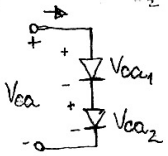
2)

V_{ca} = Tensão em circuito aberto ($I = 0$) I_L = Corrente de luz

$V_{ca_1} = 0,5\,V$ $I_{L_1} = 1\,A$ $V_{ca_2} = 0,6\,V$ $I_{L_2} = 0,8\,A$

a) I



$V_{ca} = V_{ca_1} + V_{ca_2} = 0,5 + 0,6 \Rightarrow \boxed{V_{ca} = 1,1\,V}$

Circuito aberto $\rightarrow I = 0 \Rightarrow I = I_S\left(e^{\frac{eV}{k_BT}} - 1\right) - I_L = 0 \Rightarrow I_S = \dfrac{I_L}{e^{\frac{eV_{ca}}{k_BT}} - 1}$

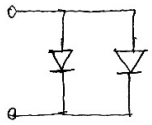
- $I_{S_1} = \dfrac{I_{L_1}}{e^{\frac{eV_{ca_1}}{k_BT}} - 1} = \dfrac{1}{e^{\frac{0,5}{0,026}} - 1} \Rightarrow \boxed{I_{S_1} = 4,45 \cdot 10^{-9}\,A}$

- $I_{S_2} = \dfrac{I_{L_2}}{e^{\frac{eV_{ca_2}}{k_BT}} - 1} = \dfrac{0,8}{e^{\frac{0,6}{0,026}} - 1} \Rightarrow \boxed{I_{S_2} = 4,6 \cdot 10^{-11}\,A}$

Curto Circuito ($V_{ca} = 0$ & $I_{cc} = I_S\left(e^{\frac{eV}{k_BT}} - 1\right) = I_L$)

$I_{cc} = I_{L_2} = 0,8\,A$ (I_{L_2} é a corrente escolhida por ser a menor entre elas)

b)



$I_{cc} = I_{L_1} + I_{L_2} = 1 + 0,8 = 1,8\,A$

circuito aberto $\Rightarrow I = 0$

$I = 0 \Rightarrow I_1 + I_2 = 0 \Rightarrow I_{S_1}\left(e^{\frac{eV}{k_BT}} - 1\right) - I_{L_1} + I_{S_2}\left(e^{\frac{eV}{k_BT}} - 1\right) - I_{L_2} = 0 \Rightarrow$

$\left(I_{S_1} + I_{S_2}\right)\left(e^{\frac{eV}{k_BT}} - 1\right) = 1,8 \Rightarrow \ln\left(e^{\frac{eV}{k_BT}}\right) = \ln\left(\dfrac{2,8}{4,45 \cdot 10^{-9}}\right) \Rightarrow \dfrac{V}{0,026} = 20,25 \Rightarrow$

$\boxed{V = 0,5265\,V}$

3)

$N_d = 10^{15}\,cm^{-3} = 10^{21}\,m^{-3}$ $\quad p = \frac{n_i^2}{N_d} = \frac{(1,5.10^{16})^2}{10^{21}} = 2,25.10^{11}\,m^{-3}$ $\quad l = 10^{-4}\,m$ $\quad A = 10^{-8}\,m^2$ $\quad \mu = 10^{21}\,cm^{-2} = 10^{27}\,m^{-3}$

a)

$\sigma_s = n e \mu_n + p e \mu_p = 10^{21} . 1,6\,10^{-19} . 0,135 + 2,25 . 10^{11} . 1,6\,10^{-19} . 0,48 \Rightarrow \boxed{\sigma_s = 21,6\,\Omega^{-1}}$

$R_s = \rho \frac{l}{A} = \frac{1}{\sigma} \cdot \frac{l}{A} = \frac{1}{21,6} \cdot \frac{10^{-4}}{10^{-8}} \Rightarrow \boxed{R_s = 463\,\Omega}$

$V = I R \Rightarrow I = \frac{V}{R} = \frac{5}{463} \Rightarrow \boxed{I = 10,8\,mA}$

b)

$\mu = \frac{N}{\gamma_\mu} \Rightarrow N = \mu . \gamma_\mu = 10^{21} . 10^{-6} \Rightarrow \boxed{N = 10^{15}\,cm^{-3}}$

c)

$\Delta\sigma = \mu \gamma_\mu e (\mu_n + \mu_p) = 10^{27} . 10^{-6} . 1,6.10^{-19} (1350 + 480)\,10^{-4} = 29,28\,\Omega^{-1}$

d)

$\Delta I = \frac{A . \Delta\sigma V}{l} = \frac{10^{-8} . 29,28 . 5}{10^{-4}} \Rightarrow \boxed{\Delta I = 14,6\,mA}$

e)

$G = \frac{\Delta I}{e \mu . A l} = \frac{14,6 . 10^{-3}}{1,6.10^{-19} . 10^{27} . 10^{-8} . 10^{-4}} = 91,5$

f)

4)

$LED_1 = \begin{cases} \lambda_1 = 0,65\,\mu m \\ \eta_1 = 0,5\% \end{cases}$ $\quad LED_2 = \begin{cases} \lambda_2 = 0,55\,\mu m \\ \eta_2 = 0,12\% \end{cases}$

$\phi_1 = \frac{\eta_1 P_0}{\hbar \omega_1}$ $\quad \phi_2 = \frac{\eta_2 P_0}{\hbar \omega_2}$ $\quad \frac{\phi_1}{\phi_2} = \frac{\frac{\eta_1 P_0}{\hbar \omega_1}}{\frac{\eta_2 P_0}{\hbar \omega_2}} = \frac{\eta_1}{\omega_1} \cdot \frac{\omega_2}{\eta_2}$

$\frac{\phi_1}{\phi_2} = \frac{\eta_1}{\eta_2} \cdot \frac{2\pi f_2}{2\pi f_1} = \frac{\eta_1}{\eta_2} \cdot \frac{\lambda_1 c}{\lambda_2 c} = \frac{0,5}{0,12} \cdot \frac{0,65.10^{-6}}{0,55.10^{-6}} \Rightarrow \frac{\phi_1}{\phi_2} = 4,93 \Rightarrow \boxed{\phi_1 = 4,93\,\phi_2}$

"O LED de GaAsP é mais brilhante, pois gera mais fotons que o LED de GaP"

5) $A = 10\,cm^2$ $N_a = 2.10^{16}\,cm^{-2} = 2.10^{20}\,m^{-2}$ $N_d = 5.10^{19}\,cm^{-3} = 5.10^{25}\,m^{-3}$ $\tau_p = 0{,}5\,\mu s$ $\tau_n = 10\,\mu s$

$FF = 0{,}7$

$I = 0{,}14\,W/cm^2$ $I_L = 500\,mA$

$L_p = \sqrt{D_p \cdot \tau_p} = \sqrt{12{,}5.10^{-4}.0{,}5.10^{-6}} \Rightarrow \boxed{L_p = 2{,}5.10^{-5}\,m}$

$L_n = \sqrt{D_n \tau_n} = \sqrt{35.10^{-4}.10.10^{-6}} \Rightarrow \boxed{L_n = 18{,}71.10^{-5}\,m}$

$$I_S = eAn_i^2\left(\frac{D_p}{L_p N_d} + \frac{D_n}{L_n N_a}\right) = 1{,}6.10^{-19}.10^{-3}.(1{,}5.10^{10})^2\left(\frac{12{,}5.10^{-4}}{2{,}5.10^{-5}.5.10^{25}} + \frac{35.10^{-4}}{18{,}71.10^{-5}.2.10^{22}}\right)$$

$I_S = 3{,}6.10^{10}\left(10^{-25} + 0{,}94.10^{-21}\right) \Rightarrow \boxed{I_S = 3{,}36.10^{-11}\,A}$

a)

$$I = I_S\left(e^{\frac{eV}{k_B T}} - 1\right) - I_L = 0 \Rightarrow e^{\frac{eV}{k_B T}} = \frac{I_L}{I_S} + 1 \Rightarrow \frac{V}{0{,}026} = \ln\left(\frac{I_L}{I_S} + 1\right) \Rightarrow$$

$V = 0{,}026 \cdot \ln\left(\frac{500.10^{-3}}{3{,}36.10^{-11}} + 1\right) \Rightarrow \boxed{V = 0{,}6\,V}$

b)

$$FF = \frac{I_m V_m}{I_{cc} V_{ca}} \;;\; \begin{matrix} I_{cc} = I_L \\ I_m V_m = P_e \end{matrix} \Rightarrow FF = \frac{P_e}{I_{cc} V_{ca}} \Rightarrow P_e = I_{cc} V_{ca} FF = 500.10^{-3}.0{,}6.0{,}7 \Rightarrow$$

$\boxed{P_e = 0{,}21\,W}$

c)

$$\eta = \frac{P_e}{P_L} = \frac{P_e}{I.A} = \frac{0{,}21}{0{,}14.10^{-3}} \Rightarrow \boxed{\eta = 15\%}$$

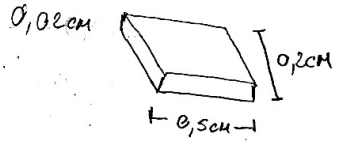
d) Diminuir a area da célula.

6)

$\frac{P}{P_g} = 5\% \Rightarrow \frac{68.10^{-3}}{5.10^{-2}} = P_g \Rightarrow \boxed{P_g = 1{,}36\,W}$

$P = V.I \Rightarrow V = \frac{P}{I} = \frac{1{,}36}{0{,}4} \Rightarrow \boxed{V = 3{,}4\,V}$

$V = {}^{Eg}/_{q} + IR_S \Rightarrow 3{,}4 = 1{,}43 + 0{,}4\,R_S \Rightarrow \boxed{R_S = 4{,}925\,\Omega}$

7) 

$E_g = 1,7\,eV$ $\quad \lambda = 0,45\,\mu m$

$\mu_n = 400\,cm^2/V.s$ $\quad I_0 = 1,5\,mW/cm^2$

$\mu_p = 0$ $\quad \eta = 1$

$\gamma_r = 10^{-3}\,\lambda$ $\quad f = \frac{c}{\lambda}$ $\quad \omega = 2\pi f$

a)

$$g = \frac{\eta I_0}{\hbar \omega d} = \frac{\eta I_0}{h 2\pi f d} \cdot 2\pi = \frac{\eta I_0}{h f d} = \frac{\eta I_0}{h c d} \cdot \lambda \Rightarrow g = \frac{1 . 1,5 . 10^{-3} . 0,45 . 10^{-6}}{6,62 . 10^{-34} . 3 . 10^{8} . 2 . 10^{-4}} \Rightarrow$$

$$g = 1,69 . 10^{23}\, m^{-3}\lambda^{-1} = 1,69 . 10^{17}\, cm^{-3}\lambda^{-1}$$

$$\Delta I = \frac{b . d . g . \gamma_r . e (\mu_n + \mu_p) V}{\ell} = \frac{0,02 . 0,2}{0,5} . 1,69 . 10^{17} . 10^{-3} . 1,6 . 10^{-19} (400 + 0) 5 \Rightarrow$$

$$\boxed{\Delta I = 0,435\,mA}$$

$$G = \frac{\Delta I}{e g b d \ell} = \frac{0,435 . 10^{-3}}{1,6 . 10^{-19} . 1,69 . 10^{17} . 0,2 . 0,02 . 0,5} \Rightarrow \boxed{G = 8}$$

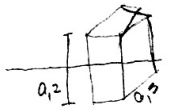
$$G = \frac{\gamma_r (\mu_n + \mu_p) V}{\ell^2} = \frac{10^{-3} . 400 . 5}{(0,5)^2}$$

$$G = 8$$

b)

$$g = \frac{\eta I_0 \lambda}{h c d} \Rightarrow \Delta I = \frac{b d}{\ell} . \gamma_r e (\mu_n + \mu_p) V . \frac{\eta I_0 \lambda}{h c d} \Rightarrow \Delta I_M = \frac{b}{\ell} \gamma_r e (\mu_n + \mu_p) V \frac{\eta I_0 \lambda}{h c}$$

Para ΔI ser máximo ℓ tem que ser mínimo e b máximo



$$\Delta I_M = \frac{5 . 10^{-3}}{2 . 10^{-4}} . 10^{-3} . 1,6 . 10^{-19} (400 + 0) . 5 . \frac{1 . 1,5 . 10^{-3} . 0,45 . 10^{-6}}{6,62 . 10^{-34} . 3 . 10^{8} . 2 . 10^{-4}} \Rightarrow \boxed{\Delta I_M = 27,2\,mA}$$

$$G_M = \frac{\Delta I_M}{e g b d \ell} = \frac{27,2 . 10^{-3}}{1,6 . 10^{-19} . 0,2 . 0,02 . 0,5 . 1,69 . 10^{17}} \simeq 500 \quad ??? \quad \frac{10^{-3} . 400 . 5}{4 . 10^{-4}} = 5000$$

c)

$$\hbar\omega < E_g \Rightarrow \frac{h}{2\pi} . 2\pi f < E_g \Rightarrow h . \frac{c}{\lambda} < E_g \Rightarrow 6,62 . 10^{-34} . \frac{3 . 10^{8}}{\lambda_c} < 1,7 . 1,6 . 10^{-19}$$

$$\boxed{\lambda_c > 730,1\,nm}$$

8)

$A = 10^{-6}\ cm^2$

$\lambda = 850\ nm$

$I = 0,1\ W/cm^2$

$I_S = 1\ pA$

$\eta = 0,8$

a) $P_L = I A = 0,1 \cdot 10^{-6} \Rightarrow \boxed{P_L = 10^{-7}\ W}$

$$I_L = \frac{\eta \cdot e \cdot P_L \cdot \lambda}{h c} = \frac{0,8 \cdot 1,6 \cdot 10^{-19} \cdot 10^{-7} \cdot 850 \cdot 10^{-9}}{6,62 \cdot 10^{-34} \cdot 3 \cdot 10^{8}} \Rightarrow I_L = 1,08$$

$$I_L = \frac{1,088 \cdot 10^{-32}}{19,86 \cdot 10^{-26}} \Rightarrow \boxed{I_L = 54,78\ nA}$$

b) $$r = \frac{I_L}{P_L} = \frac{54,78 \cdot 10^{-9}}{10^{-7}} \Rightarrow \boxed{r = 0,54\ A/W}$$

c) $$I_e = I_S\left(e^{\frac{eV}{k_B T}} - 1\right) \Rightarrow \boxed{I_e = 0A} \quad (V = 0V)$$

d) $$I_e = I_S\left(e^{\frac{eV}{k_B T}} - 1\right) \Rightarrow I_e = -I_S = |I_S| \Rightarrow \boxed{I_e = 1pA}$$