ECE 467 Solar Cells and Their Applications

Midterm Exam I

Feb. 21st, 2020

Name: Spencer Goulette

- Detailed descriptions of how you solved the problem will get you maximum partial credit if your final answer is wrong.
- You may use standard calculators, including calculator software on cell phones and tablets. .
- A table of commonly used constants and semiconductor parameters is at the end of the exam.
- A graph of electron and hole mobilities vs. doping density for Si is at the end of the exam
- Unless noted otherwise, assume room temperature conditions, i.e. T = 300K

	Grade	Out of
Section A	9	10
Section B	9	10
Section C		
#1	4	4
#2	4	4
#3	6	6
#4	4	4
#5	6	6
#6	10	10
#7	6	6
Total Grade	58	60

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Section A. Fill in the blanks section *Choose words from the word bank given below.*

1. Solar, wind and tidal energy are examples of renewable energy.
2. A solid that has no long-range or short-range order is amorphous.
3. B is an acceptor-type dopant in Si.
4. The conductivity effective mass is used to calculate mobility.
5. Photons represent optical energy as particles.
6. An electron transition from the valence band to the conduction band corresponds to generation.
7. An electron's velocity is proportional to its mobility and the electric field's magnitude.
8. In general, a photon's energy must be more than a semiconductor's bandgap for it to be absorbed by the semiconductor.
9. The solar ~~peak-sun-hours~~ insolation is solar energy density incident at a particular location.
10. The energy band which consists of the energy levels of free electrons in a semiconductor is known as the conduction band.

Word bank:

~~amorphous~~	donor	spectrum
electron	density of states	~~more~~
hole	~~conductivity~~	less
~~acceptor~~	~~peak-sun-hours~~	insolation
~~generation~~	recombination	bandgap
~~renewable~~	~~conduction~~	~~mobility~~
crystalline	thermal	~~optical~~

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Section B. True / False section *Indicate if the following statements are True or False:*

1. F A p-type semiconductor has very few holes compared to electrons.

F 2. T Arsenic (As) is a group V element. It is an acceptor-type dopant in Si, which is a group IV element.

3. T Diffusion current in a semiconductor is due to a gradient in the carrier concentration.

4. T The resistivity of a semiconductor is related to the drift current. $I_{drift} \propto \frac{1}{\rho}$ $J_{drift} = \frac{\vec{E}}{\rho}$

5. F Si (E_g = 1.12 eV) will absorb more of the energy in incident sunlight than Ge (E_g = 0.67 eV). $I_{drift} = A$ $h\nu - E_g$

6. T There is more available sunlight (in peak-sun-hours) at 45°N compared to 60°N.

7. F The electronic properties of a semiconductor are temperature independent. are temperature dependent

8. T A single green photon (λ = 532 nm) has more energy than a single red photon (λ = 650 nm). $\frac{1240}{\lambda}$

9. T There can be large variability in the daily solar insolation for a given location.

10. T A two axis tracking photovoltaic system will always collect more solar energy than a horizontal flat photovoltaic system.

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Section C. Problem Set

1. A GaAs sample is doped with $N_A = 4\times10^{16}$ cm^{-3} acceptor atoms, and is at room temperature. What are the free carrier concentrations, n and p? $n_i = 2\times10^6$ cm^{-3} at 300K.

p-type so $p = N_A = 4\cdot10^{16}$

$n = \frac{n_i^2}{N_A} = \frac{(2\cdot10^6)^2}{4\cdot10^{16}} = 1\cdot10^{-4}$ cm^{-3}

n $1\cdot10^{-4}$ cm^{-3}

p $4\cdot10^{16}$ cm^{-3}

2. The average daily solar insolation at Tucson, AZ, is 6.5 peak-sun-hours. What is the total energy incident on a 20 m^2 surface during an average day at Tucson, expressed in kWh?

6.5 kWh/m^2 $\cdot$ 20

kWh 130

3. A sufficiently thick solar cell with a broadband anti-reflective coating absorbs 750 W/m^2 of the 1000 W/m^2 optical power density available in the AM1.5 spectrum, but the power density available for extraction is only 450 W/m^2. What is its thermalization efficiency?

45%/75%

750/1000 = 75% 450/1000 = 45%

.45/.75 = .6 60% →

η_2 60%

4. The absorption coefficient for Si at a wavelength of $\lambda = 650$ nm (red) is $\alpha = 2800$ cm^{-1}. How much of the incident green light will a 10 µm thick Si sample absorb, expressed in [%]?

$1 - e^{-2800\cdot10\cdot10^{-4}} = 93,9\%$

93,9%

5. The Fermi level in a Si sample at room temperature is 250 meV below its conduction band. What is the dopant type and concentration? $N_C = 2.8\times10^{19}$ cm^{-3}, $N_V = 1.04\times10^{19}$ cm^{-3} @300K

$n = N_C e^{-(E_C - E_F)/k_BT}$

$n = 2.8\cdot10^{19} e^{-(250m)/26m}$

$n = 1.87\cdot10^{15}$ cm^{-3}

Dopant type n-type

Concentration $1.87\cdot10^{15}$ cm^{-3}

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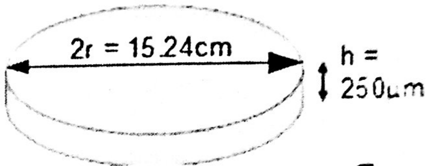
6. A monocrystalline Si solar cell is made using a 6" diameter wafer. The n-type Si wafer is doped with $N_D = 10^{15}$ cm^{-3}. It has a diameter of 2r = 6" (15.24 cm), and is 250 μm thick. Use the following values: $n_i = 10^{10}$ cm^{-3}, $\mu_n = 1200$ cm^2/Vs, and $\mu_p = 400$ cm^2/Vs.
   a) What is the conductivity of this wafer?
   b) What is the resistance of this wafer, if the current flows from the top surface to the bottom surface?



a. $\sigma \cong q n \mu_n$

$\sigma = 1.6 \cdot 10^{-19} \cdot 10^{15} \cdot 1200$

$\boxed{\sigma = 0.192}$

$A = \pi r^2$

$A = \pi \left(\frac{15.24}{2}\right)^2$

$A = 182.4$

b. $R = \frac{L}{\sigma A} = \frac{250 \cdot 10^{-4} \text{ cm}}{0.192 (\Omega \text{cm})^{-1} \cdot 182.4 \text{ cm}^2}$

$\boxed{R = 714 \; \mu\Omega}$

(a) Conductivity $0.192 \; (\Omega \text{cm})^{-1}$

(b) Resistance $714 \; \mu\Omega$

7. (a) What is the energy of light with a wavelength of $\lambda = 496$ nm, expressed in eV?
   (b) What is the excess energy of these photons compared to the bandgap of GaAs ($E_g = 1.42$ eV @ room temperature), expressed in eV?

a. $E = \frac{1240}{496} = 2.5$ eV

Excess $= h\nu - E_g$

Excess $= 2.5 - 1.42$

Excess $= 1.08$ eV

(a) hν 2.5 eV

(b) Excess energy 1.08 eV