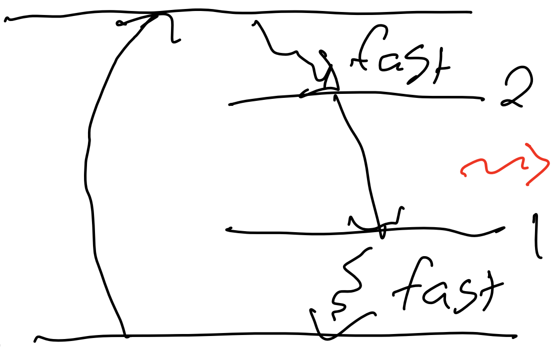
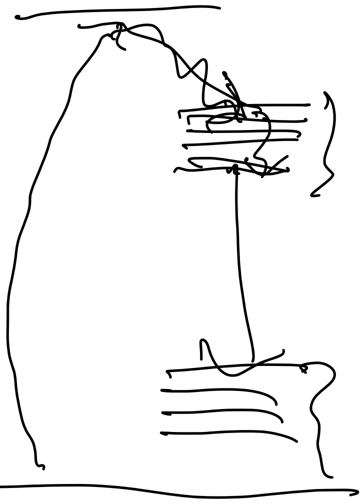
PHYS 525 Lasers - Lecture ~~#2~~ 4

3-level

4-level



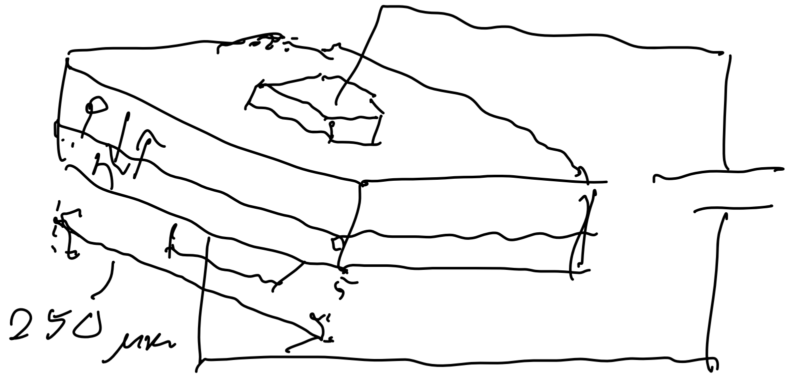
more realistic



(see handouts for examples)

Semiconductor lasers

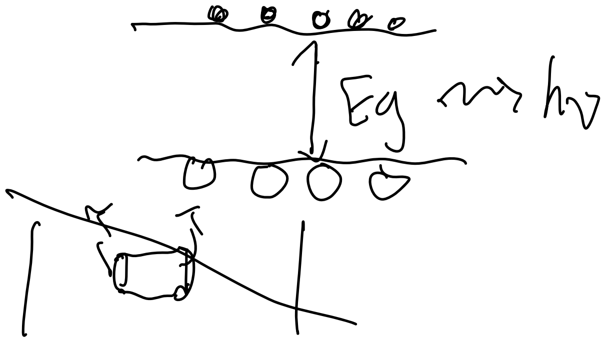
GaAs



forward bias

p - electron poor

n - electron rich



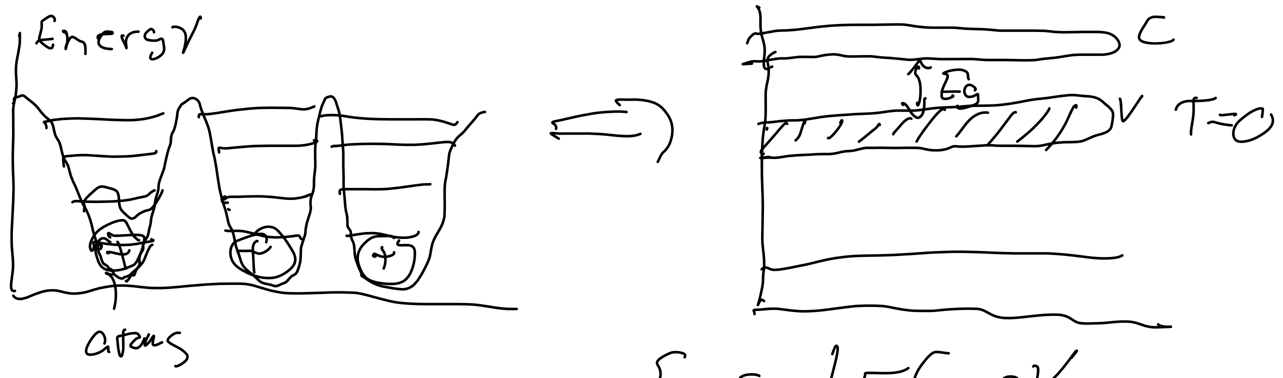
$R \approx 30\%$

$$R_1 R_2 e^{2(\gamma-\alpha)\ell_g} \geq 1$$

$$(\gamma-\alpha) \geq \frac{1}{2\ell_g} \ln\left(\frac{1}{R_1 R_2}\right)$$

semiconductor: without trying hard → $\approx 50\ \mathrm{cm}^{-1}$

most other types → $(0.1 \sim 1.0\ \mathrm{cm}^{-1})$



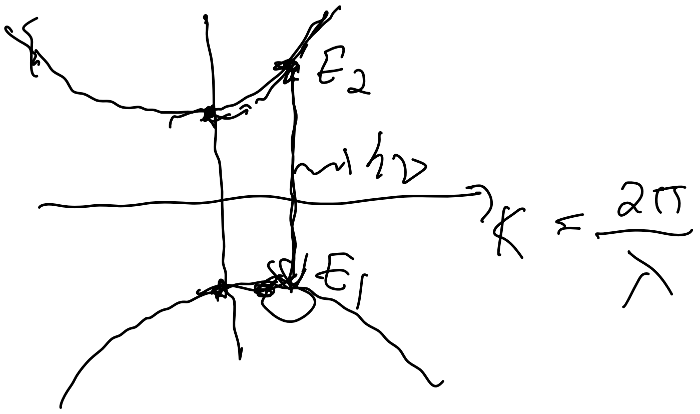
$E_g = 1 \sim 6$ eV

$$E_c = E_c^{(0)} + \underbrace{\frac{p^2}{2m_e^*}}$$ effective mass (material properties)

$$p = \frac{h}{\lambda}\frac{2\pi}{2\pi} = \hbar k$$

$$E_2 \approx E_c(0) + \frac{\hbar^2 k^2}{2m_e^*}$$

$$E_1 \approx E_v(0) - \frac{\hbar^2 k^2}{2m_h^*}$$



$E_2 - E_1 = h\nu$ energy conservation

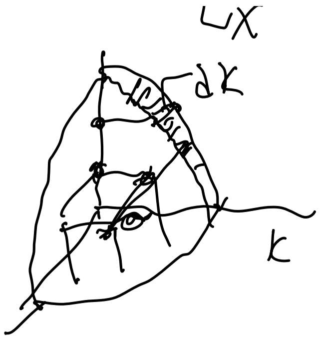
$\hbar k_e - \hbar k_h \approx \cancel{\hbar k_\nu} \approx 0$ momentum conservation

$$E_2 - E_1 = h\nu = (E_c - E_v) + \frac{\hbar^2}{2}\underbrace{\left(\frac{1}{m_e^*} + \frac{1}{m_h^*}\right)}_{\text{reduced effective mass } \frac{1}{m_r^*}} k^2$$

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

How many states are allowed?

$$k_x = \frac{\pi}{L_x} n_x \quad k_y = \frac{\pi}{L_y} n_y \quad k_z = \frac{\pi}{L_z} n_z$$



Volume $\dfrac{\frac{1}{8}4\pi k^2\,dk}{\left(\frac{\pi}{L}\right)^3}$ L^3

$\rho(k)dk = \dfrac{k^2}{\pi^2}dk$ density of states

$\rho(E)\,dE =$

$$\boxed{\rho_{jnt}(\nu) = \frac{1}{2\pi^2}\left(\frac{2m_r^*}{\hbar^2}\right)^{3/2}\sqrt{h\nu - E_g}}$$

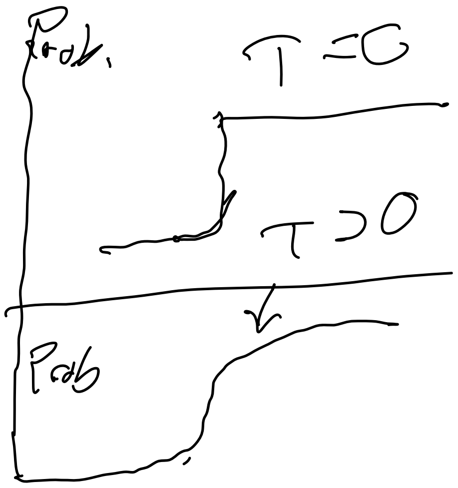
Joint density of states

3-D case

$$\gamma \propto \rho_{jnt}(\nu)\left(f(E_2) - f(E_1)\right)$$

Fermi-Dirac distribution

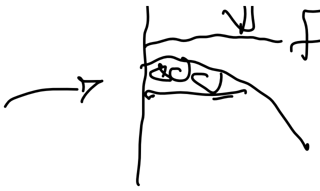
$$f(E) \approx \frac{1}{1+e^{(E-E_f)/kT}}$$



Apply voltage - not in equilibrium

Quasi-Fermi levels

$$f_c(E_2) = \frac{1}{1+e^{\frac{(E-F_n)}{kT}}}$$



$$f_c(E_1) = \frac{1}{1 + e^{\frac{(E - F_p)}{kT}}}$$

Semiconductor

$$\gamma(\nu) = A_{21} \frac{\lambda_0^2}{8\pi n^2} h \rho_{int}(\nu) \left[f_c(E_2) - f_c(E_1) \right]$$

atomic

$$\gamma(\nu) \approx A_{21} \frac{\lambda_0^2}{8\pi n^2} g(\nu) \left(N_2 - \frac{g_2}{g_1} N_1 \right)$$