at a temperature of 300 K.

N_D	donor density on n-type side	1.0×10^{25} m^{-3}
N_A	acceptor density on p-type side	5.0×10^{22} m^{-3}
n_i	intrinsic carrier density	1.0×10^{16} m^{-3}
τ_e	minority carrier electron lifetime	1 μs
L_e	electron diffusion length	100 μm
L_h	hole diffusion length	$L_h \ll L_e$

The junction area is 10^{-2} m^2. The junction is formed so that the uniformly doped n-type region extends 1 μm from the surface, followed by the uniformly doped p-type region extending a further 250 μm to form the bulk of the cell. When operating as a solar cell the light enters from the surface adjacent to the n-type region.

(a) Consider the excess minority electron concentration, Δn, in the p-type region. The continuity equation is

$$\frac{\partial(\Delta n)}{\partial t} = -\frac{\Delta n}{\tau_e} + \mu E \frac{\partial(\Delta n)}{\partial x} + D_e \frac{\partial^2(\Delta n)}{\partial x^2}$$

where μ is the electron mobility, E is the electric field, τ_e is the minority carrier electron lifetime and D_e is the electron diffusion constant. Show that under steady-state, zero-bias conditions, Δn is given by

$$\Delta n = \frac{{n_i}^2}{N_A}\left[\exp\left(\frac{qV}{kT}\right) - 1\right]\exp\left(\frac{-x}{L_e}\right)$$

where $L_e = \sqrt{D_e \tau_e}$, V is the applied bias, q the electronic charge, T the temperature and x the distance from the edge of the depletion region. State all assumptions. [35%]

(b) The current density, J_n, due to electrons is given by

$$J_n = qD_e \frac{dn}{dx}$$

Hence, estimate the reverse saturation current, I_s. State all assumptions. [25%]

(c) When the cell is exposed to AM1.5 sunlight it develops an open circuit voltage of 0.60 V.

(i) What is the ideal short circuit current which could be expected from the cell? You may estimate the reverse saturation current as $I_s = 327$ pA. [20%]

(ii) Estimate the optical generation rate. [20%]

2 (a) A p–n junction crystalline Si solar cell is typically 300 µm to 500 µm thick. A p-n amorphous Si (a-Si:H) solar cell has a typical thickness of 1 µm. Therefore, the latter is termed a 'thin film' solar cell. Explain why an a-Si:H solar cell can be achieved in thin film form, whereas a crystalline Si cell requires a significantly greater thickness. [15%]

(b) Show diagrammatically the major manufacturing process steps required for a conventional single junction crystalline Si solar cell. The function of each process step should be clearly indicated. [30%]

(c) How could a crystalline Si solar cell be realised with a 10 µm to 50 µm thickness (Si foil) without a significant loss in efficiency compared to a thicker cell. [35%]

(d) Show the changes/additions in the process steps used for manufacturing a conventional Si cell in (b) above required to realise the structure required for the Si foil cell in (c). [20%]

3 A multi-crystalline Si solar cell has experimentally measured open circuit voltage (V_{oc}) and short circuit current (I_{sc}) values of 0.65 V and 1.5 A respectively when exposed to AM 1.5 (1 kWm^{-2}) solar illumination. The area of the cell is 50 cm^{2} and the temperature during the measurement was 300 K.

(a) Estimate the efficiency of the cell. [20%]

(b) When the cell is characterised with its p-n junction forward biased under dark conditions (no illumination) an ideality factor of 1.05 is measured. Under condition of strong forward bias the current is seen to be resistively limited above 1 A. The limiting resistance is 25 mΩ.

(i) What is the reverse saturation current (I_s) for the cell? [20%]

(ii) What is the Fill Factor (FF_o) for the p-n junction in the cell. [30%]

(iii) Give a better estimate for the efficiency of the cell taking into consideration the parameters measured under dark conditions. [30%]

4 (a) Why is Maximum Power Point Tracking (MPPT) implemented in solar photovoltaic power plants? [20%]

(b) Show in block diagram form the main components of an inverter used to connect a solar photovoltaic power plant to the AC grid. [30%]

(c) Write a commentary on whether the use of solar power will continue to expand globally if the price of fossil fuels continues to be low. [50%]

END OF PAPER

Answers:

1(b) 320pA

1(c)(i) 3.44A

1(c)(ii) 2.15×10^{25} $m^{-3}s^{-1}$

3(a) 16.4%

3(b)(i) 6.05×10^{-11} A

3(b)(ii) 0.83

3(b)(iii) 15.2%