UNIVERSITY OF CAMBRIDGE

ENGINEERING TRIPOS PART IIB

Wednesday 11 May 2005 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*

Attachments:
Formulae and constants (1 page)

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

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1 A Si p-n junction solar cell has the following parameters.

(i)	n-doping	$10^{25}m^{-3}$
(ii)	p-doping	$5 \times 10^{22}m^{-3}$
(iii)	minority carrier hole lifetime	1ns
(iv)	minority carrier electron lifetime	2μs
(v)	electron diffusion length	80μm
(vi)	hole diffusion length	0.5μm
(vii)	intrinsic carrier concentration	$1.6 \times 10^{16}m^{-3}$
(viii)	band edge states	$N_C = N_V$

The junction temperature is 300 K. The junction has a uniformly doped n region of 1μm depth from the surface followed by a 250 μm p-region with uniform doping. When operating as a solar cell light enters from the surface adjacent to the n-region. The junction area is $10^{-2}m^2$.

Calculate the following:

a) The built in potential across the junction under dark conditions. [20%]

b) The width of the depletion region on the p-side of the junction under dark conditions. [20%]

c) The forward bias voltage across the junction when the minority carrier electron concentration is equal to $10^{21}m^{-3}$ at the edge of the p-depletion region under dark conditions. [20%]

d) The optical generation rate when the cell develops a short circuit current of 4A on exposure to the solar spectrum. [15%]

Comment on why the measured open circuit voltage from the solar cell will be less than the built in potential under dark conditions. [25%]

2 a) Explain the major difference in the photon to electron energy conversion process in a direct band-gap semiconductor compared to an indirect band-gap semiconductor. [10%]

b) Compare the photo generated electronic carrier transport process in hydrogenated amorphous - Si (a-Si:H) solar cells and crystalline – Si (c-Si) solar cells. Hence propose the optimum structure for an amorphous – Si cell. Your answer should give reasons for any differences in the relative thicknesses of the effective photon absorption and conversion regions in the two types of cell. [25%]

c) Discuss the fundamental limitations, which govern the efficiency with which photon energy over the entire solar spectrum can be converted to electronic energy in a photovoltaic process based on absorption in a single semiconducting material. Your answer should also consider implications for total power conversion efficiency in terms of open circuit voltage (V_{oc}) and short circuit current (I_{sc}). [25%]

d) In a – Si:H cells it is possible to change the band-gap with depth. Usually this involves 'sandwiching' the a-Si:H layer with wider band-gap a-SiC:H and narrower band-gap a-SiGe:H layers. Solar light enters through the a-SiC:H layer. Such a structure is shown in Fig.1.

(i) What is the major advantage of such a variable band-gap with depth a-a-Si:H solar cell? [20%]

(ii) Consider the regions with different band-gaps to be separate cells. The entire cell can be then taken to be individual cells with different band-gaps connected in series. Hence comment on the major limitation inherent in the multi band-gap cell structure for photovoltaic power conversion. [20%]

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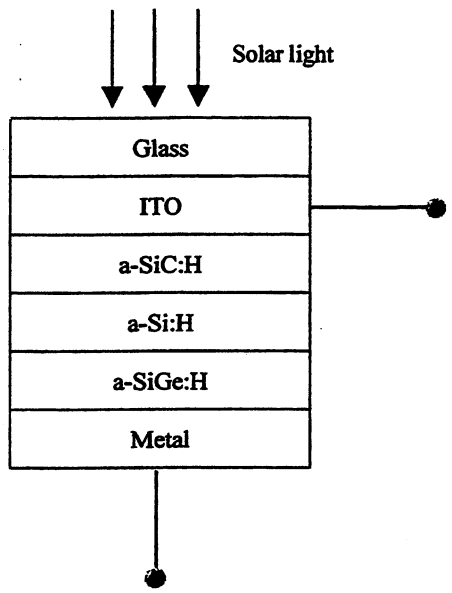

Fig.1.
An amorphous Si based solar cell with its distinct band-gap regions.

3 A multi-crystalline Si solar cell has the following measured parameters at 300 K.

Reverse saturation current under dark conditions	50nA
Short circuit current under AM 1.5 (energy flux of 1kW m^{-2})	2.0A
Ideality factor of the forward I-V characteristic	1.1

a) What is the open circuit voltage V_{oc} which can be expected from this cell? [15%]

b) Estimate the power conversion efficiency for the cell under AM 1.5 illumination. The cell area is $10^{-2}\ \text{m}^2$. [25%]

c) An anti-reflective (AR) coating is applied to the cell to improve its power output. The refractive index of the material available for the AR coating is 2.2.

i) Calculate the thickness of the most suitable AR coating. Give reasons for all assumptions made. [15%]

ii) What is the minimum reflectivity achieved with this anti-reflection coating? [10%]

iii) Comment on improvements in efficiency of the multi-crystalline cell, which may be expected from the application of the AR coating. [15%]

d) Discuss in detail the physical processes which determine the ideality factor of the solar cell. [20%]

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4 a) Show in block diagram form an entire solar cell generation system, which is grid connected. You may assume that the system is sized for an average UK family home. [25%]

b) Comment on the best strategy in terms of cost of ownership and reliability over twenty years for the inverter stage in the system of part a). Your answer should examine the relative merits of a single inverter, multiple-string inverters and multiple ac modules (where each solar-panel has an inverter stage). [25%]

c) Write a commentary on ***one*** of the following topics:

i) Solar power generation will become a standard feature in new housing in Europe over the next 25 years.

OR

ii) Will solar power generation ever be economic? [50%]

END OF PAPER

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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:

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

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**