ENGINEERING TRIPOS PART IIB

Wednesday 7 May 2008 9 to 10.30

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

1 (a) Sketch a cross sectional structure of a typical p-n junction Si solar cell, marking clearly the n-doped and p-doped regions and the electrical contacts. Also indicate clearly the region in which photogeneration of electron-hole pairs occurs and the region which is depleted of free carriers. [25%]

(b) A Si solar cell at 300K has parameters as given in Table 1. Calculate the doping of the p-region in this cell. [30%]

V_{bi}	Built in potential	0.92eV
N_D	n-doping	$2x10^{25}m^{-3}$
τ_e	electron minority carrier lifetime	5μs
τ_h	hole minority carrier lifetime	1ns
L_e	electron diffusion length	250μm
L_h	hole diffusion length	0.2 μm
n_i	Intrinsic carrier concentration	$10^{16}m^{-3}$
N_C, N_V	Band edge density of states	$N_C = N_V$

The operational parameters for a p-n junction
Table 1

(c) If the cell specified in Table 1 has a junction area of $10^{-2}m^2$, what would be the predicted reverse saturation current under dark conditions [20%]

(d) When the cell is exposed to sun light an open circuit voltage (V_{oc}) of 0.65V is measured. Assuming the p-n junction is ideal, what would the corresponding short circuit current be? [10%]

(e) Estimate the optical generation rate (g_{opt}) in the cell when exposed to sunlight conditions as in (d) above. [15%]

2 (a) Sketch the cross section structure of a typical hydrogenated amorphous Si (a-Si:H) solar cell showing clearly the doping, contact, and light absorbing regions. [25%]

(b) Why is it possible to make an a-Si:H solar cell as a thin film structure without a bulk semiconductor region? [25%]

(c) Both a-Si:H and bulk-Si solar cells operate on the principle of absorbing photons to create electron-hole pairs. By comparing the band-diagrams for the two types of cell comment on the major differences between a-Si:H and bulk Si solar cells in terms of photogenerated electron and hole currents when delivering power. [30%]

(d) An a-Si:H solar cell of area $10^{-2}m^2$ operates at 10% efficiency under AM1.5 solar irradiation (1kW m^{-2}). The panel has an open circuit voltage of 1.0V and a fill factor of 0.6. What is the short circuit current? [20%]

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3 (a) Explain why heat generation is an inevitable consequence of photovoltaic energy conversion from the solar spectrum using a semiconductor. [20%]

(b) Which operational parameter of a solar cell is most affected by heating. Give reasons for your answer. [10%]

Hence comment on the advantages and disadvantages of concentrating solar light onto a solar cell. [15%]

(c) Bulk solar cells are manufactured with a thin transparent insulating dielectric layer on the surface through which light enters.

(i) What is the purpose of this insulating dielectric layer? [10%]

(ii) If the relative permittivity of the dielectric layer is 2.5, what is optimum thickness of the layer? [10%]

(d) (i) Draw an equivalent circuit representation for an ideal solar cell. [10%]

(ii) Sketch the output current - voltage characteristic for a solar cell and hence explain the significance of the term 'fill factor'. [10%]

(iii) Modify the equivalent circuit of d(i) to include parasitic resistance and leakage current and comment on their influence on the 'fill factor'. [15%]

4 (a) Why is Maximum Power Point Tracking (MPPT) essential for operation of a solar power plant. [10%]

(b) Describe an empirical or a mathematical method to implement maximum power point tracking. Your answer should also include practical limitations of the chosen method. [15%]

(c) Explain how the DC power output from a solar power plant is converted to frequency and phase controlled AC power through the use of pulse-width modulation (PWM). Your answer should also clarify the significance of amplitude modulation index and frequency modulation index in PWM operation. [25%]

(d) Write a commentary on **one** of the following topics.

(i) The relative importance of reducing carbon emissions versus rising oil and gas prices in driving the rapid growth of the solar power sector.

OR

(ii) The expansion of nuclear power generation will not suppress the adoption of solar power in the UK. [50%]

END OF PAPER

D14 SOLAR CELL ELECTRONIC POWER: GENERATION AND DISTRIBUTION

Formulae and Constants

Reflection co-efficient 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_2. Direction of light flow is taken to be from m_1 to m_3.

Fill Factor for a solar cell

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

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**