(a)

(1) $L = 100\,\mu m$. $W = 1\,\mu m$  $\Gamma = 1\%$  $\lambda = 1\,\mu m$

$t = 10\,nm$

$R_1 = 100\%$, $R_2 = 50\%$ . $n_{eff} = 3$

$\alpha_i = 10\ cm^{-1}$

$$\alpha_m = \frac{1}{2L} \ln \frac{1}{R_1 R_2} = 34.6\ cm^{-1}$$

$$g_{th} = \frac{1}{\Gamma}(\alpha_i + \alpha_m) = 4460\ cm^{-1}$$

(b) $$\tau_p = \frac{1}{v_g \alpha}$$

$$v_g = \frac{c}{n_{eff}} = 10^{10}\ cm/sec$$

$$\alpha = \alpha_i + \alpha_m$$

$$\tau_p = 2.2\ ps$$

(c) $$Q = \omega\tau = \left(2\pi \frac{c}{\lambda}\right)\left(\frac{n_{eff}}{c \cdot \alpha}\right) = \frac{2\pi n_{eff}}{\lambda \cdot \alpha}$$

$$= 4224$$

(d) $$\eta = \frac{\alpha_m}{\alpha_i + \alpha_m} = \frac{34.6}{44.6} = 77.6\%$$

$$R = \eta \frac{\hbar\omega}{q} = 0.96\ W/A$$

$$\hbar\omega \cong E_g = \frac{1.24}{\lambda} = 1.24\ eV$$

(e) $g(N) = g_0 \ln\left(\frac{N}{N_{tr}}\right)$ . $g_0 = 5000\ cm^{-1}$

$$N = N_{tr}\, e^{\frac{g_{th}}{g_0}} = 10^{18} \times 2.4 = 2.4 \times 10^{18}\ cm^{-3}$$

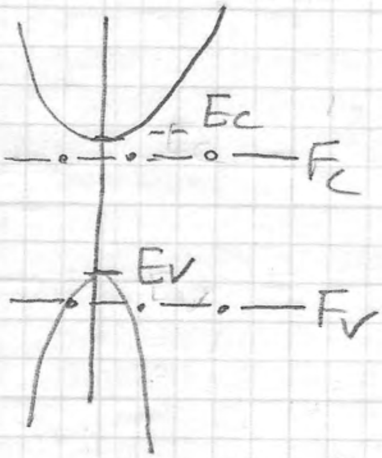
$$I_{th} = \frac{qN}{\tau} \times t \cdot L \cdot W = 0.38\ mA$$ #

2. $m_e^* = 0.2\, m_0 \qquad L_z = 10\text{ nm}$

$m_h^* = 0.1\, m_0$

(a)

(b)




(c) Let $\Delta = \dfrac{E_c - F_c}{k_B T}$

$$N_c^{2d} \cdot e^{-\Delta} = N_v^{2d} \cdot \Delta$$

$$e^{-\Delta} \approx 1 - \Delta = \frac{m_h^*}{m_e^*} \Delta = \frac{1}{2} \Delta$$

$$\Rightarrow \Delta = \frac{2}{3}$$

$$\Rightarrow E_c - F_c = \frac{2}{3} \times 26\text{ meV} = 17.3\text{ meV}.$$

(d) $$N_{tr} = N_v^{2d} \cdot \Delta = \frac{m_h^* k_B T}{\pi \hbar^2 \cdot L_z} \cdot \Delta$$

$$= 0.1\, N_0^{2d} \cdot \Delta$$

$$= 0.1 \times 10^{19} \times 0.67 = 6.7 \times 10^{17}\text{ cm}^{-3}$$

3. (a) $E_{e1} = \frac{\hbar^2}{2m_e^*}\left(\frac{\pi}{L_z}\right)^2 = \left(\frac{m_0}{m_e^*}\right) \cdot E_0$ , $E_0 = \frac{\hbar^2}{2m_0}\left(\frac{\pi}{L_z}\right)^2$

$= 3.7 \text{ meV}$

$E_{e2} = 4E_{e1}$

$\Delta E_e = E_{e2} - E_{e1} = 3E_{e1} = 3 \times 10 \times 3.7 \text{ meV}$

$= 111 \text{ meV}$

$\lambda = \frac{1.24}{0.111} = 11.2\ \mu m$

(b). $N_{min} = \rho_e^{2d} \cdot \Delta E_c = \frac{m_e^*}{\cancel{\pi} \cancel{\hbar^2} L_z} \cdot \frac{\cancel{\hbar^2}}{2\cancel{m_e^*}} \frac{\pi^{\cancel{2}}}{L_z^2} \cdot 3$

$= \frac{3\pi}{2L_z^3} = 4.7 \times 10^{18} \text{ cm}^{-3}$

(c) $\Delta E_h = \frac{m_e^*}{m_h^*} \cdot \Delta E_e = \frac{1}{5} \times 111 \text{ meV} = 22.2 \text{ meV}$

$\lambda = \frac{1.24}{0.022} = 56\ \mu m$

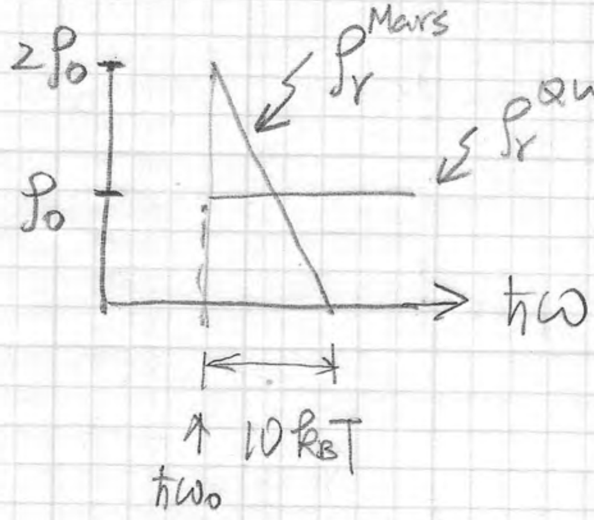
(d) Peak absorption $\alpha_N \propto \omega_N N_{min}$

$\alpha_p \propto \omega_p P_{min}$

$N_{min} = P_{min} = \frac{3\pi}{2L_z^3}$

$\frac{\alpha_N}{\alpha_p} = \frac{\omega_N}{\omega_p} = \frac{\lambda_p}{\lambda_N} = 5$ *

4.




$$\rho_0 = \frac{m^*_{r,QW}}{\pi \hbar^2 L_z}$$

(a) $$g^{QW}_{max} = C_0 |\hat{e}\cdot\vec{P}_{cv}|^2 \underbrace{\rho_r^{QW}(\hbar\omega_0)}_{=\rho_0} \underbrace{f_g(\hbar\omega_0)}_{=1}$$

$$g^{Mars}_{max} = C_0 |\hat{e}\cdot\vec{P}_{cv}|^2 \underbrace{\rho_r^{Mars}(\hbar\omega_0)}_{=2\rho_0} \cdot \underbrace{f_g(\hbar\omega_0)}_{=1}$$

$\Rightarrow$ Mars semiconductor has higher maximum gain.

(b) The peak optical gain always happen at $\hbar\omega = \hbar\omega_0$. For $\Delta F = \hbar\omega_0 + k_B T$, the Fermi Inversion functions above have the same value. Therefore

$$\frac{g_p^{Mars}}{g_p^{QW}} = \frac{\rho_r^{Mars}(\hbar\omega_0)}{\rho_r^{QW}(\hbar\omega_0)} = \frac{2\rho_0}{\rho_0} = 2 \quad \#$$