ENGINEERING TRIPOS PART IIB

Thursday 26th April 2012 2.30 to 4

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 p-type, boron doped Si wafer with a doping density of 10^{16} cm^{-3} is used to produce a crystalline silicon (c-Si) solar cell. The wafer is heated in a furnace with a phosphorous atmosphere to produce an n-type coating. Upon finalisation of the solar cell fabrication process, the following parameters are measured at 300 K in the dark.

Built in potential (V_{BI})	0.90 eV
Minority carrier hole life time (τ_h)	0.5 ns
Minority carrier electron lifetime (τ_e)	1 μs
Electron diffusion length (L_e)	180 μm
Hole diffusion length (L_h)	0.5 μm
Intrinsic carrier concentration (n_i)	1.5×10^{16} m^{-3}

Assume that the density of available states at the edges of the conduction band (N_c) and valence band (N_v) are equal (i.e. $N_v = N_c$). The junction area is 10^{-2} m^2 and formed such that the n-region penetrates to a depth of 1 μm from the surface, followed by a p-type region extending a further 250 μm to form the bulk of the cell.

Calculate the following:

(a) The resulting doping density in the n-type region. [30%]

(b) When the cell is exposed to sunlight, an open circuit voltage (V_{OC}) of 0.62 V is measured. Assuming the p-n junction is ideal, what would the corresponding short circuit current be? [20%]

(c) State and justify any assumptions made for (a). [15%]

(d) Assuming that the transport of electrons outside the depletion region is only due to diffusion, sketch the minority carrier distribution in (i) equilibrium conditions; (ii) in the presence of 0.5 V forward bias. [20%]

(e) The solar cell manufacturer is constantly looking to improve the process conditions. Qualitatively, how would you expect the solar cell properties to change if the furnace temperature is increased during phosphorous doping? [15%]

2 (a) Describe the structure of a typical crystalline silicon (c-Si) p-n junction solar cell. Illustrate your answer with a suitable diagram showing typical dimensions and key features. Also indicate clearly the region in which photogeneration of electron-hole pairs occurs, and the region which is depleted of free carriers. [20%]

(b) Amorphous Si (a-Si:H) solar cells are generally much thinner than c-Si cells. Why is this? Would there be a benefit in making thicker a-Si:H solar cells? [15%]

(c) A typical c-Si solar cell has a bandgap of 1.12 eV. For such a cell, is the energy conversion efficiency higher for light with a wavelength of 550 nm or 800 nm? Justify your answer. [15%]

(d) Fig. 1 shows the equivalent circuit diagram for a c-Si solar cell. Explain the physical origin of each circuit element. [20%]

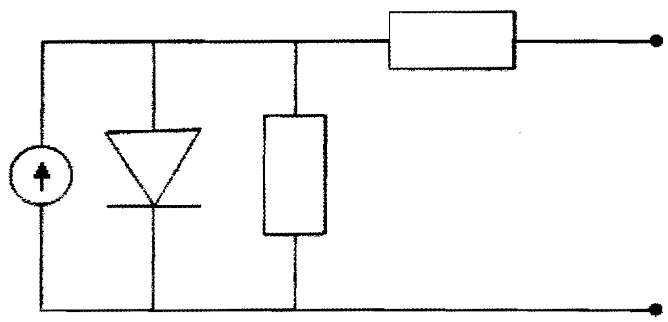

Fig. 1

(e) What is the fundamental difference between a solar cell and a battery as an energy source? [10%]

(f) How does a change in the resistive circuit elements in Fig. 1 affect the shape of the I-V curve of an ideal solar cell? Illustrate your answer with annotated I-V curves. [20%]

3 Two companies, one in the Canary Islands, Spain, and the other in Cambridge, UK, are planning an identical solar installation to exploit their rooftops to generate electricity and possibly some revenue. The rooftops have an area of 450 m^2. The technical characteristics of the panels and inverters chosen, as well as the annual insolation in both locations is given below. Assume you can cover 50% of the roof area with solar panels.

Photovoltaic Module		
Nominal output (P_{mpp})	250 W	
Size	1.5 m^2	
Module cost	375 €	
Efficiency	15 %	
Inverter		
Rated output	30 kW_{ac}	
Cost	25,000 €	
Installation, Operation and Maintenance		
Cost	22,000 €	
Location Data		
	Average annual insolation at optimal tilt angle	Average temperature
Canary Islands, Spain	2075 kWh/m^2	20.7°C
Cambridge, UK	1100 kWh/m^2	10.7°C

(a) Assuming the inverter remains functional for the lifetime of the plant and feed-in tariffs are 0.30 and 0.40 € / kWh in Spain and in the UK, respectively, what is the payback time for each location? State any assumptions made. [30%]

(b) Given the differences in weather of both locations, how would the actual performance differ from that calculated in part (a)? Why? [10%]

(c) What are the advantages and disadvantages of using a microinverter on each module compared to a string inverter for grid connection of a solar installation? [20%]

(d) Write a commentary on the following topic. "Within the next 10 years, photovoltaic power generation will be economically competitive with traditional energy sources". [40%]

4 In order to maximise the photocurrent, it is important that a solar cell absorbs as much light as possible, with photon energies above the bandgap, within the active region of the cell.

(a) Why is the intensity of light in the active region of a solar cell less than the incident light intensity? [15%]

(b) Identify and explain three methods by which absorption in the active region can be maximised with the aid of diagrams. [30%]

(c) It is common to apply a thin transparent insulating dielectric layer on the surface through which light enters. If the refractive index of the dielectric layer is 2.2, what would be an optimal dielectric layer film thickness for a c-Si solar cell? [25%]

(d) What is the optimum height to place the p-n junction in a c-Si cell? What problems does this lead to? Justify your answer. [30%]

END OF PAPER