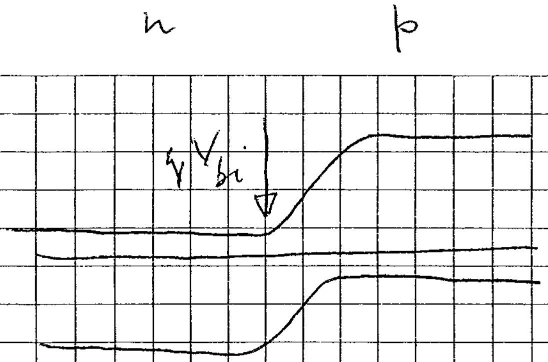
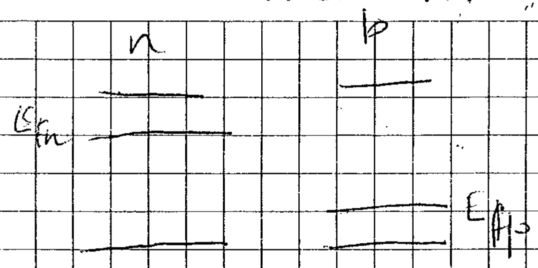
PART IIB 4B14 - Solar Electronic Power - Answers 2010

PROF G AMARATUNGA





$$0.92 = qV_{bi} = E_{Fn} - E_{Fp}$$

$$n = N_c \exp\left(\frac{E_{Fn} - E_c}{kT}\right) \qquad p = N_V \exp\left(\frac{E_V - E_{Fp}}{kT}\right)$$

$$\ln\left[\frac{n}{N_c}\right] kT + E_c = E_{Fn} \qquad -\ln\left[\frac{p}{N_V}\right] kT + E_V = E_{Fp}$$

Considering ~~either n or~~ p side away from junction in the equilibrium region

$pn_p = n_i$ $\quad$ $\therefore N_V \exp\left(\frac{E_V - E_F}{kT}\right) \cdot N_C \exp\left(\frac{E_F - E_C}{kT}\right) = n_i^2$

$N_V \approx N_c$ $\quad$ $\therefore N_C N_V \exp -\frac{E_g}{kT} = n_i^2$

$$N_V \exp -\frac{E_g}{2kT} = n_i$$

$$N_V = \frac{10^{16}}{\exp\left(-\frac{1.12q}{2kT}\right)} = 2.58 \times 10^{25}$$

$$\therefore E_{F_n} - E_{F_p} = \ln\left[\frac{n}{N_C}\right]kT + E_C + \ln\left[\frac{p}{N_C}\right]kT - E_V$$

$$= \ln\left[\frac{n}{N_C}\right]kT + E_g + \ln\left[\frac{p}{N_C}\right]kT$$

$$0.92\,q = \ln\left[\frac{n}{N_C}\right]kT + 1.12\,q + \ln\left[\frac{10^{23}}{2.58\times10^{25}}\right]kT$$

~~$0.026 \times \frac{0.92}{0.026} = \ln\left[\frac{n}{N_C}\right] + \frac{1.12}{0.026} \times 0.026$~~

$$\frac{0.92}{0.026} = \ln\left[\frac{n}{N_C}\right] + \frac{1.12}{0.026} \cancel{4}\ 5.55$$

$$\ln\left[\frac{n}{N_C}\right] = -2.19$$

$$\therefore n = \cancel{\ln}\ \exp(-2.19) \times 2.58\times10^{25}$$

$$\underline{\underline{n = 2.89\times10^{24}\ m^{-3}}}$$

[30%]

(b) $n_{p0} = n \exp\left(\frac{q(V - V_{bi})}{kT}\right) = 2.89\times10^{24} \exp\left(\frac{-0.42}{0.026}\right)$

$$= \underline{\underline{2.79\times10^{17}}}\ m^{-3}$$

$p_{n0} = p \exp\left(\frac{q(V - V_{bi})}{kT}\right) = \underline{\underline{9.65\times10^{23}\ m^{-3}}}$

[40%]

(c) (i) $V_{oc} = \frac{kT}{q} \ln\left[\left(\frac{I_{sc}}{I_S}\right) + 1\right]$

$I_S = qA\left[\frac{L_e}{\tau_e}\cdot\frac{n_i^2}{N_A} + \frac{L_p}{\tau_p}\frac{n_i^2}{N_D}\right] = 0.24\,nA$

$I_{SC} = \exp\left(\frac{0.6}{0.026}\right)\times 0.24\times10^{-9} - 0.24\times10$

$I_{SC} =$ ~~mA~~ $2.52\ A$ [15%]

(ii) $I_{SC} = qAg_{opt}\left[L_e + L_h\right]$

$g_{opt} = \frac{2.52}{qA\left[L_e + L_h\right]} = 1.04\times10^{25}\ m^{-3}s^{-1}$

[15%]

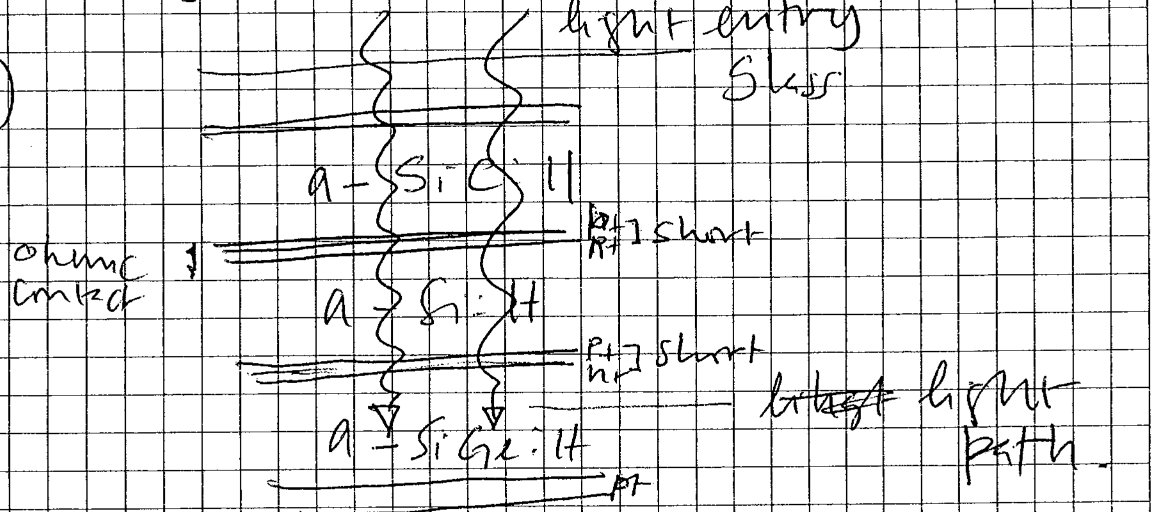
(3)

2 (a) 600 nm light

E_g of a-Si:H ≃ 1.6 - 1.8 eV

600 nm light has an energy closer to that of the gap value. Hence more of the photon energy captured as the V_{oc}. For 300 nm light more excess energy than the gap. Hence more of the photon energy has to be dissipated as heat. [20%]

(b)



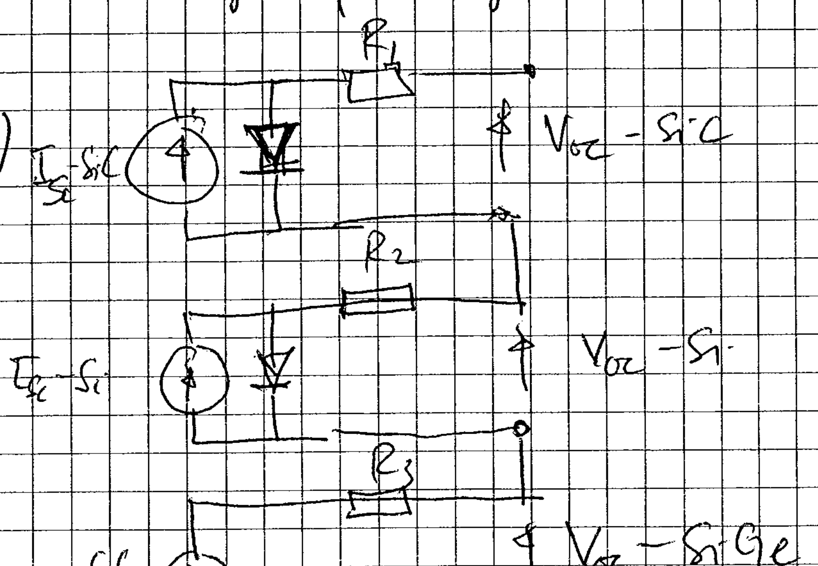
[25%]

D

ii) The expected efficiency is greater. This is because each part of the solar spectrum is absorbed by a three band gaps rather than one. Short wavelength light absorbed first by wide band-gap a-SiC:H (develops highest V_{oc}). Then the next segment by a-Si:H and the longer wavelength part of the spectrum by a-SiGe:H.

There are in effect three cells in series with 3 V_{oc} values – $V_{oc1}+V_{oc2}+V_{oc3}$ summing up to give overall cell V_{oc}. [20%]

iii)



[15%]

⑤

D

iv) The cell structures have to be carefully designed so that their I_{sc} values are very closed to each other through absorption of different parts of the spectrum. Otherwise there is imbalance like in series connected solar cells and power can be dissipated within the low I_{sc} cell(s). This also points to the series resistances of the cells have to be minimised. Again needs careful optimisation to ensure contacts between cells do not introduce excessive resistance. [20%]

3)

a) $$V_o = \frac{\eta KT}{q} \ln\left[\frac{I_{sc}}{I_s} + 1\right]$$

~~$= 0.026 \ln[2\times10^{8} + 1] = 0.5V$~~

$$= \frac{1.1\,KT}{q} \ln\left[\frac{I_{sc}}{I_s} + 1\right]$$

$$\underline{\underline{V_{oc} = 0.026 \times 1.1 \times \ln\left[2\times10^{8} + 1\right] = 0.55V}}$$

[30%]

b) $$\text{Efficiency} = \frac{V_{oc} I_{sc} \times FF_o}{1000\times10^{-2}} = \frac{1.1}{10} \times FF_o$$

FF_o = from formula sheet

$$= \frac{\dfrac{qV_{oc}}{\eta KT} - \ln\left(\dfrac{qV_{oc}}{\eta KT} + 0.72\right)}{\dfrac{qV_{oc}}{\eta KT} + 1}$$

$$= \frac{\dfrac{0.55}{1.1\times0.026} - \ln\left(\dfrac{0.55}{1.1\times0.026} + 0.72\right)}{\dfrac{0.55}{1.1\times0.026} + 1} = 0.80$$

[20%]

$$\therefore \text{Efficiency} = \frac{8.8}{10} = \underline{\underline{8.8\%}}$$

⑦

$FF_1 = FF_0 \left(\frac{r_0}{r_0 + r_c'} \right)$ Where $r_c' = \frac{0.03}{r_0}$

$FF_1 = FF_0 \times 0.71$ $r_0 = \frac{V_{oc}}{I_{ss}} = \frac{0.55}{2}$

$\therefore$ Efficiency $= 8.8 \times 0.71\ \%$ $= 0.275$

$= \underline{\underline{6.3\%}}$

[20%]

d) For anti reflection coating (from Formulae sheet)

$\theta = \pi/2 = \frac{2\pi n_2 d}{\lambda}$

$n_2 d = \lambda/4$

Solar peak at 600 nm (assumption)

$\therefore n_2 d = 150$ nm

If one takes Si_3N_4 as a coating material, then $\varepsilon_r \simeq 8$

$\therefore n = \sqrt{8} = 2.8$

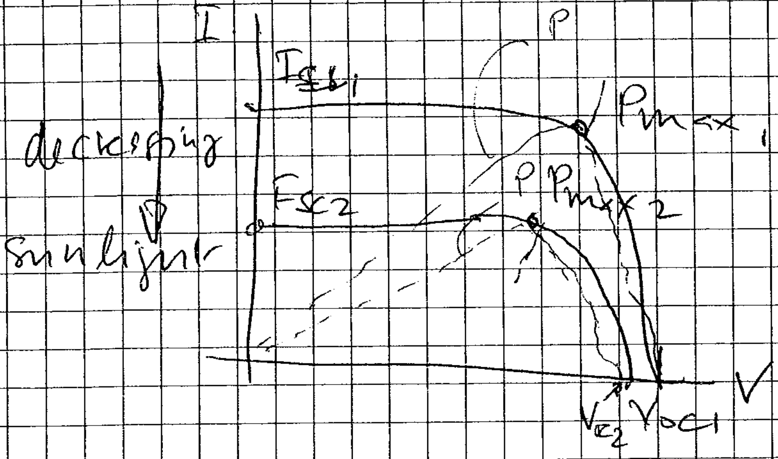
$d = \frac{150}{2.8} = 53\text{ nm} \simeq \underline{\underline{50\text{ nm}}}$

[30%]

DI

Q4

a) MPPT is necessary to gain maximum power output as the insolation conditions change.



[20%]

b) Perturb and observe.

1) Keep increasing current starting from Voc, I=0

2) Measure V and I at each point and calculate power V×I

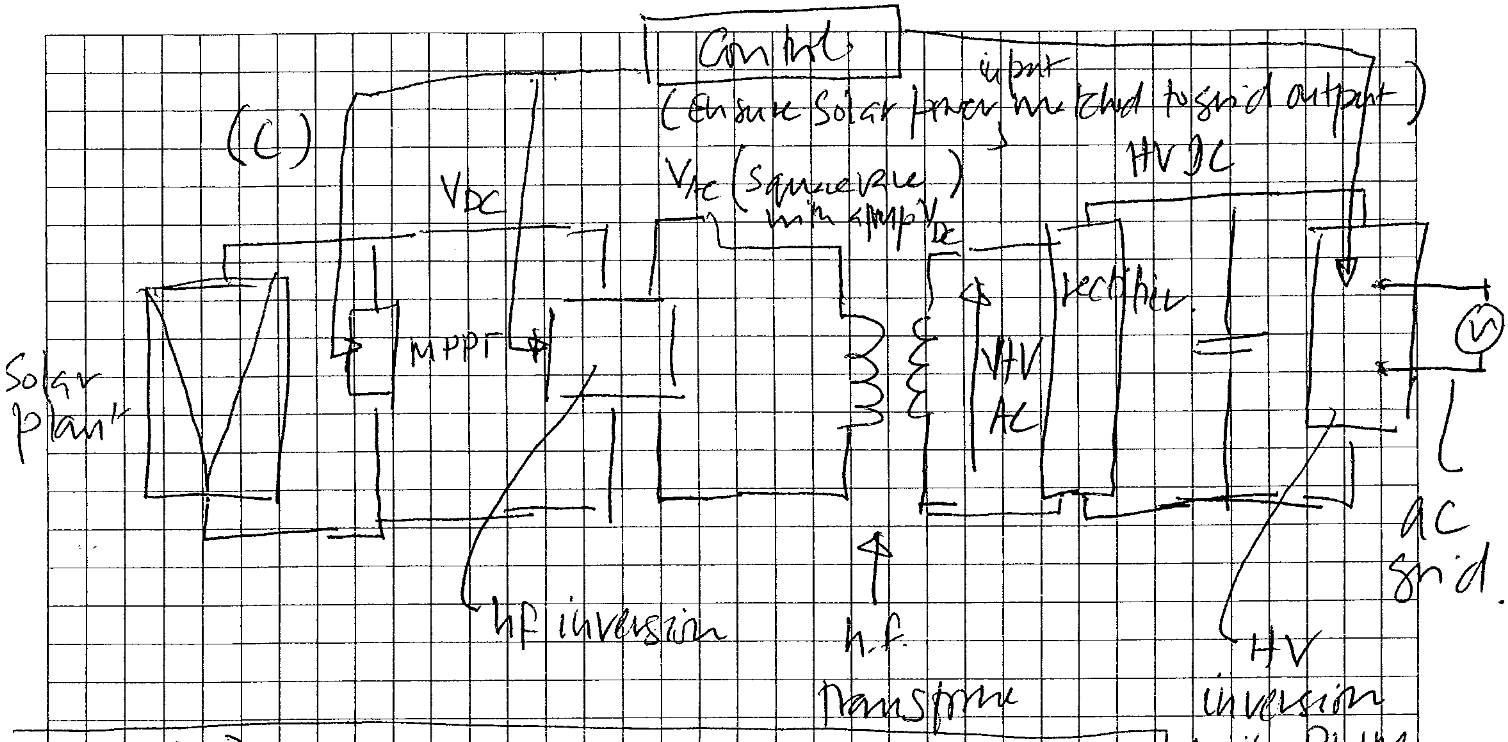
3) Keep increasing current as long as $V_n \times I_n > V_{n-1} \times I_{n-1}$

4) When 3) is not met, V_{n-1}, I_{n-1} taken as Max power point

5) Periodically (every 10 secs) Attempt to increase I. If power drops then also reduce I below operating point and track power. (9)

[20%]

(c)



[25%]

(d)

Feed in tariffs are a way of offsetting the capital investment required to set up a solar plant. Selling back electricity to the power company even at parity will not recover the investment over a ~~20 year~~ plant lifetime.

This is because current power generation technologies are not costed for CO₂ emissions nor were they built with the idea of recovering capital cost - most electricity generation plants subsidised as infrastructure costs.

10

Feed in traifts [illegible] are a way of providing the equivalent infrastructure subsidy provided to conventional power generation plants. Also applies to wind power.

[30%]

Paper 4B14 – Solar Electronic Power: Generation and Distribution

Examiner's Comments:

Q1.

Taken by most students with nearly all, except two, showing a very good understanding of the semiconductor physics and carrier dynamics in a p-n junction solar cell.

Q2.

All except one student understood the concept of efficient photon to electron conversion based on band-gap matching. The concept of multi-band gap cells was also well understood. The tricky issue of optimising design to have current matching between the layer was not generally appreciated. But there were three excellent answers.

Q3.

An analytic question with some clear cut calculations. Generally very well answered. The final section on anti-reflection coating design was also well understood. The finer points of efficiency limitation in solar cells were also appreciated.

Q4.

The essential features required to convert DC solar power to AC grid power was well understood. Maximum Power Point Tracking of the solar plant was generally well covered. The question had an essay element covering policy aspects of solar power take up. This was adequately answered by most.