Fundamentals of Photovoltaics: C1 Problems

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These problems will be highly relevant to the exam that you will sit very shortly. Work through them and make sure you have a good understanding of their solutions. You are permitted to work collaboratively to answer these problems. We encourage you to use #**cdtpvC1** to raise points/queries and to post links to your solutions. The rest of the cohort will benefit greatly from your contributions - don't keep them to yourself.

Lecture 2: Basic device response

1. The current-voltage response of a solar cell is given by

$$J(V) = J_{SC} - J_0 \left(exp\frac{eV}{nk_bT} - 1 \right) \tag{1}$$

   (a) For a cell with values of $J_0 = 10^{-8}$ mAcm^{-2}, $n = 1.5$ and $J_{SC} = 28$ mAcm^{-2}, calculate the open circuit voltage.
   (b) The cell has a fill factor of 80%. What is its conversion efficiency? (Assume AM1.5 incident spectrum)
   (c) If the cell's area is 1 cm^2 what area would be needed to generate a power of 1 kW?
   (d) Sketch the ideal J-V response curve for the cell and show the effects of parasitic series, R_s, and shunt, R_{sh}, resistances.
   (e) In the case of high R_s and high R_{sh} show that $1/R_s$ is proportional to the slope of the $J - V$ curve in the vicinity of $J = 0$.
   (f) In the case of low R_s and low R_{sh} show that $1/R_{sh}$ is proportional to the slope of the $J - V$ curve in the vicinity of $V = 0$.

2. Two ideal solar cells have an open circuit voltage of 0.8 V and the same short circuit current under an AM1.5 solar spectrum. One has an ideality factor of 1, the other has an ideality factor of 2. What is the relative difference in the efficiencies of the two cells.

Lecture 3: Detailed balance

1. The peak power output of a solar module, under AM1.5 illumination, is 1kW. What would be its peak power output on Mars? State your assumptions.
2. For an ideal two level system, explain qualitatively how the band gap determines the upper limit of conversion efficiency.
3. List the key requirements for an ideal solar cell.
4. List and describe three separate strategies for beating the Shockley-Queisser limit.

Lecture 4: Semiconductors

See last two slides of Lecture 4!

Lecture 5: Junctions

1. The direct band gap of $Al_xGa_{1-x}As$ is given empirically by

$$E_G = 1.424 + 1.155x + 0.37x^2 eV \tag{2}$$

For a GaAs-AlGaAs heterojunction, the direct band gap difference ΔE_G is accommodated approximately $\frac{2}{3}$ in the conduction band and $\frac{1}{3}$ in the valence band for an Al composition of 0.3. Sketch the band diagrams for the following cases: n-$Al_{0.3}Ga_{0.7}As$ on p-GaAs, and n^+-$Al_{0.3}Ga_{0.7}As$ on n-GaAs.

2. An ideal Si $p-n$ junction has $N_A = 10^{18}$ cm^{-3} and $N_D = 10^{15}$ cm^{-3} in the p and n regions respectively at 300K

   (a) Calculate the built-in potential.

   (b) Calculate the width of the depletion in the p and n regions.

   (c) Calculate fractional change in total width of the depletion region under biases of +0.7 V and −0.7 V.

3. The parameters of an ideal Si $p-n$ junction are:

$N_A = 5 \times 10^{16}$ cm^{-3}, $N_D = 10^{16}$ cm^{-3}
$D_n = 21$ cm^2/s, $D_p = 10$ cm^2/s
$\tau_p = \tau_n = 5 \times 10^{-7}$s

   (a) Sketch the band diagram for this junction.

   (b) Calculate the reverse saturation current density.

   (c) Estimate the junction's V_{OC} under AM1.5 illumination. State the assumptions that you have made[1]

   (d) Assuming a fill factor of 80%, estimate the conversion efficiency.

   (e) Sketch the JV response of the junction in dark and light conditions.

Lecture 6: Junction Characterisation

1. The figure below shows an external quantum efficiency (EQE) curve for a high efficiency solar cell. Using the information in the plot, determine:

   (a) The band gap of the p-type absorber layer in electron-volts (eV)

   (b) The bandgap of the n-type window layer in eV.

   (c) The type of solar cell you believe this may be.

2. The figures below are EQE curves for cells which have lower efficiency that the high efficiency cell in Q1. For each curve identify a likely cause for the reduced performance of the cell.

[1] You'll have to refer the slides from L3

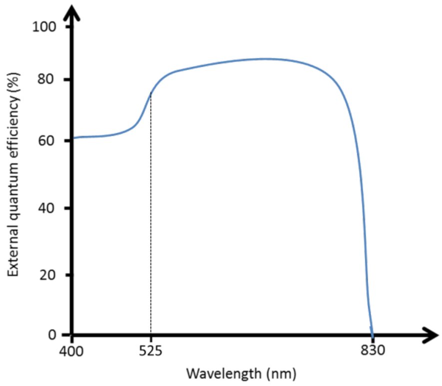

Figure 1: Lecture 6, Question 1.

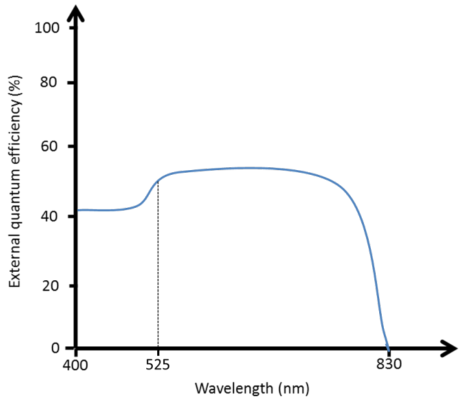

Figure 2: Lecture 6, Question 2a.

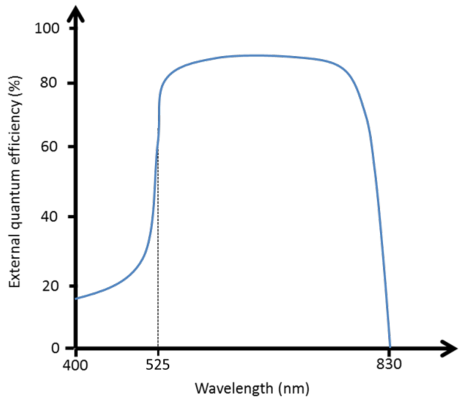

Figure 3: Lecture 6, Question 2b.

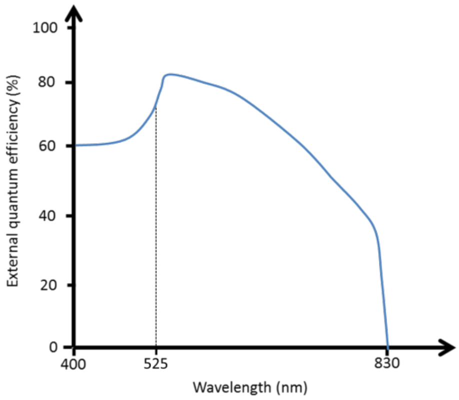

Figure 4: Lecture 6, Question 2c.

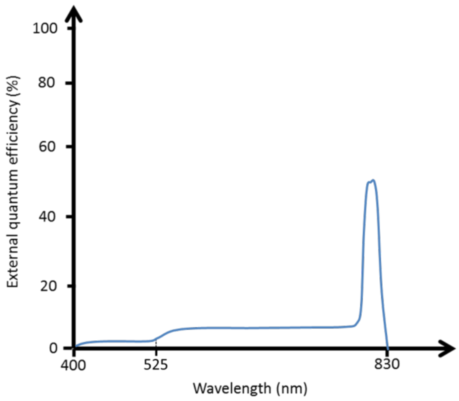

Figure 5: Lecture 6, Question 2d.

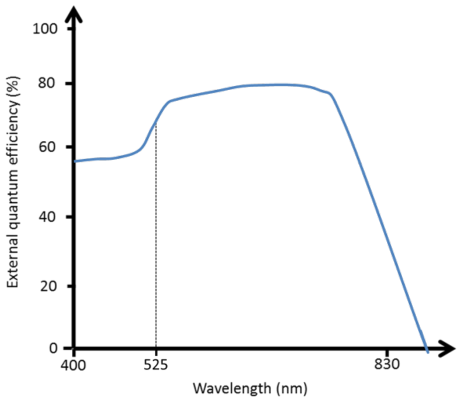

Figure 6: Lecture 6, Question 2e.

Lecture 7: Optical Properties of Semiconductors

1. The absorption edge of a particular semiconductor is well described by

$$\alpha(h\nu) = 2 \times 10^4 (h\nu - E_g)^{1/2} \tag{3}$$

   where α is the absorption coefficient, in cm^{-1}. $h\nu$ and E_g are the photon energy and band gap respectively in eV.

   (a) Does this semiconductor have a direct or indirect band gap?

   (b) What function of α would you plot against $h\nu$ to obtain linear data from which to estimate the band gap?

   (c) If the band gap is 1.2 eV, from the above equation, calculate α at the band gap and at 0.1, 0.5 and 2.0 eV above the band gap.

2. Calculate the thickness of PV absorber material, in nm, required to absorb 50%, 90% and 99% of incident photons at a wavelength for which the absorption coefficient is 10^5 cm^{-1}.

Lecture 8: Materials Stability

Lecture 9: Advanced Characterisation