ENGINEERING TRIPOS   PART IIB

Thursday 2 May 2013   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.*

STATIONERY REQUIREMENTS
Single-sided script paper
CUED approved calculator allowed

SPECIAL REQUIREMENTS
Engineering Data Book

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

wim08

1 The current density in an ideal pn^+ solar cell under illumination with light is given by

$$J = \frac{eL_e n_{p0}}{\tau_e}\left[\exp\left(\frac{eV}{kT}\right) - 1\right] - eg_{0p}(L_h + L_e)$$

where all symbols have their usual meaning and g_{0p} is the generation rate of electron-hole pairs per unit volume per unit time.

(a) Sketch a graph of how the current density varies with voltage for an ideal pn^+ solar cell in the dark and under AM1.5 illumination. Mark on the graph the approximate region in which the solar cell should be operated to maximise output power. [10%]

(b) For a particular pn^+ solar cell, the diffusion length of electrons and holes is 0.5 μm and the electron carrier lifetime is 10 μs. The minority carrier concentration in the p-type semiconductor is 10^{14} m^{-3}. It is illuminated with AM1.5 light (a total power of 1 kW m^{-2}) and an open circuit voltage of 0.52 V is measured. The device is operated at a temperature of 298 K.

(i) Calculate the optical generation rate, g_{0p}. [20%]

(ii) Calculate the short circuit current density. [10%]

(iii) If the voltage at maximum power output under these conditions is 0.45 V, calculate the fill factor and cell efficiency. [35%]

(iv) Describe qualitatively what will happen to the voltage at maximum power output if the illumination power is halved. Hence, explain the principles of *maximum power point tracking* applied to solar cells. [25%]

2 (a) Sketch the cross sectional structure of a typical hydrogenated amorphous Si (a–Si:H) solar cell showing clearly the doped, contact and light absorbing regions. [20%]

(b) 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 and structures of 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%]

(c) Figure 1 shows the correlation between the open circuit voltage V_{oc} and the short circuit current density J_{sc} of single junction semiconductor materials. Explain the correlation. Taking into account the AM1.5 solar spectrum, what would be the ideal bandgap to minimise heat production? Why? [30%]

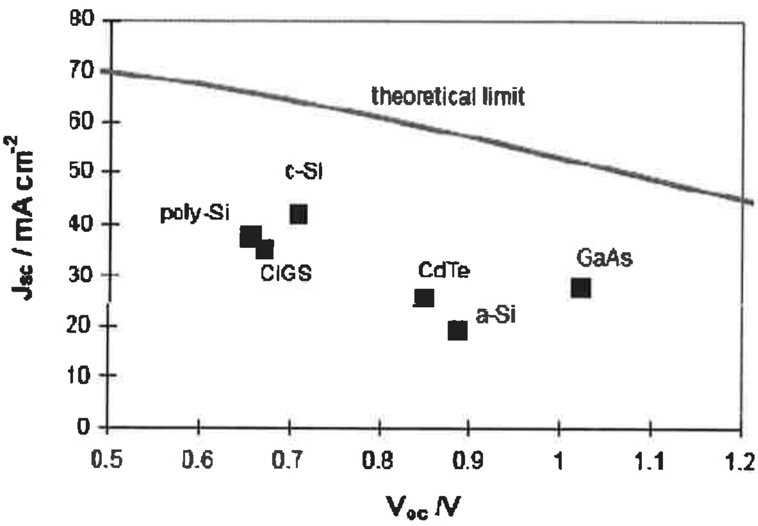
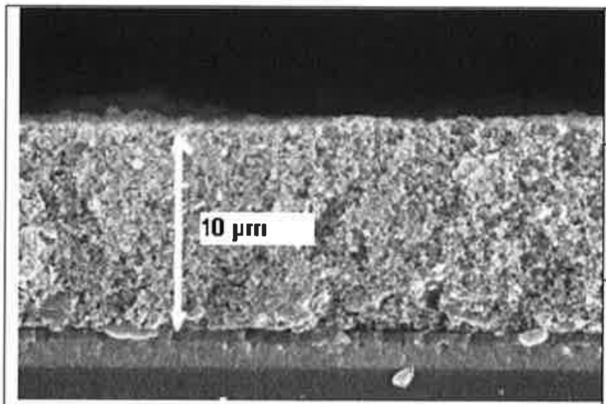


Fig. 1

(d) What factors lead to a reduction in V_{oc} from the ideal solar cell model? Explain with the aid of a sketch how this affects the I-V characteristic of the solar cell. [20%]

3 Figure 2 shows a cross sectional scanning electron microscope image of the nanocrystalline electrode of a dye-sensitised solar cell.



Thickness: 10 μm	
Particle size: 20 nm	
Porosity: 50%	

Fig. 2

(a) Estimate the gain in surface area of such a structure as compared to a flat electrode and hence explain the advantages of using a high surface area electrode for this purpose. [20%]

(b) What are the main technological advantages and limitations of the dye-sensitised solar cell technology as compared to crystalline technology? [20%]

(c) The bandgap of TiO_2, used in the manufacture of a solar cell, is about 3.2 eV. The properties of the resulting solar cell depend, amongst other things, on the bandgap and the absorption spectrum of the dyes used. Fig. 3 below shows the number of photons per wavelength under AM1.5 conditions (left axis) and the absorption spectra of several dyes, labelled 1–8 (right axis). How would your choice of dye affect the photogenerated current and the aesthetics of your solar cell? [20%]

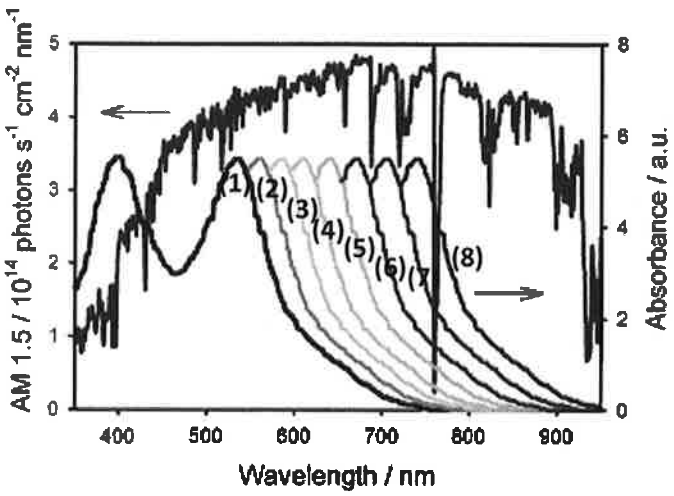


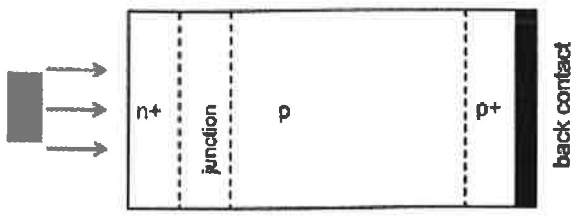
Fig. 3

(d) Write a commentary on the cost effectiveness of photovoltaic power generation today. [40%]

4 (a) Draw the equivalent circuit for a solar cell and explain the physical origin of each component. [20%]

(b) Sketch the output current – voltage characteristic for a solar cell and hence explain the significance of the term *fill factor*. How do the resistances in your equivalent circuit affect the fill factor? [30%]

(c) In order to maximise the short circuit current I_{sc} , it is important to maximise the probability of charge collection. There are many modifications to the basic c-Si p-n structure which are commonplace in order to improve carrier collection. One such modification is the addition of a highly doped region at the back contact, to create a back surface field (BSF), as shown in Fig. 4. With the aid of a diagram, show how this modification affects the collection probability of charge carriers generated at different positions. Explain the mechanism using an appropriate band diagram. [25%]



Cross section of a solar cell with BSF (back surface field)

Fig. 4

(d) Figure 5 shows the Passivated Emitter with a Rear Locally diffused (PERL) cell, which has reached record 25% power conversion efficiencies for a crystalline Si solar cell under AM1.5 light. Describe the design aspects of this cell and explain how each modification from the basic pn-junction solar cell contributes towards enhancing its efficiency. [25%]

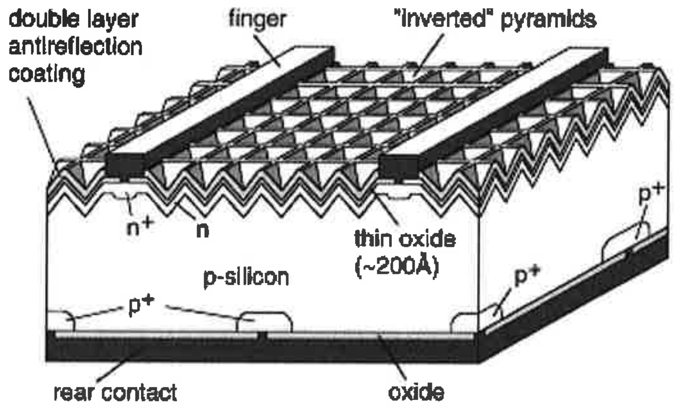


Fig. 5

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