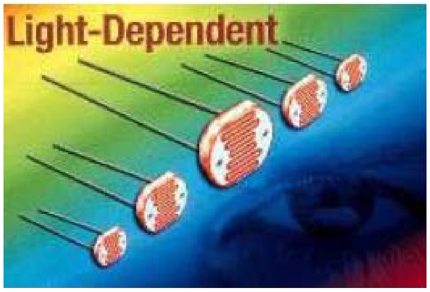
ECE 3040 Homework 3

The goal of this homework is to design a photocell (also known as a photoelectric cell or photoelectric resistor) that will respond to light and change its resistance. This device may be used in a later homework problem. The photocell is basically nothing more than a resistor made out of semiconductor material and is typically arranged in a package as a long skinny slither of very thin semiconductor, most often CdS due to its near optimal bandgap for absorbing the solar spectrum and relative inexpensive material. While a real device has a long serpentine shape (see below) we will simply use a rectangular block as was done in class.



The working specifications of your design are for a resistance of 1 Giga-ohm in dark and 3 Mega-ohms in bright light (Intensity, I_o=60mW/cm^2).

Given:

The CdS material is p-type with Na=1e14 cm^{-3} and n_i=2e6 cm^{-3}

The mobilities are μ_n=100 cm^2/V-sec and μ_p=500cm^2/V-sec;

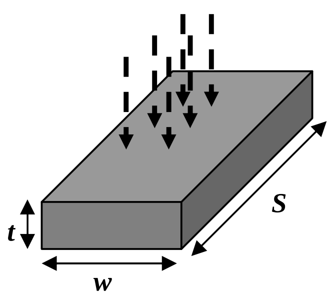
Note: For this problem it is okay to assume low level injection and thus valid to use the formula:

$$\left.\frac{\partial n}{\partial t}\right|_{\substack{i-thermal\\R-G}} = -\frac{\Delta n}{\tau_n} \qquad \text{(pp. 115, 3.34b)}$$

But if this were a real world problem, the type of variations we want to achieve in resistance are so large that high level injection conditions come into play, and the formula

$$\left.\frac{\partial n}{\partial t}\right|_{\substack{i-thermal\\R-G}} = \left.\frac{\partial p}{\partial t}\right|_{\substack{i-thermal\\R-G}} = \frac{n_i^2 - np}{\tau_p(n+n_i)+\tau_n(p+p_i)} \qquad \text{(pp. 115, 3.35)}$$

1) It is determined that the resistor "trace" (width viewed from the light's perspective as shown in figures above) will have a width (w) of 0.2 mm and a thickness (t) of 4 μm. What is the needed length (S) to achieve 1 Giga-ohms resistance in the dark?



2) Assuming that the bandgap energy is 1.4 eV and that the light has the same photon energy (1.4 eV). What is the generation rate G_L in the semiconductor if the absorbing efficiency of light is 0.9? (90% of the photons have been absorbed and converted into electron-hole pairs)
   Hint: Calculate the flux of photons in 1 cm^2 from the power density (intensity) and the amount of energy needed to generate each electron-hole pair, then find how much of this flux is incident on the photocell given your results from part 1, then convert this to a generation rate using the assumption of uniform absorption/generation throughout the thickness of the semiconductor film.
3) If the semiconductor has dimensions as defined in part 1, what minority carrier lifetime is needed to have the desired "light on resistance" of 3 Mega-ohms?
4) Quasi-Fermi Level: Calculate and sketch the Fermi level when the CdS is in dark. What are the Quasi-Fermi Levels if the light is on? (T=300K, Assuming no current flow in the device)
5) Temperature Dependence: Assuming the variation of carrier concentrations is negligible, will the resistance increase or decrease if the temperature gets higher, why?
6) If 120 Volts DC is applied to the resistor (i.e. applied along the longest dimension) and if the semiconductor is assumed to be a single rectangular resistor (not serpentine as shown in the figures above but simply a block).
   a. What is the electric field on the resistor?
   b. What is the electron current flow in dark?
   c. What is the hole current flow in dark?
   d. What are the answers to b&c in light?
7) If the light is instantly turned off, sketch and label the electron concentration as a function of time. Mark the equilibrium value n_o, the total concentration n, and the excess electron concentration Δn.
8) Purpose: Demonstrate the relationship between diffusion current and excess minority carrier concentration.
   For the above semiconductor, a non-uniform light source is applied with the excess electron concentration depicted by:

$$\Delta n(x) = 1e13 + 1e14\cos\left(\frac{\pi x}{2S}\right) \qquad cm^{-3}$$

   where S is the length determined in part 1. What is the steady state minority carrier current density at all positions in the photocell? (No electric field)
9) Strong suggestion: Review the minority carrier diffusion equation problems on the web test solutions page.