ENGINEERING TRIPOS PART IIB

Wednesday 10 May 2006 9.00 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 crystalline Si p-n junction solar cell has the following parameters.

(i)	n-doping (N_D)	$10^{25}m^{-3}$
(ii)	minority carrier hole lifetime (τ_h)	5 *ns*
(iii)	minority carrier hole lifetime (τ_e)	2μs
(iv)	electron diffusion length (L_e)	100μm
(v)	hole diffusion length (L_h)	0.5μm
(vi)	intrinsic carrier concentration (n_i)	$1x10^{16}m^{-3}$
(vii)	reverse saturation current (I_S)	$10^{-11}A$

The cell is formed by having a uniformly doped *n* region with a depth of 1μm, measured from the top surface. Below the *n* region a p-doped region of 200 μm forms the bulk substrate. The junction area is $10^{-2}m^2$.

Calculate the following:

(a) The doping (N_A) on the p-side of the junction. You may assume the relationship

$L_e = \sqrt{(D_e \tau_e)}$ and $L_h = \sqrt{(D_h \tau_h)}$ where D_e and D_h are the electron and hole diffusivities respectively. [20%]

(b) The built in potential across the junction. [20%]

When exposed to the solar spectrum on a summer's day the short circuit current (I_{SC}) measured was 3A. Under these conditions calculate:

(c) The corresponding open circuit voltage which would be measured, stating clearly all assumptions made. [20%]

(d) The effective generation rate of electron-hole pairs within the solar cell. [20%]

(e) The estimate the efficiency of the cell (if the power density in the solar spectrum was $900Wm^{-2}$). [20%]

2 (a) Compare the optical absorption characteristics of crystalline Si (c-Si) and amorphous Si (a-Si:H). Hence explain why a-Si:H layers are typically 2-5μm thick whereas c-Si layers are typically 200-500 μm thick in solar cells. [25%)]

(b) Comment on the relative importance of the 'drift' and 'diffusion' processes for separation of photogenerated carriers in a-Si:H and c-Si solar cells. Your answer should also address how the differences in carrier transport are reflected in the conversion efficiencies of the two types of cells. [25%]

(c) Sketch a schematic of an a-Si:H photovoltaic panel suitable for power generation. Your schematic and explanation should make clear how the rated voltage and current for the panel are obtained. [25%]

(d) Discuss why a-Si:H photovoltaic panels are cheaper than c-Si panels? [25%]

3 A multi-crystalline Si solar cell without an anti-reflection (AR) coating has the following measured parameters at 300K. The cell area is $10^{-2}m^2$.

Reverse saturation current	25nA
Short circuit current under AM 1.5 (energy flux of $1kW\,m^{-2}$)	2.5A
Ideality factor	1.1

(a) Explain the difference between Shockley-Read-Hall recombination and Auger recombination of photogenerated carriers. Your answer should state which type of recombination dominates in standard solar cells, giving reasons. [20%]

(b) What is the physical origin of the ideality factor? [20%]

(c) Estimate the power conversion efficiency of the multi-crystalline cell under AM 1.5 illumination when it has no anti-reflection (AR) coating. Give reasons for all assumptions made. [20%]

(d) If an anti-reflection coating material with refractive index 2.4 is available, what would be the most appropriate thickness for a coating on a multi-crystalline Si Cell? Give reasons for any particular choice of wavelength for which reflection is minimised. [20%]

(e) Estimate the improvement in efficiency achievable through the application of the AR coating. [20%]

4 (a) Describe how a 2KW peak solar power system for a domestic installation can be constructed using 100W peak 24V nominal panels. Your answer should consider the relative advantages and disadvantages of series and parallel power connection. [10%]

(b) Outline a Maximum Power Point Tracking (MPPT) algorithm for the solar power system in a). [15%]

c) Show a transistor level circuit diagram for a power conversion stage suitable for grid connection of the solar power system in a). The control features can be shown in block diagram form. Your answer should consider the appropriate use of MOSFET and IGBT transistors in the power conversion stage. [25%]

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

i) Solar photovoltaics is the most suitable technology for urban power generation.

OR

ii) Solar photovoltaics is the most suitable technology for stand alone power generation in isolated rural communities. [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**