# ECE 4833 Devices for Renewable Energy

*Exam 2*

*April 6$^{th}$, 2010*

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Print your name clearly and largely: Solutions

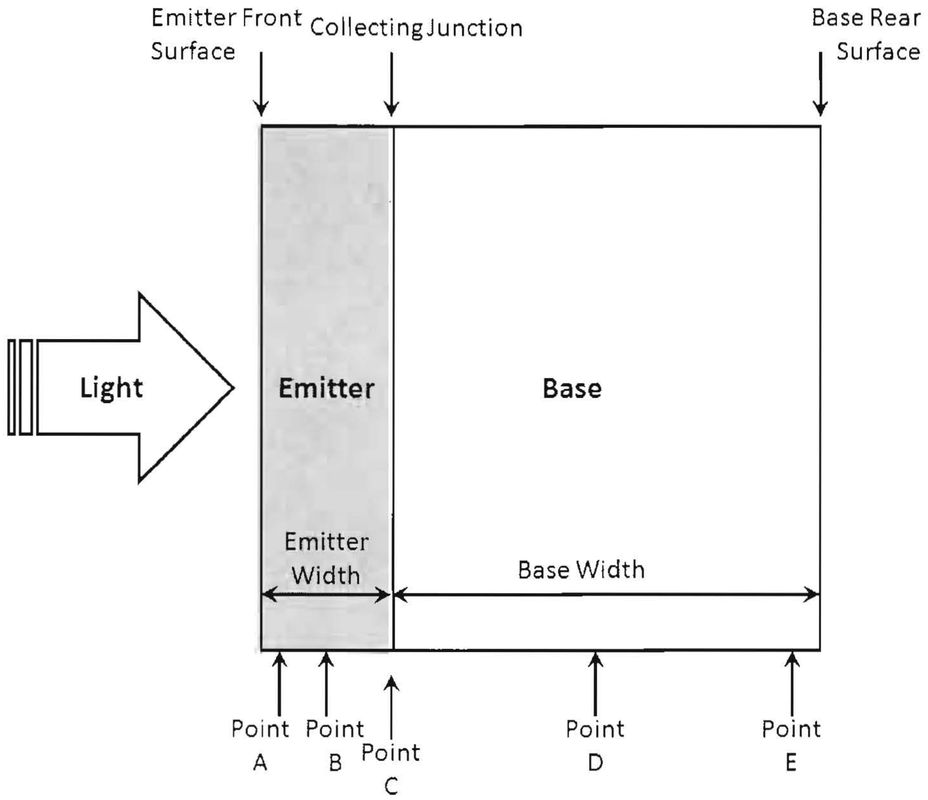
**Instructions:**
Read all the problems carefully and thoroughly before you begin working. You are allowed to use as many hand written sheets of notes as you like as well as a calculator (without any IR ports). There are 100 total points. Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. ***If I cannot read it, it will be considered a wrong answer***. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. A periodic table is supplied on the last page. Good luck!

Sign your name on **ONE** of the two following cases:

I DID NOT observe any ethical violations during this exam:

I observed an ethical violation during this exam:

**Multiple Choice, Short Answer and True/False**
**(Circle the letter of the most correct *answer or answers* ) Unless otherwise noted, refer to the generic one dimensional solar cell below for explanation of terms.**




1.) (2-points) True or False: In a real solar cell, the effective minority carrier lifetime is always smaller than the Shockley-Read-Hall minority carrier lifetime.

$\frac{1}{\tau_{eff}} = \frac{1}{\tau_{SRH}} + \frac{1}{\tau_{BB}} + \frac{1}{\tau_{Auger}} + \frac{2S}{L}$

2.) (2-points) True or False: Since the emitter width is generally small, it is okay to have a minority carrier diffusion length in the emitter that is much smaller than the emitter width.

3.) (2-points) True or False: If the minority carrier diffusion length in the base is equal to ½ the base width, on average, few carriers will be collected beyond point d (beyond meaning towards point e).

poorly worded credit given

4.) (2-points) True or False: If the minority carrier diffusion length in the base is equal to ¼ the base width, ~~and~~ energy from light with an absorption coefficient equal to twice the base width is poorly collected – assume no rear reflector.

5.) (2-points) True or False: If the minority carrier diffusion length in the base is equal to ¼ the base width, ~~and~~ energy from light with an absorption coefficient equal to twice the base width is poorly collected – assume 100% rear reflection.

6.) (2-points) True or False: The majority of the power in the solar AM1.5G spectrum is in the visible range (~400 to 640 nm).

7.) (2-points) True or False: Blue photons will be preferentially absorbed in the base.

8.) (2-points) True or False: Since they have a longer absorption coefficient, infrared photons always have an absorption peak (point of maximum absorption) in the base.

9.) (2-points) True or False: In a thick (relative to diffusion length) solar cell, the back surface recombination velocity (rear base surface) is more important than in a thin solar cell.

10.)(4-points) Given the emitter minority carrier diffusion length is 0.5 um, the emitter with is 1 um, the base minority carrier diffusion length is 200 um and the base is 500 um wide, the shunt resistance is infinity, and the series resistance is negligible, if a photon is absorbed at point C.

a) The collection efficiency is 32.5%

b) The collection efficiency is 0%

c) The collection efficiency is 100%

d) Most of the information provided in this problem is irrelevant.

11.) (8 – points in 4 parts) Describe the relative importance (i.e. Circle the relative importance, "most", "less" and "not" important for each mechanism) of SRH, direct band to band and Auger recombination in …

a) …a lightly doped silicon base under low level injection ($\Delta n << n_o$).

| | | | |
|---|---|---|---|
| **SRH:** | Most Important | Less Important | Not Important |
| **Direct band to band:** | Most Important | Less Important | Not Important |
| **Auger:** | Most Important | Less Important | Not Important |

b) …an extremely heavily doped silicon emitter under low level injection ($\Delta n << n_o$).

| | | | |
|---|---|---|---|
| **SRH:** | Most Important | Less Important | Not Important |
| **Direct band to band:** | Most Important | Less Important | Not Important |
| **Auger:** | Most Important | Less Important | Not Important |

c) … a lightly doped GaAs (direct bandgap) base under moderately high level injection ($\Delta n \sim n_o$)

| | | | |
|---|---|---|---|
| **SRH:** | Most Important | Less Important | Not Important |
| **Direct band to band:** | Most Important | Less Important | Not Important |
| **Auger:** | Most Important | Less Important | Not Important |

d) … a lightly doped GaAs (direct bandgap) base under extremely high level injection ($\Delta n >> n_o$)

| | | | |
|---|---|---|---|
| **SRH:** | Most Important | Less Important | Not Important |
| **Direct band to band:** | Most Important | Less Important | Not Important |
| **Auger:** | Most Important | Less Important | Not Important |

**Short Answer**

12.) (~~4~~-points in two parts) In one sentence, explain why most solar cells use a p-type base.

3

since $\mu_n > \mu_p$ ~~higher due to~~ $\Rightarrow$ $L_n >> L_p$ and thus, collection is enhanced for electrons

x

13.) (~~5~~ points) List 2 methods of making an ohmic contact to a semiconductor that does not have metal with an appropriate electron affinity that allows a "traditional" ohmic contact.

- Heavily doped Schottky tunnel junction
- Degenerate semiconductor tunnel junction

14) (5 points) List 3 ways the surface recombination velocity can be reduced is a solar cell.

- Well passivated surfaces
- Heterojunction window layer
- Moderately Heavily doped surface creating a Back/front surface field.
- Point contacted metal instead of full metalization

15) (8-points) List 4 ways ~~to~~ the light impinging on a solar cell can be better absorbed within the cell.

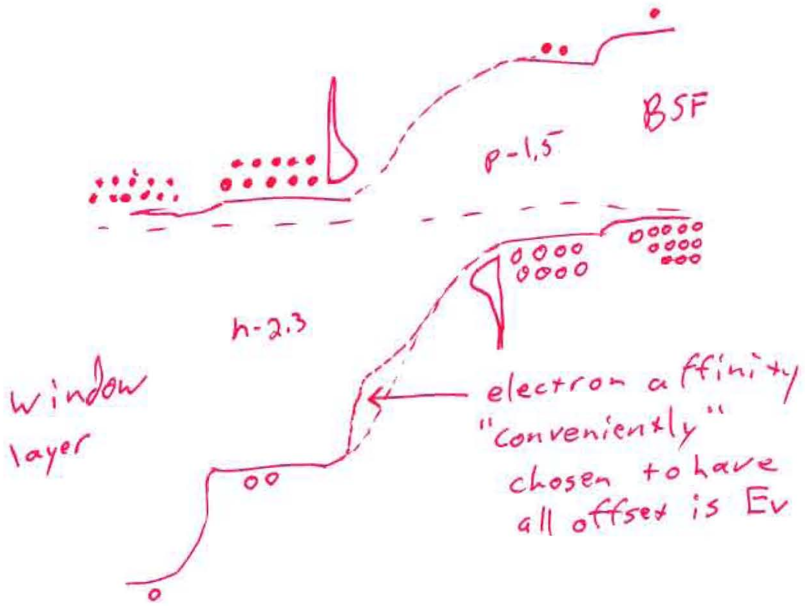
- AR coatings
- Texturing front to get multiple bounces + longer photon path
- Texturing back to get longer photon path + trap photon
- Narrowed metal fingers

16) (8-points) Explain in 6 sentences or less the difference in external quantum efficiency and spectral response AND how these measurements can be used to diagnose where a solar cell is underperforming.

At each $\lambda$, EQE is the ratio of # collected carriers to # of incident photons. SR is the ratio of generated current to incident power at each $\lambda$ accounting for photon energy at each $\lambda$. $SR = \frac{q\lambda}{hc} EQE$. These graphs can be used to determine where a problem in a cell physically is and is compared to absorption depth. If the front surface is problematic then the blue response will be low. If the back surface is problematic then the red/IR response will be low.

17.) (40 - points)

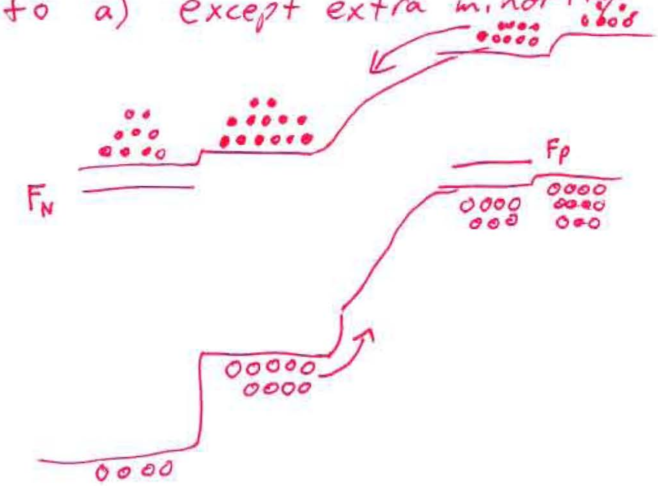
a) 10 points – Sketch the energy band diagram of a Ga Tech (i.e. very good design) n-type CdS (2.3 eV bandgap) – p-type CdTe (1.5 eV bandgap) solar cell in the dark. Include in your band diagram some means of minimizing minority carriers recombination at both surfaces. You may assume whatever electron affinities are needed to make your diagram convenient and free of electron/hole wells that may trap carriers. Show qualitatively, what the electron and hole concentrations would look like (open and closed circles) at all relevant locations.




To avoid wells, a type II Heterojunction is preferred.

b) 10 points – Sketch the same energy band diagram for (a) above but under short circuit conditions. Show what the electron and hole concentrations would look like (open and closed circles) under high level injection. Indicate the direction of electron and hole flows AND their associated drift and diffusion currents.

Note: @ Jsc, $V_A = 0$ so band diagram is identical to a) except extra minority carriers + current flows




p-type CdTe

min. Electron flow ←

" Drift Current →

Hole Diffusion current/flow ←

n-type CdS

min. Hole flow →

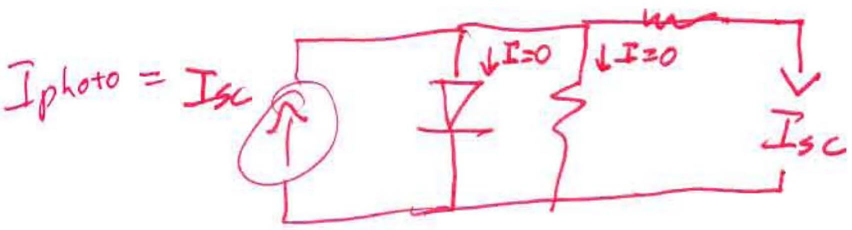
" Drift current →

electron Diffusion →

" " current ←

Net Current (n to p) →

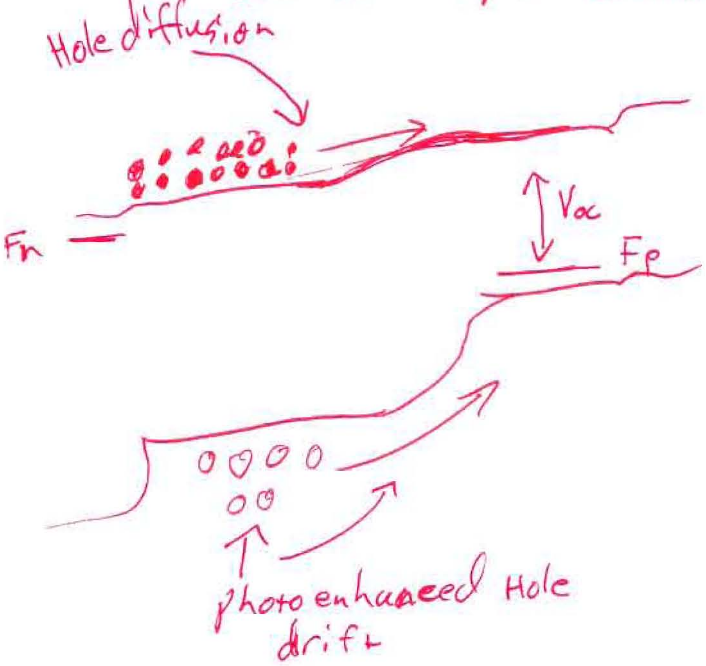
c) 5 points – Draw the solar cell electrical model for the case in (b) and indicate with arrows the direction of all currents flowing in the model. You may assume a small (finite) but negligible series resistance.




Drift + Diff.

d) 10 points – Sketch the same energy band diagram for (a) above but under open circuit conditions. Show what the electron and hole concentrations would look like (open and closed circles) under high level injection and the direction of electron and hole flows AND their associated currents.

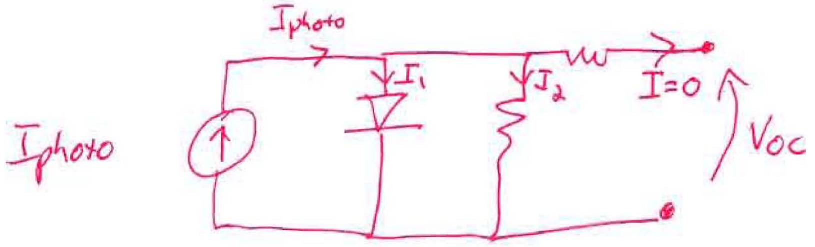
@ $V_{OC}$, $V_A$ is max and approachs but cannot equal $V_{BI}$ ⇒ $V_{Flat\ band}$




flow + current

All directions are same as in b) but now Diffusion current is large enough to cancel out photo enhanced drift

e) 5 points – Draw the solar cell electrical model for case (d) and indicate with arrows the direction of all currents flowing in the model. You may assume a small (finite) but negligible series resistance.




$I_{photo} = I_1 + I_2$

All photo generated current is lost to diffusion and shunt current inside the cell