UNIVERSITY OF CAMBRIDGE

ENGINEERING TRIPOS PART IIB

Wednesday 5 May 2004 9 to 10.30

Module 4B14

SOLAR-ELECTRONIC POWER: GENERATION AND DISTRIBUTION

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

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

There is a one-page datasheet attachment

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 p-n junction Si solar cell has the following junction parameters under dark conditions:

(i)	built in potential	**0.93 eV**
(ii)	p-doping	**10^{23}m^{-3}**
(iii)	minority carrier hole life time	**1ns**
(iv)	minority carrier electron lifetime	**1μs**
(v)	electron diffusion length	**200μm**
(vi)	hole diffusion length	**0.5μm**
(vii)	intrinsic carrier concentration	**2.0 x 10^{16}m^{-3}**

The junction temperature is **300K**. Assume that the number of available states at the edge of the valence band and conduction band are equal, i.e. $N_v = N_C$. The junction area is $10^{-3}m^2$. The junction is formed so that the n-type region extends **1 μm** from the surface, followed by the p-type region extending a further **300 μm** to form the bulk of the cell. Calculate the following;

a) Doping of the n-type region [30%]

b) If the transport of electrons outside the depletion region is only due to diffusion;

(i) calculate the peak value of the minority carrier density in the p-type bulk region when a forward voltage of **0.5V** is applied across the junction, and

(ii) sketch the minority carrier distribution. [40%]

c) When the surface of the p-n junction is exposed to the solar system an open circuit voltage of **0.6V** is measured. Estimate the ideal short circuit current and optical generation rate under these conditions. Hence sketch the corresponding current (I) vs voltage (V) characteristic for the p-n junction when operating as a solar cell. [30%]

State all assumptions made

2 a) Would the energy conversion efficiency of a Si solar cell be higher for **600 nm** light or **800 nm** light? Give reasons for your answer.
Hence comment on the theoretical limit to terrestrial photovoltaic solar energy conversion efficiency. [20%]

b) In practice what limits the open circuit voltage V_{oc} and short circuit current I_{sc} available from a Si solar cell? [20%]

c) Draw the equivalent circuit for a solar cell and explain the physical origin of each component. [30%]

d) It is common to apply a thin transparent insulating layer on the front surface of Si solar cells.

(i) What is the purpose of this layer?
(ii) If the layer has a refractive index of **2.0**, calculate an appropriate thickness for the layer. State reasons for any assumptions made.
(iii) What would the ideal refractive index be? [30%]

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3. A multi-crystalline Si solar cell has the following measured parameters:

Short circuit current under AM 1.5 solar light	**2.0 A**
Dark *I-V* characteristic ideality factor	**1.2**
Open circuit voltage V_{oc}	**0.55 V**

Cell temperature was 300 K during all measurements.

a) What is the typical dark current that can be expected from this cell under reverse bias? [20%]

b) Estimate the power conversion efficiency of the cell if it has a surface area of $\mathbf{10^{-2}}\boldsymbol{m}^2$ and AM 1.5 light is considered to have an energy flux of **1 kW** $\boldsymbol{m}^{-2}$ [25%]

c) Give a better estimate for the efficiency for the cell taking into account its contact resistance, measured to be **0.05Ω**, and assuming its reverse leakage resistance under dark conditions is immeasurably large. [25%]

d) The temperature coefficient for the open circuit voltage (dV_{oc}/dT) of the multi-crystalline solar cell in (a) is – **2.0** $\boldsymbol{m}$**VK**$^{-1}$. Identify the main solar cell parameter which gives rise to the temperature coefficient and explain why it does so.

Calculate the value of this parameter at an operating temperature of **330K**. [30%]

(Conti

4. a) Explain how it is possible to have power dissipation within a solar cell when it is connected with other cells to form a power module. [20%]

b) Describe the common control strategy used for maximising power output from a large solar array. Comment on whether it would be viable to have a single control unit for a photovoltaic generator made up from power modules mounted on south, west and east facing facades of a multi-storey office block. [25%]

c) Show in block diagram form the key elements of a grid connected photovoltaic power generator. By referring to the block diagram, discuss the importance of high frequency DC power switching for efficient grid connection of photovoltaic arrays. [30%]

d) Draw the phasor diagram and AC circuit representation for a photovoltaic generating system connected onto the power network. What are the key assumptions which are inherent in such a representation? [25%]

END OF PAPER

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Paper 4B14

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:

$$R = \frac{r_1^2 + r_2^2 + 2r_1r_2 Cos\vartheta}{1 + r_1^2 r_2^2 + 2r_1r_2 Cos\vartheta}$$

where $r_1 = \frac{n_1 - n_2}{n_1 + n_2}$ $\quad r_2 = \frac{n_2 - n_3}{n_2 + n_3}$ $\quad \vartheta = \frac{2\pi n_2 d}{\lambda}$

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 m1 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} Jk^{-1}**
Speed of light	**c: 3×10^{8} mS^{-1}**
Planck's Constant	**h: 6.626×10^{-34} Js**

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** = $\varepsilon_r^{0\text{-}5}$

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