EE 119 Homework 7

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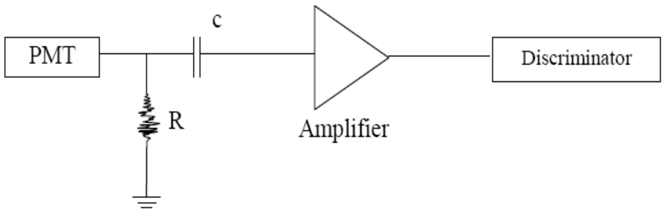
Due Tuesday, March 30th 2010
(Please submit your answers in EE119 homework box located in 240 Cory Hall)

1. Photomultiplier tube
   a) Assume constant quantum efficiency and constant power. Plot the variation of cathode current as a function of wavelength between 200nm and 1μm. (Assume a current of 10nA at 200nm).
   b) If the photocathode material has a work function of 1.8eV, what is the maximum wavelength it can detect?

2. Dark Current
   a) If the cathode dark current of a PMT is found to be 2×10^4 e/sec at room temperature (300K), what is the equivalent shot noise to this dark current? Assume the bandwidth is 1Hz.
   b) We can actually distinguish a light signal that only exceeds the shot noise level of the dark current. Based on this criterion, what is the minimum power that can be detected? Assume the quantum efficiency is 50% at λ = 630nm.
   c) If the PMT is cooled down by 50°C (250K), what are the cathode dark current and the minimum detectable power? Assume the work function is 1.4eV.

3. a) A certain PMT has 12 stages. In the first five stages, each primary electron can stimulate four secondary electrons. In the next seven stages, each primary electron can stimulate five secondary electrons. What is the gain of this PMT?
   b) The pulse width is 8nsec. With the load resistance of 50 Ohms, what is the approximate peak voltage observed for the single photon? Assume a quantum efficiency of 1.



4. A PMT has 10 dynodes and $\delta = 4$. It is used to detect a faint laser beam that is operating at 632.8 nm. The quantum efficiency of the cathode at this wavelength is 25%. The laser power incident on the PMT is 1nW.
   a) What is the number of incident photons per second?
   b) How many photoelectrons are generated at the cathode per second?
   c) What is the anode current?
   d) Given an integration time of 1 second (that is, a bandwidth of 1Hz), what is the shot noise? What is the SNR?

5. Semiconductor Photodiodes: Band Gaps

The band gaps ($E_g = E_{conduction\ band\ edge} - E_{valence\ band\ edge}$) of some common photodiode materials are given in the table below. Find the equivalent wavelength (λ) in A^o (to the nearest whole A^o) and wavenumber ($1/\lambda$) in cm^{-1}. What spectral ranges (infrared, visible, UV…etc.) of light would these photoconductors detect?

Material	E_g (eV)
CdS	2.42
CdSe	1.73
PbS	0.37
PbTe	0.29
PbSe	0.27

6. Monochromatic light is incident on the photodiodes shown in Fig. 6-1. The metal electrode is 20nm thick and has an absorption length at this wavelength of 100 nm. The semiconductor has an absorption length at this wavelength of 600 nm. The depletion region is 300 nm with no applied bias. Please note that, since the n-side of the semiconductor is heavily doped (n^+) (dopant concentration is very high) and p-side is only moderately doped, the depletion region can be considered all in the p-side of the semiconductor.

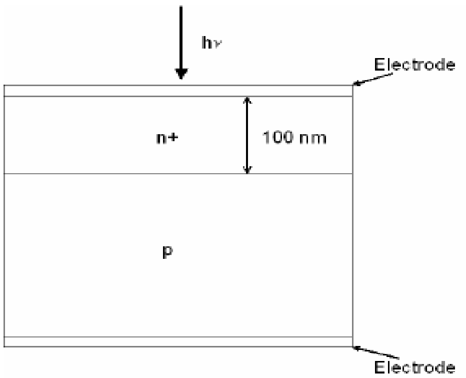


Fig. 6-1

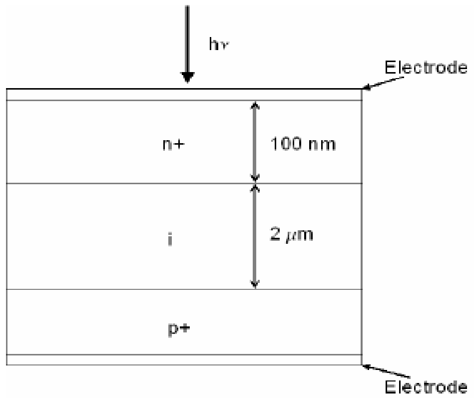


Fig. 6-2

(a) Find the conversion efficiency of this photodiode neglecting any loss due to other effects such as recombination and reflection. The conversion efficiency is defined as

$$\eta \equiv \frac{\text{The number of electron} - \text{hole pairs collected in circuit}}{\text{The number of photons incident on the diode surface}}$$

Hint: light intensity decays with distance x in an absorptive medium as $I(x) = I_o \exp(-x/L_\alpha)$ in which L_α is the absorption length; only electron-hole pairs generated in the depletion region are considered collected in circuit.

(b) Draw the energy-band diagram and label the p-side, n-side, depletion region, built-in potential and Fermi-level.

(c) Now, suppose we apply a reverse bias to the diode. How does this change your band diagram? How would it change your answer to part (a)?

(d) Now suppose we add a block of intrinsic silicon (2-mm long) between the p and n regions to the photodiode from the problem 1, as in Fig. 6-2. Redo the part (a) for this case. Which configuration has higher conversion efficiency?