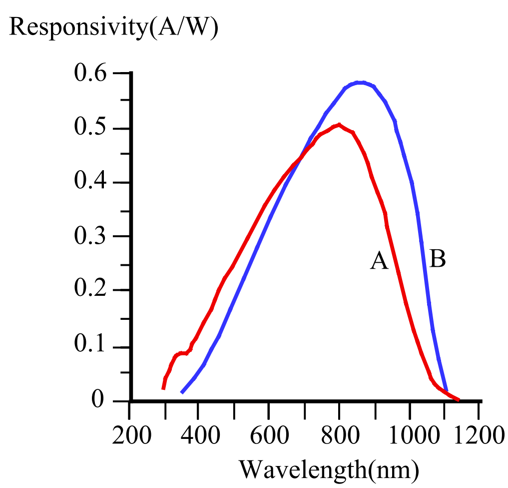
ECEn 555, Fall 2009
Homework #3
Due October 12, 5:00 pm

3.1 An ideal photodiode (of unit quantum efficiency) is illuminated with 10 mW of radiation at 0.8 μm wavelength; calculate the current and voltage output when the detector is used in the photoconductive and photovoltaic modes respectively. The reverse bias leakage current is 10 nA.

3.2. It is desired to make a silicon p-i-n photodiode with an area of 1 mm^2 with as fast a response time as possible when used in conjunction with a 50 Ω load resistor. Estimate the thickness of the intrinsic region required. Take ε_r=11.8 and v_s (the electron saturation velocity) as 10^5 m s^{-1}.
Over what wavelength range would you expect the device to be most effective?

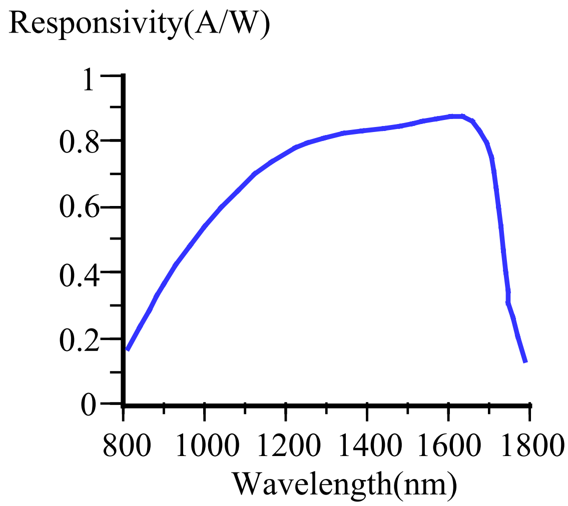
3.3 Si pin Photodiodes. Consider two commercial Si pin photodiodes, type A and type B, both classified as fast pin photodiodes. They have the responsivity shown in the Figure below. Differences in the responsivity are due to the pin device structure. The photosensitive area is 0.125 mm^2 (0.4 mm in diameter).

(a) Calculate the photocurrent from each when they are illuminated with blue light of wavelength 450 nm and light intensity 1 μW cm^{-2}. What is the quantum efficiency of each device?
(b) Calculate the photocurrent from each when they are illuminated with blue light of wavelength 700 nm and light intensity 1 μW cm^{-2}. What is the quantum efficiency of each device?
(c) Calculate the photocurrent from each when they are illuminated with blue light of wavelength 1000 nm and light intensity 1 μW cm^{-2}. What is the quantum efficiency of each device?
(d) What are your conclusions about these two devices?



The responsivity of two commercial Si *pin* photodiodes

3.4 Fiber attenuation and InGaAs pin photodiode. Consider the commercial InGaAs pin photodiode whose responsivity is shown in the Figure below. This is used in a receiver circuit that needs a minimum of 5 nA photocurrent for a discernible output signal (acceptable signal to noise ratio for the customer). Suppose that the InGaAs pin photodiode is used at 1.3 micron wavelength operation with a single mode fiber whose attenuation is 0.35 dB km^{-1}. If the laser diode emitter can launch at most 2 mW of power into the fiber, what is the maximum distance for the communication without a repeater?



The responsivity of an InGaAs *pin* photodiode

3.5 The APD and excess avalanche noise. APDs exhibit excess avalanche noise which contributes to the shot noise of the diode current. The total noise current in the APD is given by

$$i_{n\text{-}APD} = [2q(I_d + I_{ph})M^2FB]^{1/2}$$

where I_d is the dark current through the photodiode, I_{ph} is the photocurrent through the APD, F is the excess noise factor which depends in a complicated way not only on M – the gain of the APD, but also on the ionization probabilities of the carriers in the device. It is normally taken simply to be M^x where x is an index that depends on the semiconductor material and device structure.

(a) The table below provides measurements of F vs. M on a Ge APD using photogeneration at 1.55 micron light wavelength. Find x in $F = M^x$. How good is the fit?

(b) The above Ge APD has an unmultiplied dark current of 0.5 μA and an unmultiplied responsivity of 0.8 A/W at its peak response at 1.55 micron and is biased to operate at M=6 in a receiver circuit with a bandwidth of 500 MHz. What is the minimum photocurrent that will give an SNR=1? If the photosensitive area is 0.3 mm in diameter, what are the corresponding minimum optical power and light intensity?

(c) What should be the photocurrent and incident optical power for SNR =10?

M	1	3	5	7	9
F	1.1	2.8	4.4	5.5	7.5

3.6 Series connected solar cells. Consider two identical solar cells with the properties I_o= 25x10^{-6} mA, n=1.5, R_s=20 Ω, subjected to the same illumination so that I_{ph}=10 mA. Plot the individual I-V characteristics and the I-V characteristics of the two cells in series. Find the maximum power that can be delivered by one cell and two cells in series. Find the corresponding voltage and current at the maximum power point.

3.7 Series connected solar cells II. Consider two odd solar cells. Cell 1 has I_{o1}=25x10^{-6} mA, n_1=1.5, R_{s1}=10 Ω and cell 2 has I_{o2}=1x10^{-7} mA, n_2=1, R_{s2}=50 Ω. The illumination is such that I_{ph1} = 10 mA and I_{ph2} = 15 mA. Plot the individual I-V characteristics and the I-V characteristics of the two cells in series. Find the maximum power that can be delivered by each cell and two cells in series. Find the corresponding voltages and currents at the maximum power point. What are your conclusions?

3.8 Solar cell efficiency. The fill factor FF of a solar cell is given by the empirical expression

$$FF \approx (v_{oc} - \ln(v_{oc} + 0.72)) / (v_{oc} + 2)$$

Where v_{oc} = $V_{oc}/(nk_BT/q)$ is the normalized open circuit voltage (normalized with respect to the thermal voltage k_BT/q). The maximum power output from a solar cell is

$$P = FF I_{sc} V_{oc}$$

Taking V_{oc} = 0.58 V and I_{sc} = I_{ph} = 35 mA cm^{-2}, calculate the power available per unit area of solar cell at room temperature 20 ºC, at –40 ºC, and at 40 ºC for n=1 and n=2?