Electro-Optics

Theory of Lasers (3)

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Multimode Laser Oscillation

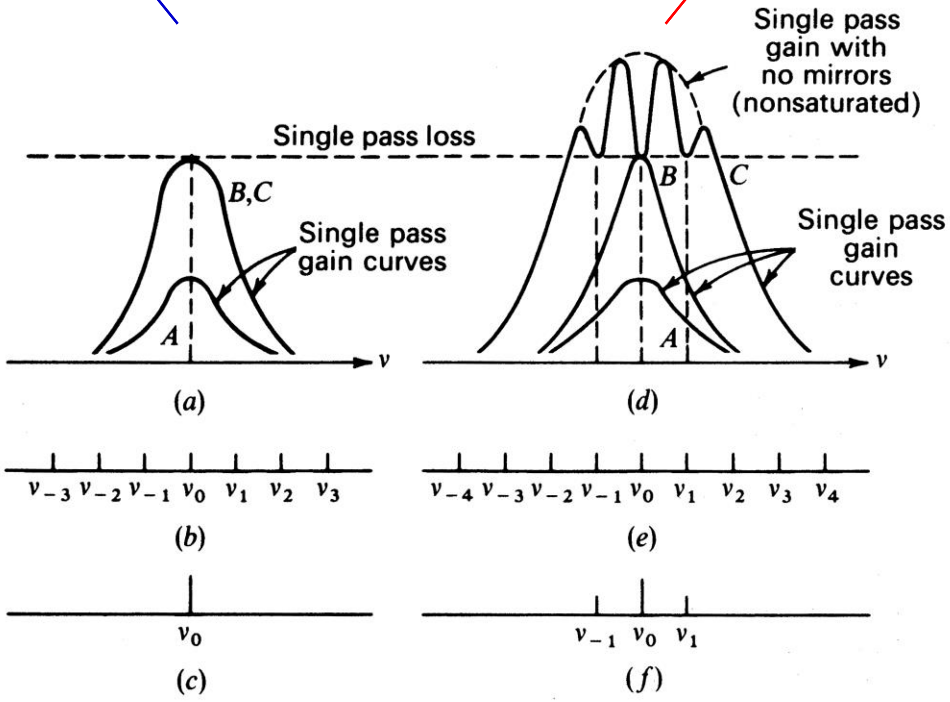
Laser oscillation condition:

$$\gamma_{th}(\nu) = \alpha - \frac{1}{l}\ln r_1 r_2 \quad \rightarrow \quad \gamma(\nu) = (N_2 - N_1)\frac{c^2}{8\pi n^2 \nu^2 \tau_{sp}} g(\nu)$$

$$\nu_{q+1} - \nu_q = \frac{c}{2nl}$$

Homogeneous atomic system:

Inhomogeneous atomic system:

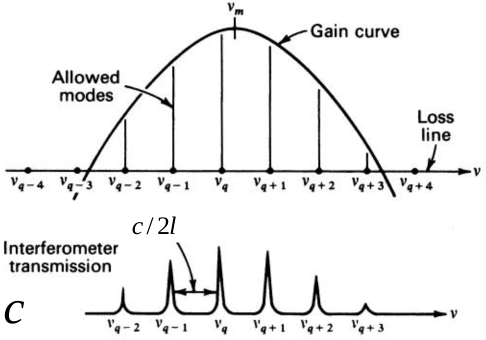


A. Yariv, *Optical Electronics*, 4th ed. Saunders, 1991.

Mode Locking (1)

Mode separation in an inhomogeneoulsy broadened system:

$$\omega_{q+1}-\omega_q = \frac{\pi c}{l} \equiv \omega \qquad \leftarrow\ n = 1$$



A. Yariv, *Quantum Electronics*, 3rd ed., Wiley, 1989.

Total electric field:

$$e(t) = \sum_n E_n e^{i[(\omega_0+n\omega)t+\phi_n]}$$

$$\leftarrow\ \omega_0 = m\pi c/l,\ \ T = 2\pi/\omega = 2l/c$$

In case E_n and ϕ_n are fixed (locked):

$$e(t+T) = \sum_n E_n \exp\left\{i\left[(\omega_0+n\omega)\left(t+\frac{2\pi}{\omega}\right)+\phi_n\right]\right\}$$

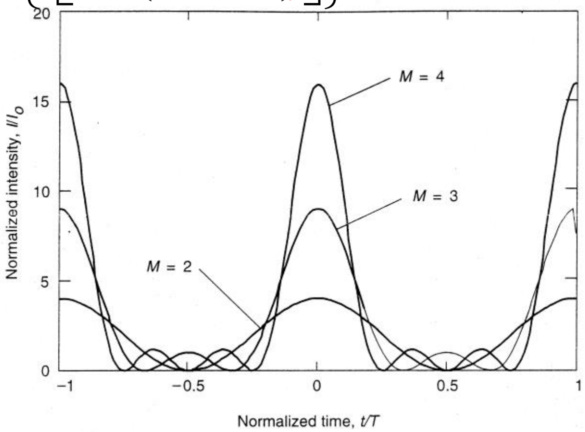
$$= \sum_n E_n \exp\{i[(\omega_0+n\omega)t+\phi_n]\}\exp\left\{i\left[\cancel{2\pi\left(\frac{\omega_0}{\omega}+n\right)}\right]\right\} \quad = e(t)$$

"Periodic"

Taking $E_\mathrm{n} = 1$ and $\phi_\mathrm{n} = 0$:

$$e(t) = \sum_{-(M-1)/2}^{(M-1)/2} \exp[i(\omega_0+n\omega)t]$$

$$= \exp(i\omega_0 t)\frac{\sin(M\omega t/2)}{\sin(\omega t/2)}$$



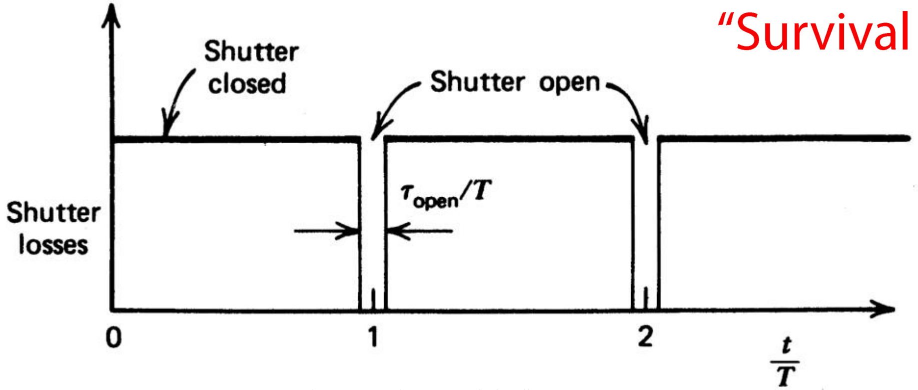
A. Yariv, *Quantum Electronics*, 3rd ed., Wiley, 1989.

Mode-Locked Lasers

Methods of mode locking: Loss (gain) modulation

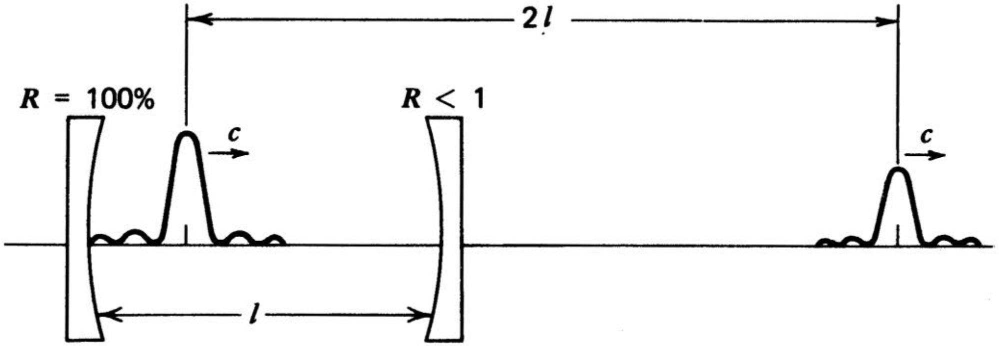
Active mode locking: EOM, AOM, etc.

Passive mode locking: Saturable absorber, e.g. dye, SESAM, etc.



"Survival of the fittest"

A. Yariv, *Quantum Electronics*, 3rd ed., Wiley, 1989.



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Q Switching (1)

Initially lasing is prohibited: $Q << 1$

Total number of photons in the cavity when Q is restored:

$$\frac{d\phi}{dt} = \phi\left(\frac{\gamma cL}{nl} - \frac{1}{t_c}\right) \quad \rightarrow \tau = \frac{t}{t_c}$$

Gain

Loss (Cavity decay time)

Total inversion

$$\rightarrow \frac{d\phi}{d\tau} = \phi\left(\frac{\gamma}{nl/cLt_c} - 1\right) = \phi\left(\frac{\gamma}{\gamma_{th}} - 1\right) \quad \rightarrow \gamma \propto \eta$$

$$\leftarrow \eta \equiv (N_2 - N_1)V$$

$$= \phi\left(\frac{\eta}{\eta_{th}} - 1\right)$$

Number of photons generated by induced emission

$$\rightarrow \frac{d\eta}{d\tau} = -2\phi\frac{\eta}{\eta_{th}}$$

$$\rightarrow \frac{d\phi}{d\eta} = \frac{\eta_{th}}{2\eta} - \frac{1}{2} \qquad \rightarrow \phi - \cancel{\phi_i} = \frac{1}{2}\left[\eta_{th}\ln\frac{\eta}{\eta_i} - (\eta - \eta_i)\right]$$

$$\rightarrow \phi \cong \frac{1}{2}\left[\eta_{th}\ln\frac{\eta}{\eta_i} - (\eta - \eta_i)\right]$$

Q Switching (2)

Final inversion: $t >> t_c$

$$\phi \cong \frac{1}{2}\left[\eta_{th} \ln \frac{\eta}{\eta_i} - (\eta - \eta_i)\right] \quad \rightarrow 0$$

$$\rightarrow \frac{\eta_f}{\eta_i} = \exp\left(\frac{\eta_f - \eta_i}{\eta_{th}}\right)$$

→ To be solved graphically or numerically

Instantaneous power output:

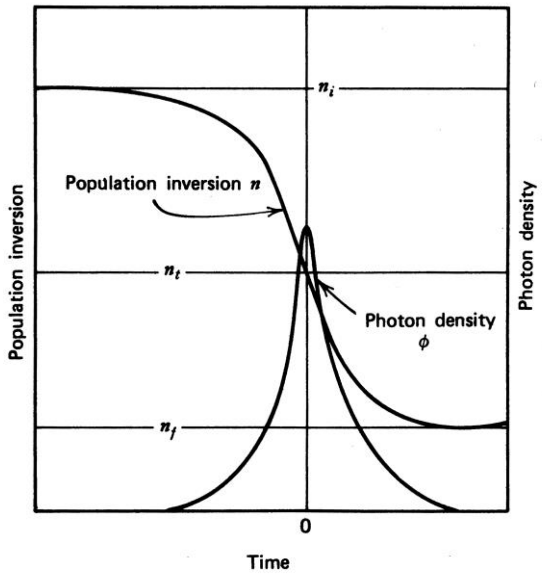
$$P = \phi h\nu / t_c$$

$$= \frac{h\nu}{2t_c}\left[\eta_{th} \ln \frac{\eta}{\eta_i} - (\eta - \eta_i)\right]$$

Peak power output:

$$\rightarrow \partial P / \partial \eta = 0 \quad \rightarrow \eta = \eta_{th}$$

$$\rightarrow P_{peak} = \frac{h\nu}{2t_c}\left[\eta_{th} \ln \frac{\eta_{th}}{\eta_i} - (\eta_{th} - \eta_i)\right]$$



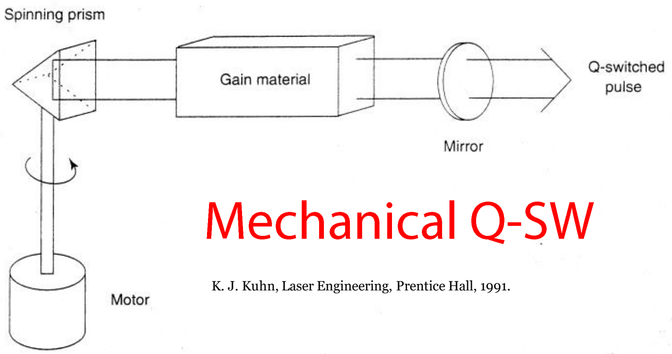
A. Yariv, *Quantum Electronics*, 3rd ed., Wiley, 1989.

Q-Switched (Giant Pulse) Lasers (1)

Methods of Q switching:

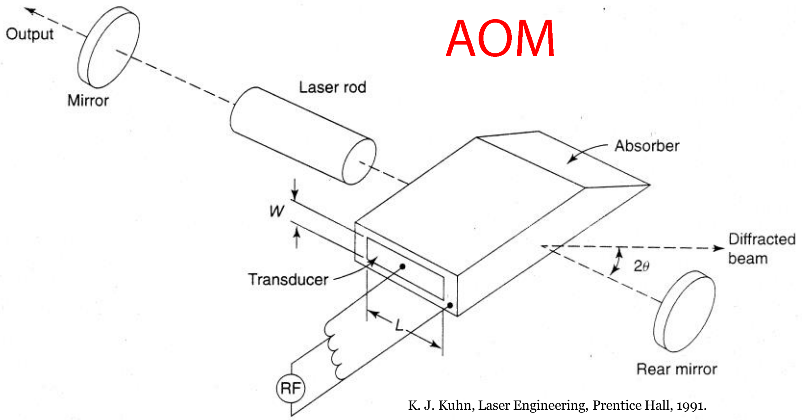
Active Q switching → Mechanical Q-SW, EOM, AOM, etc.

Passive Q switching → Saturable absorber, e.g. dye, SESAM, etc.



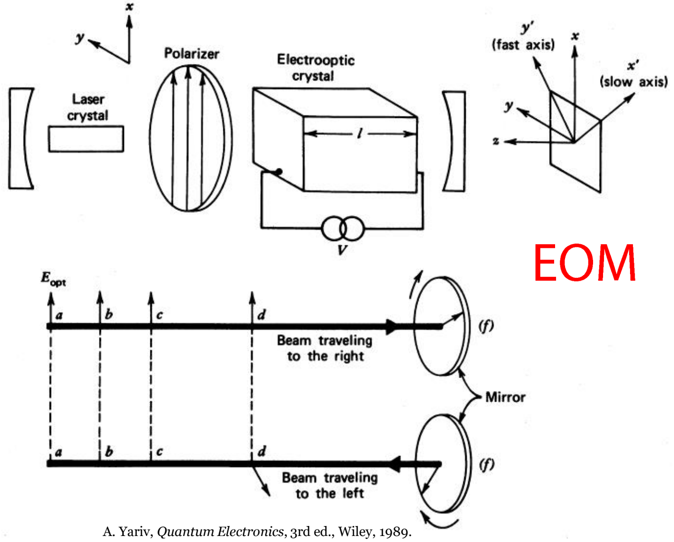
Mechanical Q-SW

K. J. Kuhn, Laser Engineering, Prentice Hall, 1991.



AOM

K. J. Kuhn, Laser Engineering, Prentice Hall, 1991.



EOM

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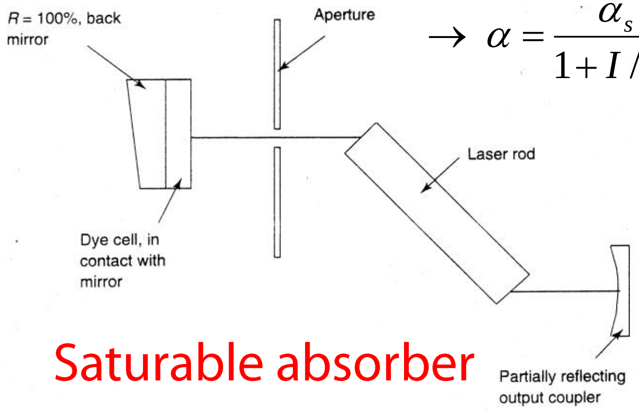

$$\rightarrow \alpha = \frac{\alpha_s}{1 + I / I_s}$$

Saturable absorber

K. J. Kuhn, Laser Engineering, Prentice Hall, 1991.