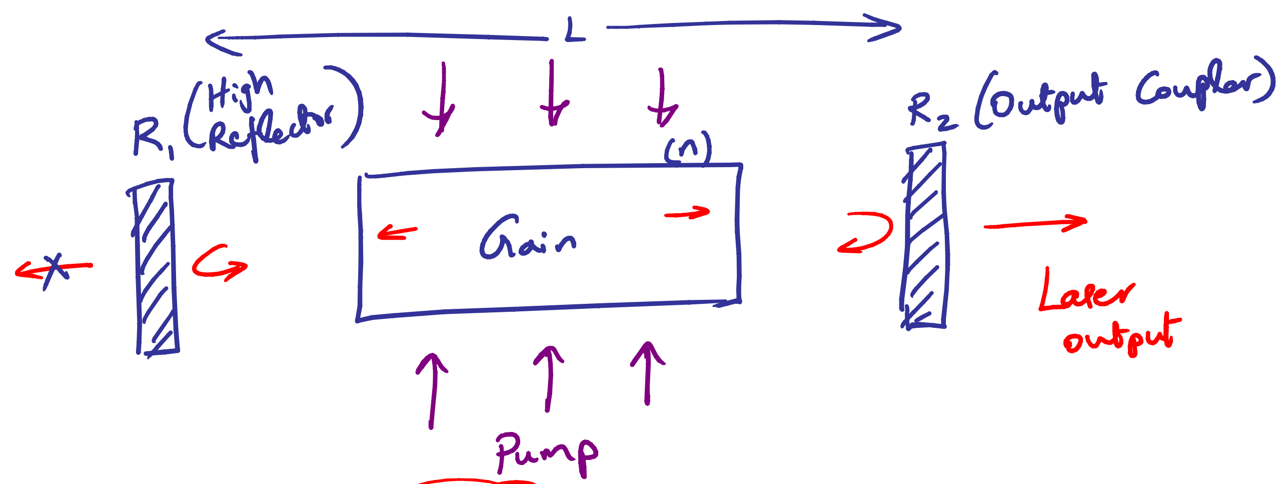
Note Title 9/17/2018

LO : Identify the fundamental principles of laser & quantify their characteristics



Laser oscillation condition

$$E_0 \, e^{+\gamma/2 \cdot 2L} \, e^{-\alpha_{int}/2 \cdot 2L} \sqrt{R_1 R_2} \cdot e^{-j k_0 n \cdot 2L} = E_0$$

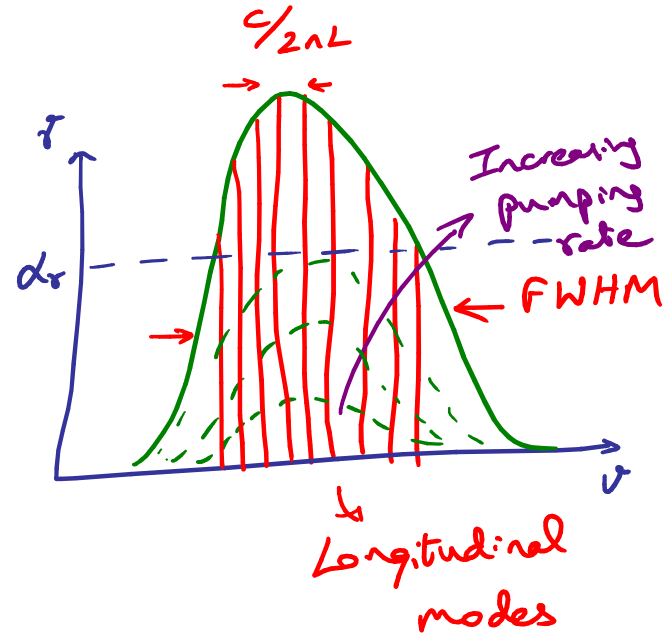
(1) $$e^{\gamma L} e^{-\alpha_{int} L} \sqrt{R_1 R_2} = 1$$

$$k_0 \cdot n \cdot 2L = 2\pi m$$ (2)

1 $\Rightarrow$ $$\boxed{\gamma = \alpha_{int} + \frac{1}{2L}\ln\left(\frac{1}{R_1R_2}\right)} = \alpha_r$$

2 $\Rightarrow$ $$\frac{2\pi}{\lambda}\cdot n\cdot 2L = 2\pi m$$

$$\boxed{\nu = m\cdot\frac{c}{2nL}}$$



For laser oscillation, $\gamma > \alpha_r$

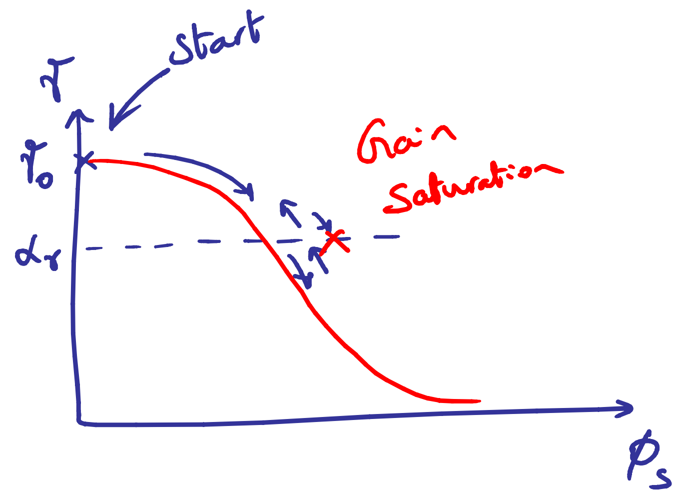
Assume $\sigma_e = \sigma_a = \sigma$, $\sigma N > \alpha_r$

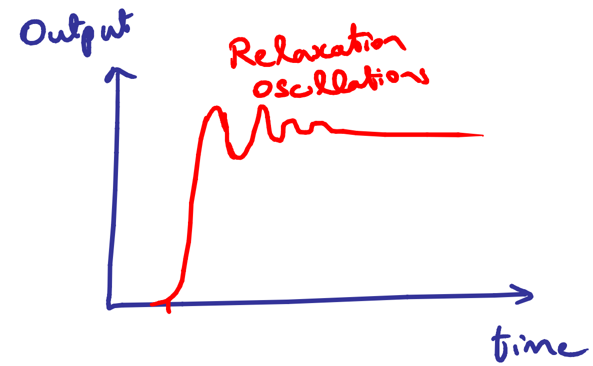
Threshold inversion $N_m = \dfrac{\alpha_r}{\sigma}$

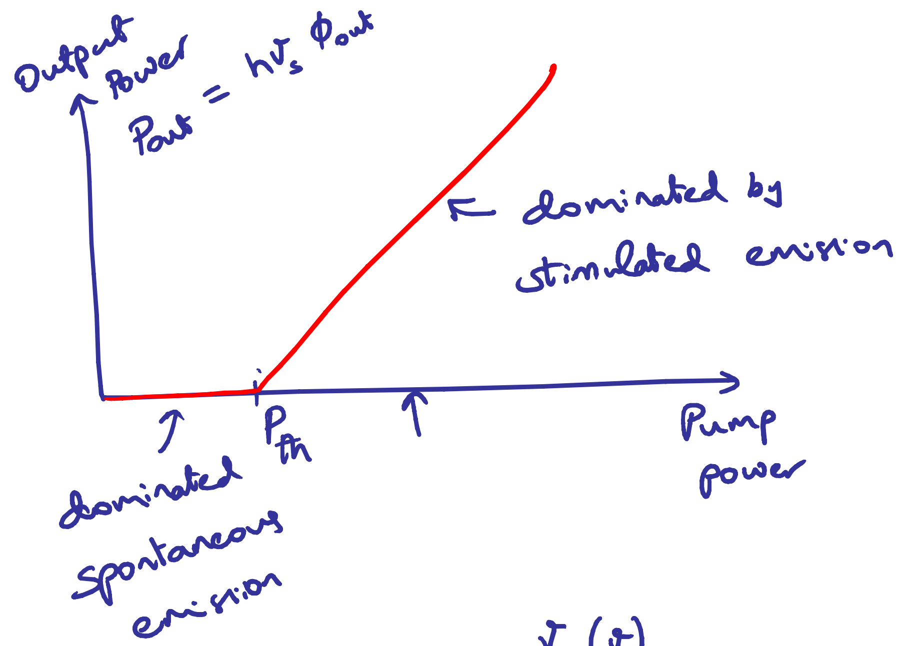
Avg. Photon lifetime, $\tau_{ph} \propto \dfrac{1}{\alpha_r}$

$$\tau_{ph} = \frac{1}{c \cdot \alpha_r} \Rightarrow \alpha_r = \frac{1}{c \cdot \tau_{ph}}$$

$$\Rightarrow \boxed{N_{th} = \frac{1}{c \cdot \tau_{ph} \cdot \sigma}}$$







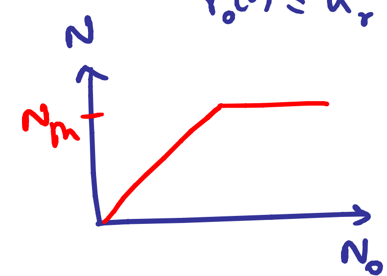
Output @ R_2

$\phi_{out} \propto \phi_s$

$$= \frac{\alpha_{m2}}{\alpha_r} \phi_s$$

$$\frac{\gamma_0(\nu)}{1 + \phi_s(\nu)/\phi_{sat}} = \alpha_r \quad \text{at threshold}$$

$$\frac{\gamma_0(\nu)}{1+\phi_s(\nu)/\phi_{sat}} = \alpha_r \implies \phi_s(\nu) = \begin{cases} \phi_{sat} \cdot \left[\dfrac{\gamma_0(\nu)}{\alpha_r} - 1\right] & \gamma_0(\nu) > \alpha_r \\ 0 & \gamma_0(\nu) \le \alpha_r \end{cases}$$

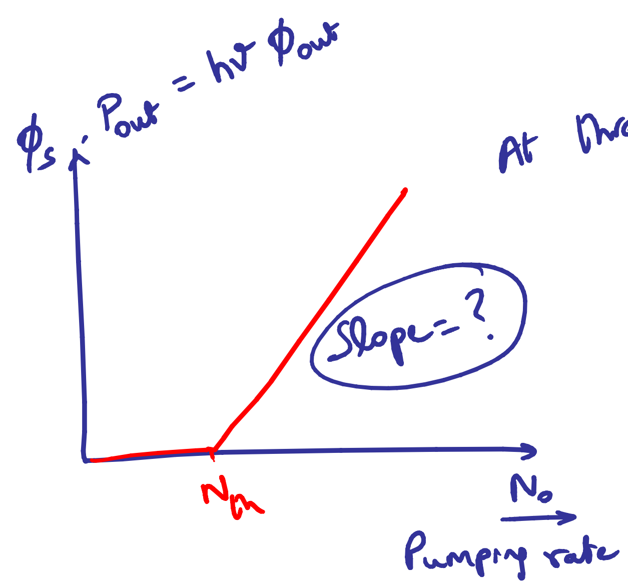


At threshold,

$$N_{th} \cdot \sigma(\nu) = \alpha_r$$

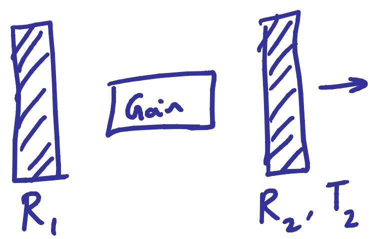
Photon flux

$$\phi_s(\nu) = \begin{cases} \phi_{sat}\left(\dfrac{N_0}{N_{th}} - 1\right) & N_0 > N_{th} \\ 0 & N_0 \le N_{th} \end{cases}$$



Output power, $P_{out} = \eta_e (P - P_{th})$

η_e ↓ slope efficiency



$$\eta_e = \frac{\alpha_{m2}}{\alpha_r}$$

$$\alpha_r = \alpha_{m1} + \alpha_{m2} + \alpha_{int}$$
$$= \frac{1}{c\tau_{ph}}$$

$$\alpha_{m2} = \frac{1}{2L} \ln\left(\frac{1}{R_2}\right)$$

$$\boxed{\eta_e = \frac{c\tau_{ph}}{2L} \ln\left(\frac{1}{R_2}\right)}$$

If $T_2 = 1 - R_2 << 1$

$$\ln\left(\frac{1}{R_2}\right) \simeq T_2$$

$$\eta_e \simeq \frac{\tau_{ph}}{\tau_{rt}} T_2$$

Optimum?

Optimization of Output Coupling.

Assume $R_1 = R_2$.

$$\phi_{out} = \frac{\phi_s}{2} \cdot T_2$$

$$= \frac{\phi_{sat} T_2}{2}\left(\frac{\gamma_0}{\alpha_r} - 1\right)$$

$$= \frac{\phi_{sat} T_2}{2}\left[\frac{\gamma_0 . 2L}{L_{ex} - \ln(1-T_2)} - 1\right]$$

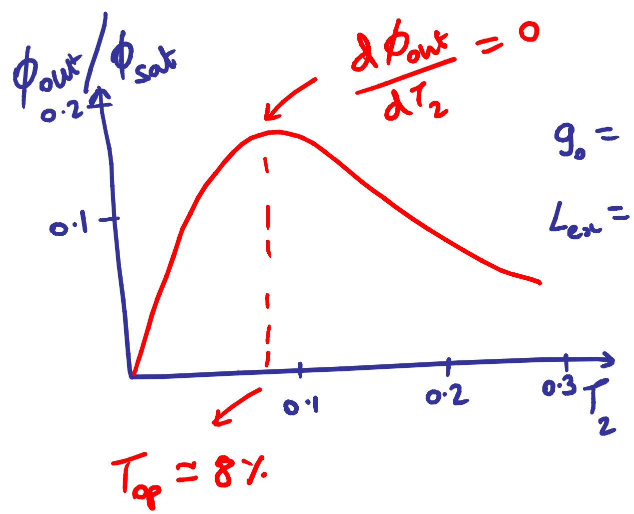
$$\alpha_r = \alpha_{int} + \alpha_{m1} + \alpha_{m2}$$

$$= \alpha_L + \frac{1}{2L}\ln\left(\frac{1}{R_2}\right)$$

$$= \alpha_L - \frac{1}{2L}\ln(1-T_2)$$

$$= \frac{1}{2L}\left[L_{ex} - \ln(1-T_2)\right]$$

$$L_{ex} = 2L(\alpha_{int} + \alpha_{m1})$$



$g_0 = 0.5$

$L_{ex} = 0.02$

$\frac{d\phi_{out}}{dT_2} = 0$ & when $T_2 \ll 1$

$$\ln(1-T_2) \simeq -T_2$$

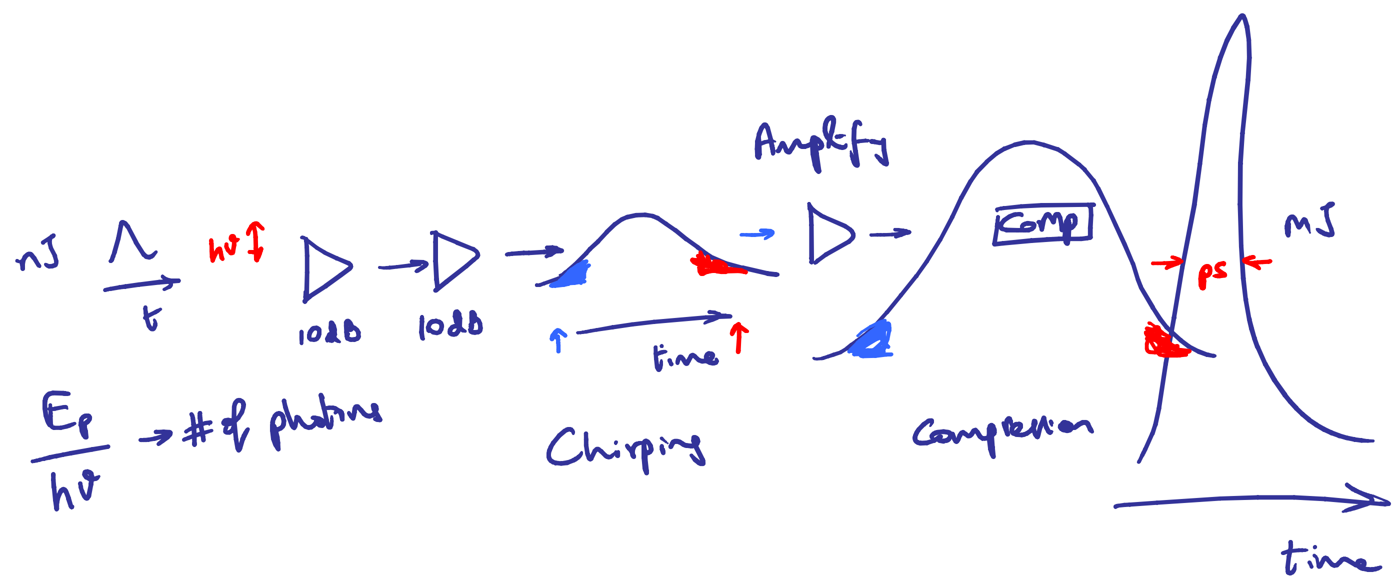
$$\boxed{T_{op} = (g_0 L_{ex})^{1/2} - L_{ex}}$$

$g_0 = \gamma_0 . 2L$

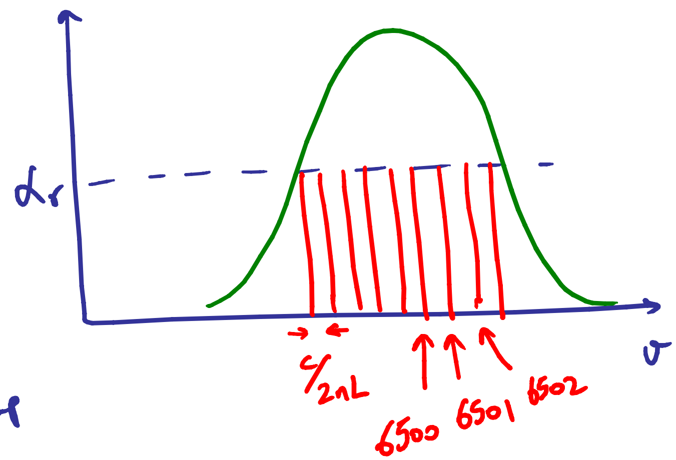
Gain factor

Chirped Pulse Amplification

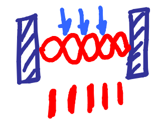
– Gerard Morou / Donna Strickland



$\frac{E_p}{h\nu} \rightarrow$ # of photons

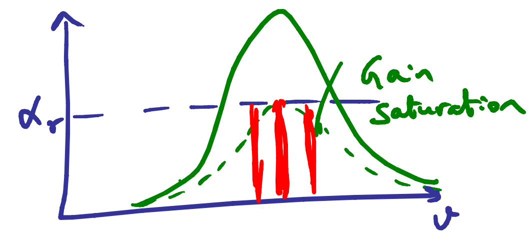


Spatial Hole Burning

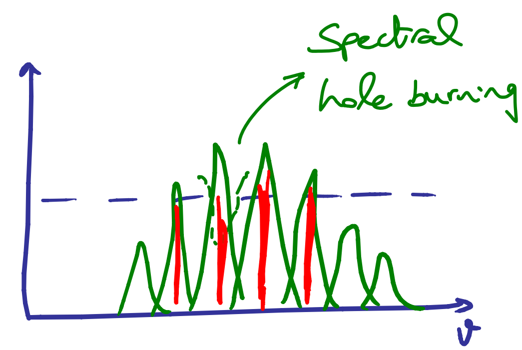


Homogeneous

Ex: Semiconductor



Inhomogeneous



Ex: Nd: glass