EE 232 Lightwave Devices
Lecture 13: Quantum Well Laser

Reading: Chuang, Sec. 10.3

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Quantum Well Gain

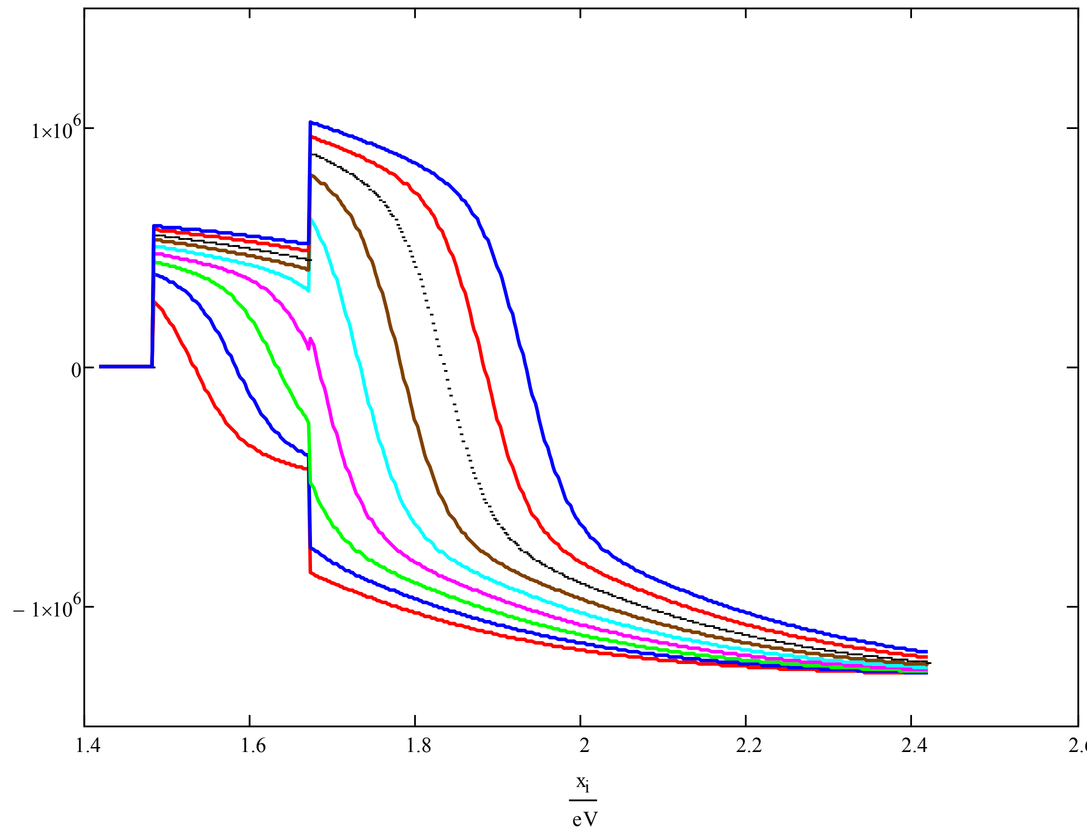
QW Material Gain:

$$g(\hbar\omega) = C_0 \left| \hat{e} \cdot \vec{P}_{cv} \right|^2 \rho_r^{2d}(\hbar\omega) f_g(\hbar\omega)$$

$$C_0 = \frac{\pi e^2}{n_r c \varepsilon_0 m_0^2 \omega}$$

$$\left| \hat{e} \cdot \vec{P}_{cv} \right|^2 \approx \frac{m_0}{6} E_p$$

$$\rho_r^{2d}(E) = \frac{m_r^*}{\pi \hbar^2 L_z} \sum_{n=1}^{\infty} H(E - E_{en})$$



Advantages of Quantum Well Lasers

(1) Low threshold current density:

Compare fundamental material property

$\rightarrow$ Transparency current density

$$J_{tr}^{bulk} = \frac{qN_{tr}^{bulk}}{\tau} d_{active}$$

$$J_{tr}^{QW} = \frac{qN_{tr}^{QW}}{\tau} L_z$$

Since $N_{tr}^{bulk} \approx N_{tr}^{QW} \Rightarrow \boxed{\frac{J_{tr}^{QW}}{J_{tr}^{bulk}} = \frac{L_z}{d_{active}}} \sim \frac{10\ \text{nm}}{100\ \text{nm}} \sim 10\%$

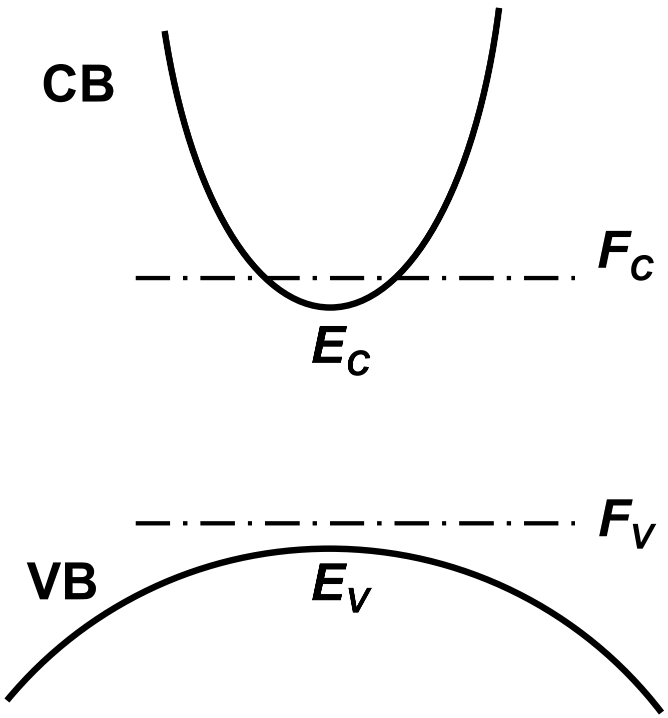
(2) Higher differential gain $\rightarrow$ Larger bandwidth:

Resonance frequency: $\omega_R = \sqrt{\frac{v_g a S}{\tau_p}} \propto \sqrt{a} = \sqrt{\frac{\partial g}{\partial N}}$

(3) Lower chirp:

Smaller wavelength shift when the laser is directly modulated

Transparency Carrier Concentration in QW



Transparency Condition
(Bernard-Duraffourg
Inversion Condition)

$$\Delta F = F_C - F_V = E_g$$

At transparency: $F_C - F_V = E_{e1} - E_{h1}$

or $F_C - E_{e1} = F_V - E_{h1}$

Let $\Delta = \dfrac{F_C - E_{e1}}{k_B T} = \dfrac{F_V - E_{h1}}{k_B T}$

Electron concentration: $\because F_C > E_{e1}$

$$N = \frac{m_e^* k_B T}{\pi \hbar^2 L_z}\left(\frac{F_C - E_{e1}}{k_B T}\right) = N_C^{2d} \cdot \Delta$$

Hole concentration: $\because F_V > E_{h1}$

$$P = \frac{m_h^* k_B T}{\pi \hbar^2 L_z} e^{-\frac{F_V - E_{h1}}{k_B T}} = N_V^{2d} e^{-\Delta}$$

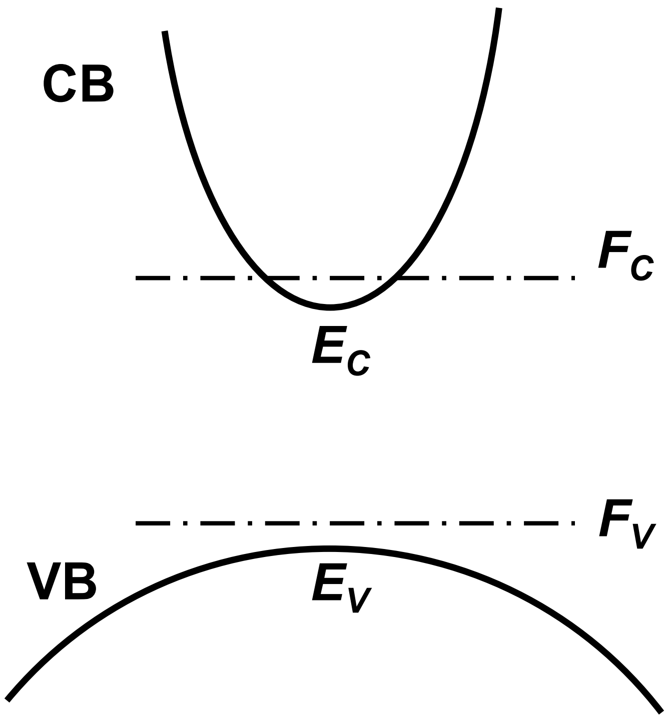
$$N = P \;\Rightarrow\; \Delta = \frac{m_h^*}{m_e^*} e^{-\Delta} \Rightarrow \text{Solve } \Delta$$

For GaAs ($m_e^* = 0.067 m_0, m_h^* = 0.5 m_0$)

$\Delta = 1.56,\;\; N = N_C^{2d} \cdot \Delta = 10^{18}\ \text{cm}^{-3}$

Note: N is independent of L_z

Transparency Carrier Concentration in Bulk



Transparency Condition

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or $F_C - E_C = F_V - E_V$

Let $\Delta = \dfrac{F_C - E_C}{k_B T} = \dfrac{F_V - E_V}{k_B T}$

Electron concentration: $\because F_C > E_C$

$$N = 2\left(\frac{\pi m_e^* k_B T}{2\pi^2\hbar^2}\right)^{3/2} \frac{4}{3\sqrt{\pi}}\left(\frac{F_n - E_C}{k_B T}\right)^{3/2} = N_C \cdot \frac{4}{3\sqrt{\pi}}\Delta^{3/2}$$

Hole concentration: $\because F_V > E_{h1}$

$$P = 2\left(\frac{\pi m_h^* k_B T}{2\pi^2\hbar^2}\right)^{3/2} e^{-\frac{F_V - E_V}{k_B T}} = N_V e^{-\Delta}$$

$$N = P \Rightarrow \frac{4}{3\sqrt{\pi}}\Delta^{3/2} = \left(\frac{m_h^*}{m_e^*}\right)^{3/2} e^{-\Delta} \Rightarrow \text{Solve } \Delta$$

For GaAs ($m_e^* = 0.067 m_0, m_h^* = 0.5 m_0$)

$\Delta = 2.15, \quad N = 9 \times 10^{17} \text{ cm}^{-3}$