Problem 1: Light Emitting Diode (60 pts.) (includes 10 pts Bonus*)

Consider a GaAs pn junction which has the following properties. \( N_a = 10^{16} \text{ cm}^{-3} \) (p-side), \( N_d = 10^{19} \text{ cm}^{-3} \) (n-side), \( B = 7.21 \times 10^{-16} \text{ m}^3 \text{ s}^{-1} \) (see pages 135-6 of the textbook), cross sectional area \( A = 1 \text{ mm}^2 \).

a. What is the diode current components due to diffusion \( I_{(P-side)} \) and \( I_{(N-side)} \) in the P and N neutral regions at 300 K when the forward voltage across the diode is 1.1 V?

b. What is the built-in potential? Calculate the thickness of the space charge (depletion) regions across the junction at \( V=0 \) and at \( V=1.1V \)? Calculate at 1.1V the recombination currents (in the space charge layers), \( I_{r(p)} \) and \( I_{r(n)} \).

c. At this bias point, how many photons, in each region of the diode, are generated per unit time? Label these as \( I_{\lambda(p-side)} \), \( I_{\lambda(n-side)} \), \( I_{\lambda(p)} \) and \( I_{\lambda(n)} \). If only 5% of these can be transmitted out, what is the total optical power output, \( P_{\lambda \text{ out TOTAL}} \) in watts and external power efficiency, \( \eta = P_{\lambda \text{ out TOTAL}} \)? Note that \( P_{\lambda \text{ out}} = 5\% \) of (photon energy . \( I_{\lambda \text{ TOTAL}} \))

d. Repeat the above calculations for a range of 0.8 < \( V < 1.2 \text{ V} \) and plot on \textit{semi-log scale}:
   All components of \( I \) vs \( V \) including \( I_{TOTAL} \),
   All components of \( I_{\lambda} \) vs \( V \) including \( I_{\lambda \text{ TOTAL}} \),
   All components of \( P_{\lambda \text{ out}} \) vs \( V \) including \( P_{\lambda \text{ out TOTAL}} \).

Problem 2: Solar Cells (60 pts.) (includes 10 pts Bonus*)

2.1 Solar cell driving a load

a. A Si solar cell of area 4 \text{ cm}^2 is connected to drive a load \( R \) as in Figure 6.8 (a). It has the I-V characteristics in Figure 6.8 (b) under an illumination of 600 \text{ W m}^{-2}. Suppose that the same cell is being used under a light intensity of 1 \text{ kW m}^{-2} with a load resistance of 20 \text{ \Omega}. What are the current and voltage in the circuit? What is the power delivered to the load? What is the efficiency of the solar cell in this circuit?
b What should the optimum load resistance be to obtain maximum power transfer from the solar cell to the load at 1 kW m\(^{-2}\) illumination. What is the efficiency of this cell under this optimum loading condition? Comment on your findings.

c Consider using a number of such a solar cells to drive a calculator that needs a minimum of 3V and draws 3.0 mA at 3 - 4V. It is to be used indoors at a light intensity of about 400 W m\(^{-2}\). How many solar cells would you need and how would you connect them? At what light intensity would the calculator stop working?

2.2 SPICE Modeling and Analysis of Series Connected Solar cells

Consider three odd solar cells. Cell No.1 has \(I_s^1 = 25\) nA, \(n_1 = 1.5\), \(R_s^1 = 10\) Ω, Cell No.2 has \(I_s^2 = 0.1\) nA, \(n_2 = 1\), \(R_s^2 = 50\) Ω, Cell No.3 has \(I_s^3 = 0.1\) nA, \(n_3 = 1\), \(R_s^3 = 5\) Ω. The illumination levels and efficiencies are such that \(I_L^1 = 10\) mA and \(I_L^2 = I_L^3 = 25\) mA.

Use equivalent circuits and PSpice to analyze and plot the I-V characteristics and power output vs operating voltage characteristics of these cells, operated individually. Determine the maximum power each cell can deliver the corresponding voltages and currents at their maximum power points.

Repeat the above when the two cells are picked and connected in series to deliver a higher voltage.

Which series combination, (1&2), or (2&3), or (1&3), would deliver the maximum power? Explain why?

*Complete answers will earn as high as 120 points out of 100.
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