Penn ESE 5150: Internet of Things Sensors and Systems

Homework 3:

Optoelectronic Sensors

1. Introduction

This homework is based on the following lecture packets:

4. Electromagnetic Sensors: Optoelectronic and Thermal Radiation Detectors

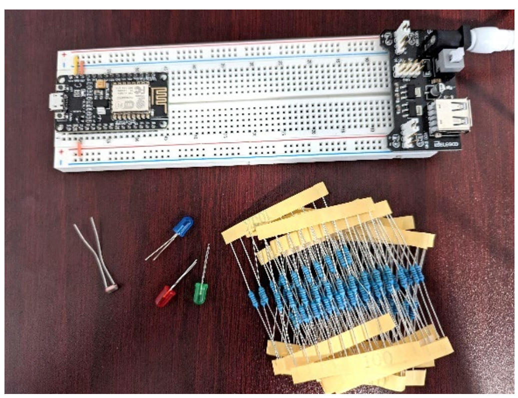
This homework will introduce you to the following hands-on components:

- Understand and operate photodiodes and photoresistors

For your homework submission, make a separate document and answer the items marked in blue boxes (like this one).

2. What you will need

a. NodeMCU and breadboard power supply (you do not need your previous homework setup, but you can add on to it if you prefer)
b. Photoresistor *(provided in ELEGOO UNO lab kit)*
c. LEDs *(provided in ELEGOO UNO lab kit)*
d. Resistors *(provided in ELEGOO UNO lab kit)*



3. Setup from Homework 2

Based, on your setup from the last part of Homework 2, please answer Question 1.

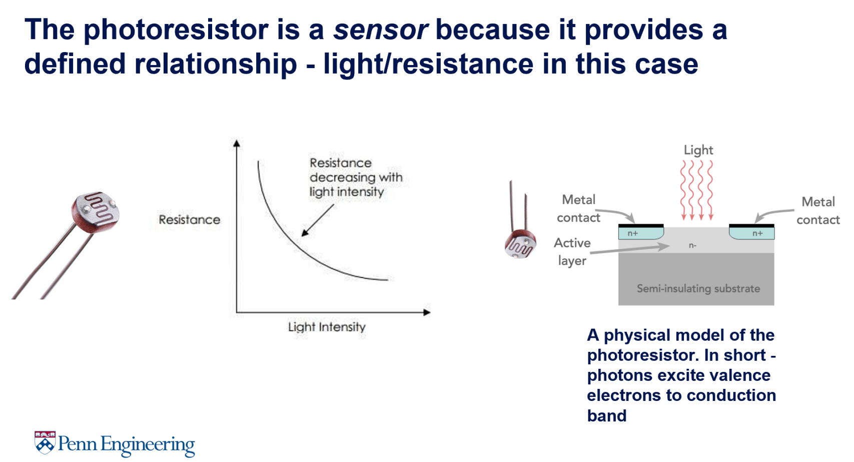
Question 1:

Did you face any issues with the NodeMCU setup from HW2?

(e.g. WiFi connectivity, sensor noise, pump failure, etc.)

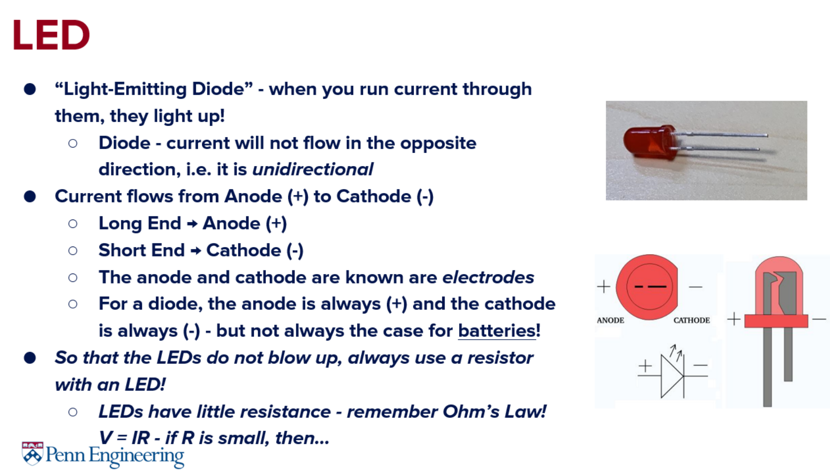
4. Devices for this homework: LEDs and Photoresistors

1. Introduction to the sensor - Light Dependent Resistor:



Photoresistor sensor datasheet: Link

2. Introduction to LEDs - Light Emitting Diodes:

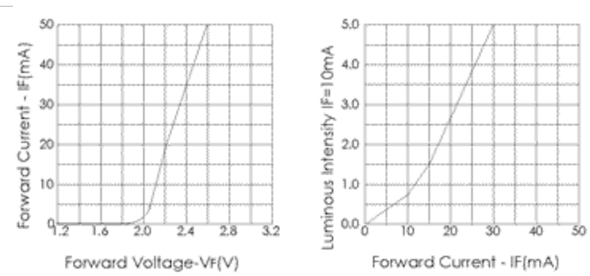


More information on LEDs: Link

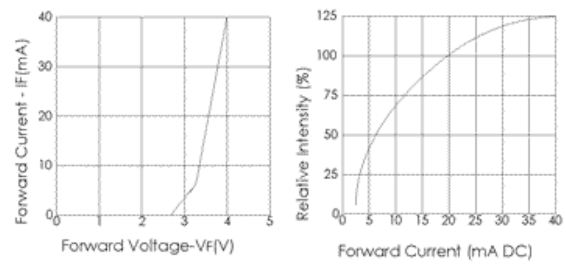
LED datasheet: Link

3. LED forward voltage (V_F) can be determined using the I-V curves in the datasheet. (I-V curves copied below from the datasheet)

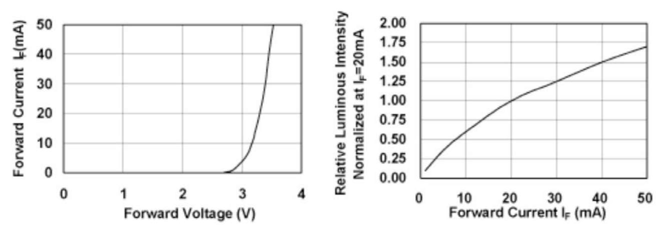
1. Red LED-



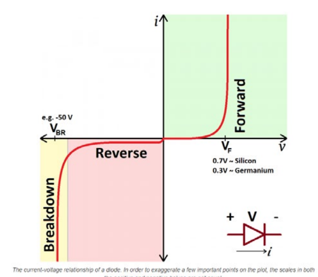
2. Green LED-



3. Blue LED-



4. Typical diode I-V plot -



Question 2:

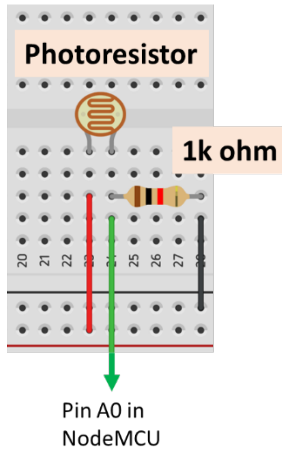
2.1. Based on the LED datasheet, what is the forward voltage V_F for Red, Green and Blue LEDs?

2.2. Correlate the increase in forward voltage with the bandgap of the semiconductors present in the LEDs in Q.2.1.

2.3. Based on the LED datasheet, what is the Luminous intensity of Red, Green and Blue LEDs, and what is the test current at which they are measured?

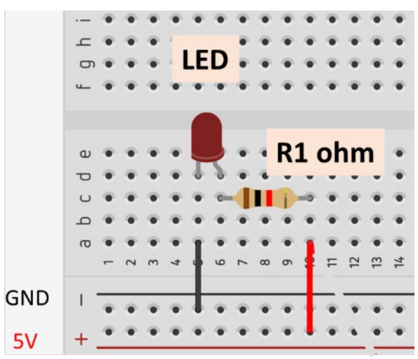
2.4. Based on the photoresistor datasheet, what is the light resistance and dark resistance of the photoresistor?

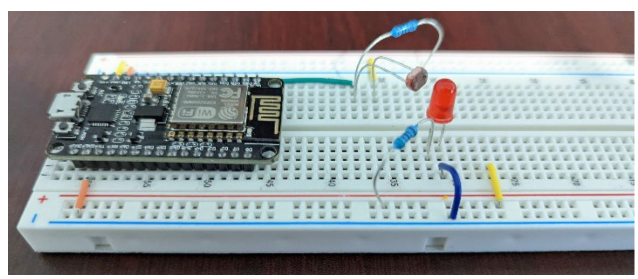
4. Connect the photoresistor (provided in the ELEGOO kit) to the nodeMCU. As there is only one analog input pin in the NodeMCU, connect the photoresistor to pin A0 for this exercise. (disconnect the soil moisture sensor if you are modifying your previous setup)



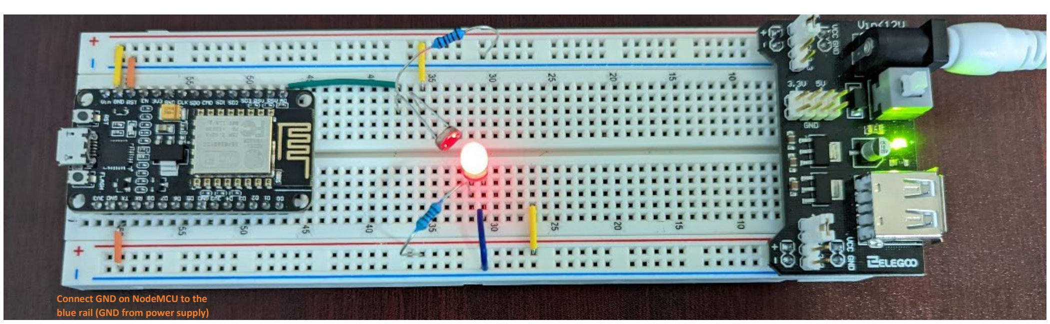
5. Connect a Red LED and a resistor (R1 = 220 ohms) to the power rails on the breadboard. **These are NOT connected to any pins in the NodeMCU.**

   Connect the LED such that it is as close to the photoresistor as possible. (See photo below for an example) Caution: LED is very bright





6. For question 3, you will modify the light intensity of the LED by changing the resistor R1, and measure the photoresistor reading for each resistor.



Question 3:

3.1. Post a photo of your LED and photoresistor setup. (With the LED turned on)

3.2. Use the following code to read the photoresistor output on your Adafruit dashboard.

Code: Link

Post a screenshot of your Adafruit dashboard with a gauge and line block (like the previous homework readings) showing the photoresistor output.

3.3. Fill in the following table. Ideally, take these measurements in a dark room, or cover the circuit to prevent surrounding light from affecting the measurements.

Use a V_{in} of 5V (red rail on breadboard with power supply connected)

V_F is the forward voltage of the LED, and depends on the color of the LED. Relative Luminous intensity vs current is shown in the LED datasheet

LED	**R1 resistor**	**Current through LED,** $I_{LED} = (V_{in} - V_F)/R1$	**Relative Luminous Intensity of LED at current** I_{LED}	**Photo-resistor reading (X)**	**Photo-resistor resistance value,** R = 1kohm* ((1023/X) – 1))
None (Dark)	None	NA	NA		
Red	220 ohm				
	330 ohm				
	1K ohm				
	2K ohm				
	5K ohm				
	10K ohm				
Green	220 ohm				
	330 ohm				
	1K ohm				
	2K ohm				
	5K ohm				
Blue	220 ohm				
	330 ohm				
	1K ohm				
	2K ohm				
	5K ohm				

3.4. Plot photoresistor resistance (R) vs Relative Luminous Intensity in table 3.3.

3.5. Calculate the sensitivity at low intensity (corresponding to 2K ohm) and high intensity (corresponding to 330 ohm) in the plot 3.4. Please show your calculations.

5. Theory

Please show your calculations and assumptions when answering the next few questions.

Question 4: Light Emitting Diodes

Assume you had two diodes at room temperature, one made of GaN and the other of InN. Use http://www.ioffe.ru/SVA/NSM/Semicond/ to find semiconductor device parameters. Assume the ideal diode equation $J = J_o\left(e^{qV/kT} - 1\right) \sim K n_i^2\left(e^{qV/kT} - 1\right)$ and that K is the same for both semiconductors (note: K depends on the doping, carrier lifetime, and carrier diffusion length of carriers on the n- and p-side of the junction; so in practice these values will not be the same, but other terms in the equation typically dominate).

4.1 Calculate the wavelength and list the color of light do you expect these diodes to emit? Sketch the emission spectrum of these diodes.

4.2 Calculate the difference you expect in the forward voltage of the diodes?

Room T = 300K

GaN, Eg = 3.2 eV

InN, Eg = 1.970 eV

N_i from lecture slides or equation

4.1. wavelength = h*c/Eg (E=hc/lambda)

Emission spectrum – light intensity vs wavelength

4.2.

Question 5: CdS ELEGOO Photoresistor

5.1 Assume the thickness of the CdS film is 1 micron. Calculate the absorbance of the photoresistor at 540 nm (assuming there is no reflection or scattering). Justify the selection of the film thickness.

5.2 Take photo of your photoresistor next to a ruler. Submit your photo with annotated dimensions of the length and width of the photoresistor. Calculate the dark carrier concentration from the dark resistance.

5.3 Using the light resistance in the specifications for excitation at 540 nm, calculate the excess carrier concentration created by the light.

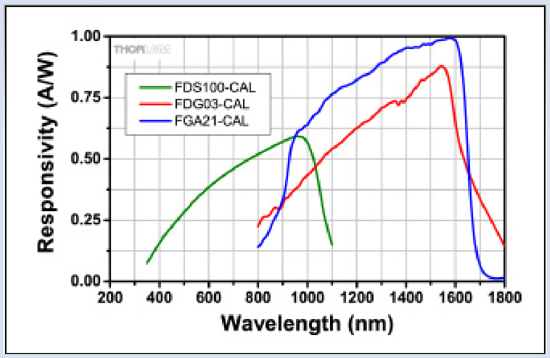
5.4 Assume the response time of the photoconductor is dominated by the carrier lifetime. Explain why one would make this assumption.

5.5 Calculate the excitation intensity for the specified light resistance.

5.6 For the V_{in}=5 V, calculate the anticipate gain of the photoresistor.

Question 6: Photodiodes

In the lecture, we compared three photodiodes from the Thor Labs catalog: Si (green), $In_{0.53}Ga_{0.47}As$ (blue), Ge (red). Use http://www.ioffe.ru/SVA/NSM/Semicond/ to find semiconductor device parameters. Again, assume the ideal diode equation $J = J_o\left(e^{qV/_{kT}} - 1\right) \sim K n_i^2 \left(e^{qV/_{kT}} - 1\right)$ and that K is the same for both semiconductors.



6.1 Draw comparatively the dark I-V characteristics of the three diodes, in both forward and reverse bias.

6.2 Is the current in the diode at V_A=-1V dominated by drift or diffusion and from electrons or holes? In one sentence, explain why.

6.3 Calculate the long wavelength absorption corresponding to the band gap of the semiconductors and the intrinsic carrier concentration (note: N_c and N_v can be found on the website).

6.3 In one to two sentences, why does the responsivity of the diode drop at short wavelengths?

6.4 For the $In_{0.53}Ga_{0.47}As$ diode, if the dark current at V_A=-1V is 50 nA, calculate the minimum power at 1590 nm that the diode can detect. Assume the diode can detect currents at 10% of the dark current.

6.5 For the Si and $In_{0.53}Ga_{0.47}As$ diodes, calculate the EQEs at the maximum of their responsivities.