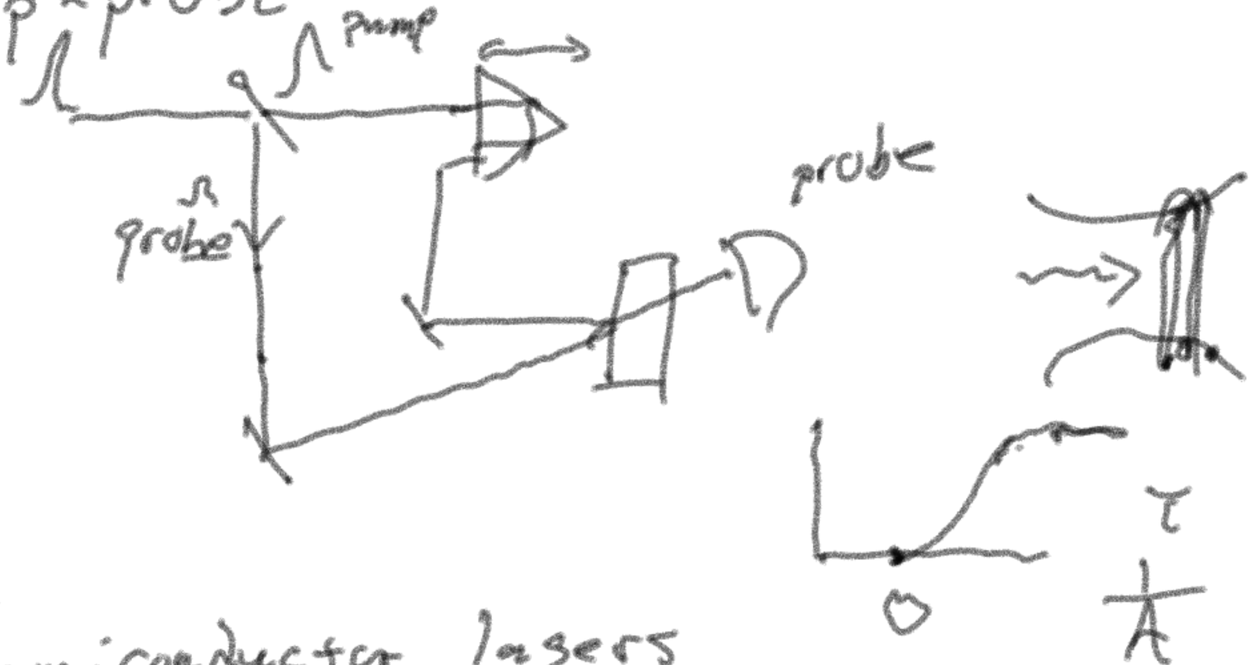
MRL tour

Pump-probe

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semiconductor lasers

$$\gamma(\nu) = A \underbrace{\frac{\lambda}{8\pi n^2}}_{\text{like} \sim \sigma} \underbrace{\lambda\,\rho(\nu)}_{g(\nu)} \underbrace{\left[f_c(E_2) - f_v(E_1)\right]}_{N_2 - \frac{g_2}{g_1} N_1}$$


find $\frac{dN}{dt}$, $\frac{dI}{dz}$

from atomic systems

$$\frac{1}{d(N)} \frac{d(\Delta n)}{dt} = -A \underbrace{\rho_{int}}_{\text{\# of states available}} f_c(E_2)\left(1 - f_v(E_1)\right) \quad \text{spont. em.}$$

$$-B \rho_{int} \rho_\nu f_c(E_2)\left(1 - f_v(E_1)\right) \quad \text{stimulated emission}$$

$$+B \rho_{int} \rho_\nu \left(1 - f_c(E_2)\right) f_v(E_1) \quad \text{absorption}$$

$$R_{sp}(\nu) = A\,\rho_{int}(\nu) \frac{1}{1 + \exp\left(\frac{E_2 - F_n}{kT}\right)} \cdot \frac{\exp\left(\frac{E_1 - F_p}{kT}\right)}{1 + \exp\left(\frac{E_1 - F_p}{kT}\right)}$$

$$\simeq e^{-\left(\frac{E_2-E_1}{kT}\right)} e^{\left(\frac{F_c-F_v}{kT}\right)}$$

qV

applied voltage

net emission
stimulated - absorbed

$$R_{em}(\nu) = B\,\rho_{int}\,\rho_\nu\,[f_c(E_2) - f_v(E_1)]$$


$$I_\nu = (\rho_\nu)\left(\frac{c}{n}\right)$$

$\frac{W}{cm^2}$ $\quad \frac{J}{cm^3}$ $\quad cm/s$

[W]

$$S\,[\overbrace{I_\nu(z+dz) - I_\nu(z)}^{dI}] = R_{em}\cdot d\nu \cdot \overbrace{(\text{volume})}^{S\cdot dz}$$

$$A/B = \frac{8\pi h}{\lambda^3}$$

$$\frac{dI}{dz} = \underbrace{A\left(\frac{\lambda_0^2}{8\pi n^2}\right)\left(h\,\rho_{int}(\nu)\right)[\underbrace{f_c(E_2) - f_v(E_1)}_{\text{population inversion}}]}_{\gamma_0}\, I$$

$$I(l) = I_0\, e^{\gamma_0 l}$$

$$f_c(E_2) > f_v(E_1)$$

$$\downarrow$$

$$E_2 - F_n < E_1 - F_p$$

$$F_n - F_p > \underbrace{E_2 - E_1}_{h\nu}$$

$$\boxed{\overbrace{F_n - F_p}^{qV} > h\nu > E_g}$$

Bernard - Duraffourg condition

$\#$ of carriers

$$n_e = \int_{E_c}^{\infty} \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2}\sqrt{E-E_c}\,\frac{1}{1+e^{\frac{E-E_F}{kT}}}\,dE$$

$\approx 10^{18}-10^{19}\ \text{cm}^{-3}$

$$I = \frac{dQ}{dt} = \frac{en\,(\text{volume})}{\tau}$$

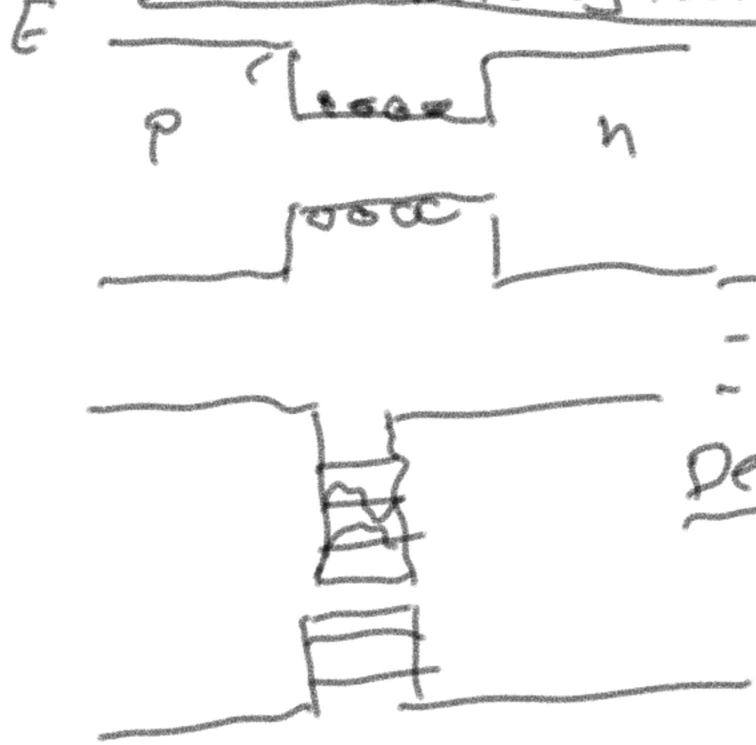

$$I = \frac{en(wLd)}{\tau}$$

$$J = ed\frac{n}{\tau}\ \left[A/cm^2\right]$$

$$= (1.6\times10^{-19})(10^{-4})(10^{26}) \approx 5\ kA/cm^3$$

very high

Double heterojunction




$1\ \mu m \rightarrow 0.1\ \mu m$

$J \downarrow$ 10x - Reduction

- easier to inject carriers
- barriers (diff n)
- mode confinement

Derive DOS

assume infinite well

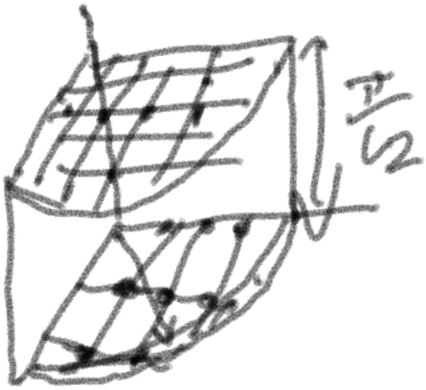

energy conservation

$$\frac{\hbar^2 k^2}{2m_r} = h\nu - E_g$$

$$\frac{\hbar^2}{2m^*}(k_x^2+k_y^2+k_z^2) \approx h\nu - E_g$$

$$\frac{\pi}{L_x} \quad \frac{\pi}{L_y} \quad \frac{\pi}{L_z}$$

$E_1$




where $k_x^2+k_y^2 = k_{\parallel}^2$

$$N_k\,dk = \frac{\frac{1}{4}(2\pi k_{\parallel}\,dk_{\parallel})\left(\frac{\pi}{L_z}\right)\cdot 2}{\frac{\pi}{L_x}\cdot\frac{\pi}{L_y}\cdot\frac{\pi}{L_z}}$$

states

$$N_k\,d_k = L_xL_yL_z\frac{1}{\pi^2}k_{\parallel}\,dk_{\parallel}\,\frac{\pi}{L_z}$$

$$k^2 = \left(\frac{\pi}{L_z}\right)^2 + k_{\parallel}^2 \qquad k = \left(\left(\frac{\pi}{L_z}\right)^2 + k_{\parallel}^2\right)^{1/2}$$

$$2k_{\parallel}\,dk = 2k\,dk \qquad \frac{dk}{dk_{\parallel}}$$

mode density

$$\frac{N_k\,dk}{L_xL_yL_z} = \rho_k\,dk = \frac{1}{\pi^2}k\,dk\,\frac{\pi}{L_z}$$

$$E = \frac{(\hbar k)^2}{2m_r} \qquad E > E_1$$

$$k = \frac{\sqrt{2m_rE}}{\hbar}$$

$$\rho_k\,dk = \rho_E\,dE$$

$$\frac{dk}{dE} = \frac{1}{\hbar}\sqrt{\frac{m}{2E}}$$

$$\rho_E\,dE = \frac{1}{\pi^2}\frac{\sqrt{2mE}}{\hbar}\cdot\frac{1}{\hbar}\sqrt{\frac{m}{2E}}\,dE\,\frac{\pi}{L_z}$$

$$dk = \frac{1}{\hbar}\sqrt{\frac{m}{2E}}\,dE$$

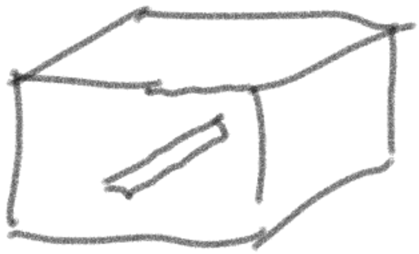
$$\rho_E = \frac{m_r}{\pi \hbar^2 L_z}$$ constant (independent of energy)

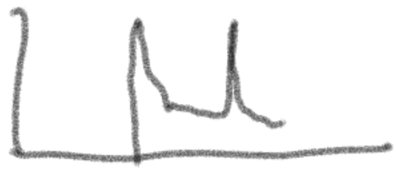
$h\nu = E_g + E_n + E_p$

2D

$$\gamma_{int}(\nu) = \frac{m_r}{\pi \hbar^2 L_z} \Theta(h\nu - (E_g + E_n + E_p))]$$

1D





0D quantum dot

See semiconductor_laser_figures.pdf