ECE 4833 Devices for Renewable Energy

Exam 1

February 16th, 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*)

1.) (2-points) True or False: The energy bandgap of a material is related to BOTH the strength of the chemical bonds holding the solid together and the spacing of the atoms.

2.) (2-points) True or False: Polar (ionic or partially ionic) bonds result in direct bandgap materials that absorb light well.

3.) (2-points) True or False: Currently, multi-junction tandem solar cells made from GaAs are produced by metal organic chemical vapor deposition.

4.) (2-points) True or False: Using more than one energy bandgap in a solar cell always results in lower voltages.

5.) (2-points) True or False: Photons with energy approximately equal to the energy bandgap of the solar cell will produce heat energy that cannot be collected.

6.) (2-points) True or False: Photons with energy approximately equal to the energy bandgap of the solar cell will produce potential energy that can be collected.

7.) (2-points) True or False: Blue photons have more energy than red photons but there are more red photons than blue photons in the solar spectrum.

8.) (4-points) Rank the following forms of silicon solar cells in order of typical solar efficiency (Highest is #1, lowest is #4):

a) Multicrystalline Si 3

b) Single Crystal Float Zone Si 1

c) Single Crystal Czochralski Si 2

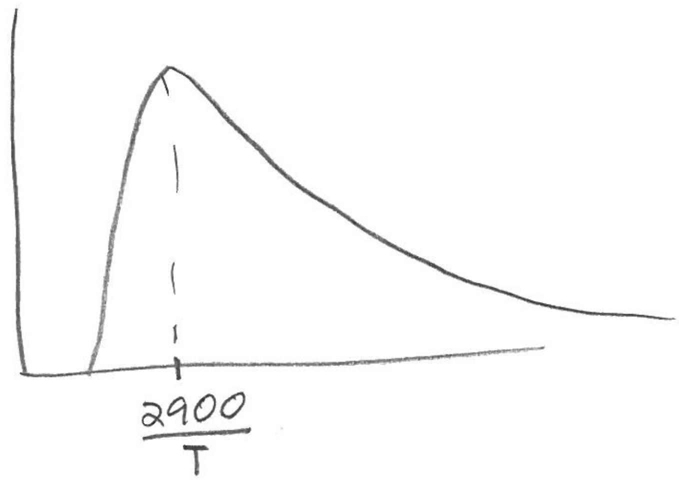
d) Amorphous Si 4

Short Answer

9.) (13-points in two parts) An industrious Georgia Tech Student will invent a "thermal-photovoltaic" solar cell that will be worn on the human body and use the heat energy of the body to power his ipod. The human body is 98.6 degrees Fahrenheit (37 degrees Centigrade).

a) (5 points) Sketch a rough estimate of the Spectral Intensity assuming perfect (emissivity = 1) blackbody radiation being sure to label the peak wavelength (in microns). Do not bother labeling magnitudes.

$$\text{Peak} = \frac{2900}{T} = \frac{2900}{(37+273)} = 9.35\ \mu m$$



b) (8 points) How much area will be needed to generate 1 watt of power if the conversion efficiency is a superb 15%? Comment on the reasonableness of the invention.

$$H = \sigma T^4$$

$$= 5.6704 \times 10^{-8} \left(\frac{\text{Watts}}{m^2 K^4}\right)(310)^4$$

$$= 523\ W/m^2$$

$$1\ \text{watt} = (0.15)\ 523 \left(\frac{W}{m^2}\right) \text{Area}$$

$$\text{Area} = 0.0127\ m^2$$

or $127\ cm^2$

$(\approx 11 \times 11\ cm)$

Doable but 15% is tough at these wavelengths reword before printing

10.) (12-points) Calculate and sketch the elevation and azimuth angle at solar noon for on August 1st for Belle Fourche, SD (the approximate geographic center of the USA, ~~with~~ at latitude of 44° 58' N, 103 ° 46' W). Hints: Longitude is not needed since calculations are at solar noon. HRA is always 0 at solar noon.

Calendar for year 2010 (United States)

January

Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

7 ◑ 15 ● 23 ◐ 30 ○

February

Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28						

5 ◑ 13 ● 21 ◐ 28 ○

March

Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

7 ◑ 15 ● 23 ◐ 29 ○

April

Su	Mo	Tu	We	Th	Fr	Sa
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

6 ◑ 14 ● 21 ◐ 28 ○

May

Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

6 ◑ 13 ● 20 ◐ 27 ○

June

Su	Mo	Tu	We	Th	Fr	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

4 ◑ 12 ● 19 ◐ 26 ○

July

Su	Mo	Tu	We	Th	Fr	Sa
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

4 ◑ 11 ● 18 ◐ 25 ○

August

Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

3 ◑ 9 ● 16 ◐ 24 ○

September

Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

1 ◑ 8 ● 15 ◐ 23 ○ 30 ◑

October

Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

7 ● 14 ◐ 22 ○ 30 ◑

November

Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

6 ● 13 ◐ 21 ○ 28 ◑

December

Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

5 ● 13 ◐ 21 ○ 27 ◑

$$\delta = \sin^{-1}\left\{\sin(23.45^\circ)\sin\left[\frac{360}{365}(d-81)\right]\right\}$$

$$\alpha = 90^\circ - \phi + \delta$$

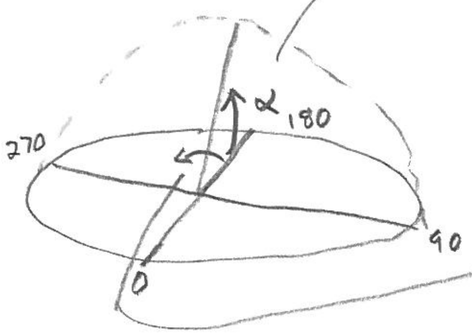
August 1 $\Rightarrow 31+28+31+30+31+30+31+1$

$d = 213$

$\delta = 17.7^\circ$

$\alpha = 90 - \phi + \delta$

$\alpha = 62.73^\circ$



Azimuth = 180° at solar noon

$$= \cos^{-1}\left[\frac{\sin\delta\cos\phi - \cos\delta\sin\phi\cos HRA}{\cos\alpha}\right]$$

$= \cos^{-1}[\ \ldots\ ]$

$= \sim 180^\circ$

11). (25-points) For each of the solar processes below, describe at least 3 complicating factors that affect the efficiency of a solar cell (either increasing it or decreasing it). Points given based on the selection of the 3 most influential factors.

a) Light entering the solar cell:
b) Absorbing light and generating carriers
c) Diffusion of electron-hole pairs
d) Collection or "separation" of electron-hole pairs
e) Driving current into solar cell metal wires and external wiring

Step 1: Light hitting the solar cell

- Reflection:
  - Anti-reflection coatings (alternating dielectric layers)
  - Texturing to increase number of bounces before reflecting (works against surface recombination)
- Wavelength of light (energy content per photon)
- Angle of incidence
- Cover glass/module optics
- Full metal back coverage can be used to give non-absorbed photons a "second chance" but the metal also creates strong points for electron-hole-pair recombination

Step 2: Absorbing Light and generating carriers

- Energy bandgap:
  - Determines which photons get absorbed and how soon
  - Direct vs. indirect bandgaps determine how thick the device has to be (thicker absorbs more light but thinner tends to produce more voltage)
- Where in the device the light is absorbed relative to the collecting junction– toward the front or back

Step 3: Diffusion of electron-hole pairs

•Recombination (electron killing off a hole) is key.
•Semiconductors "Minority carrier diffusion length"
  •Determined by the materials "mobility" and "minority carrier lifetime"
•Recombination at Internal defects: "trap states" at point defects (missing, extra or displaced atoms), extended defects (missing/extra columns or planes of atoms such as grain boundaries)
•Surfaces represent "enormous defects"
•Metal contacts kill off minority carriers.

Step 4: Collection or "separation" of electron-hole pairs

•Requires a force, most often resultant from an internal electric field. Can separate the electron from the hole to create a voltage.
  •Treating the region of the device that has an electric field as a dielectric, $Q = CV$ (capacitor, but in a solar cell, C is a highly non-linear function of V)
  •Separated charge can be "discharged" to drive current into an external circuit, i.e. generating power.
  •Local defects near the "junction" or weak electric fields will result in poor isolation of adjacent sides causing Shunting (partial shorting) of the electric fields.
  •After "separation of the electrons from the holes, the carriers are now "majority carriers ready to enter the metal wires.

Step 5: Driving current into solar cell metal wires and external wiring

- Metal "Ohmic Contacts" only carry majority carriers.
    - Separated electrons/holes can enter wires
    - Yet – to – be separated electrons-hole pairs will recombine if they get near the metal

- Resistive losses (series resistances) waste the generated power and are engineered to be minimum

- Metal-semiconductor contacts are a major source of series resistance, long term failure and manufacturing headaches.

12. (20-points) Explain the Anthropogenic Climate Change theory in 6 sentences or less. Be sure to include which gases are considered harmful and what the amplification mechanisms are.

ACC is the theory that man's industrial impact on the environment is raising the concentration of certain greenhouse gases such as CO_2, CH_4, NO_2, and water which in turn results in higher global temperatures through amplification by the greenhouse effect. Specifically, the amplification comes from increases in the absorbed IR energy from the earth's surface compared to much higher energies from the sun (greenhouse effect) making the concentration changes for these gases of significantly more importance than the actual energy expended to create them.

13.) (12-points) In four sentences or less, explain the differences in the Air mass 0, 1.5 global and 1.5 direct solar spectrums.

The AM0 spectrum is the SUN's black body approximate spectrum hitting the earth's upper atmosphere having not yet interacted with any air mass. The AM1.5Direct spectrum is used for testing concentrator solar cells and is the average daily power making it to sea level without accounting for scattered light but accounting for absorbed light in the air mass. AM1.5G is the AM1.5D spectra plus the diffuse scattered light (i.e. plus ~10% blue rich light).