Engineering Physics

(PHY1701)

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Contents

- Laser Characteristics,
- Spatial and Temporal Coherence,
- Einstein Coefficient & its significance,
- Population inversion,
- Two, three & four level systems,
- Pumping schemes,
- **Threshold gain coefficient,**
- Components of laser,
- Nd-YAG, He-Ne, CO_2 and their engineering applications

❖ William Silfvast, Laser Fundamentals, 2008, Cambridge University Press.

Threshold Condition

- Light bouncing back and forth in the optical resonator
- Undergoes Amplification as well as suffers losses

Losses occur mainly due to

(i)Transmission at the output mirror

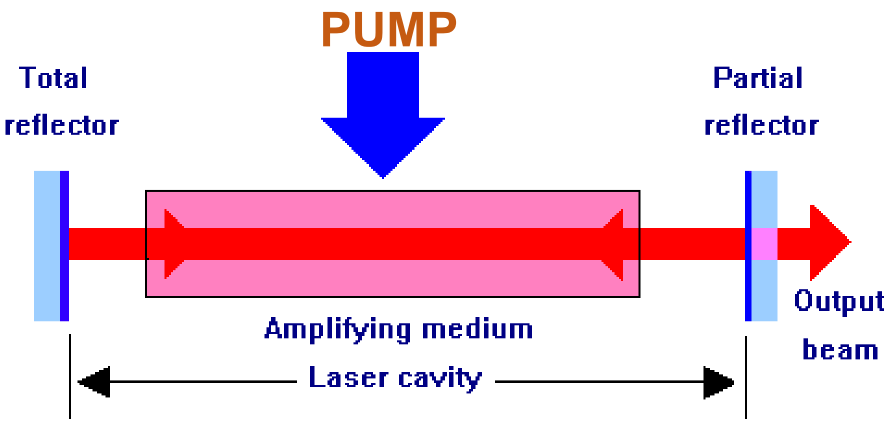
(ii)Scattering & Diffraction of light within the active medium.

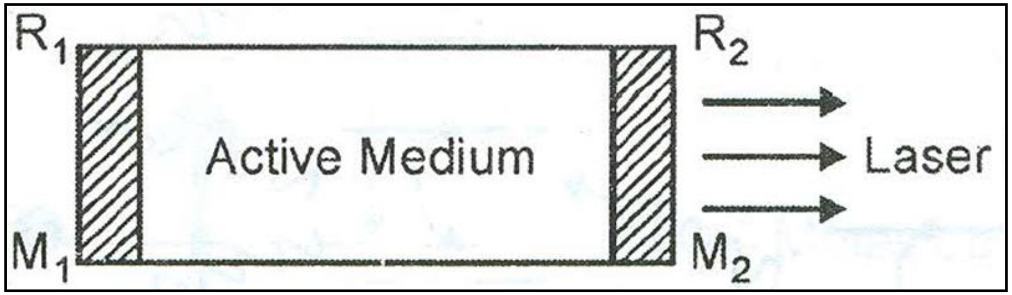
(iii)Absorption & Spontaneous Emission

For the proper build up of oscillations

- Essential is that the amplification between two consecutive reflections of light from rear end mirror can balance losses.

Threshold Gain Coefficient





- Consider the laser medium fills the space between the mirrors M_1 & M_2, of reflectivity R_1 & R_2 respectively and mirrors separated by a distance L.
- In any laser oscillator initially a few photons would be emitted spontaneously and these photons start the stimulated emission process.
- Let I_0 - the intensity of the light beam at M_1, then after travelling L distance through it, the final intensity will be I_1

$$I_1 = I_0 \exp(-\alpha L)$$

where α is the absorbsion coefficient

Threshold Gain Coefficient

- Afterwards, laser oscillator incorporates pumping energy. Hence population inversion will be maintained. Hence, here amplification dominates.

  $\mathrm{i.e} \qquad N_2 > N_1$ throughout the active medium

- In this condition, If I_0 is the initial intensity (minimum needed to start laser amplification) of light entering through the active medium (in the direction of length), then after travelling L distance through it, the final intensity will be I_1.

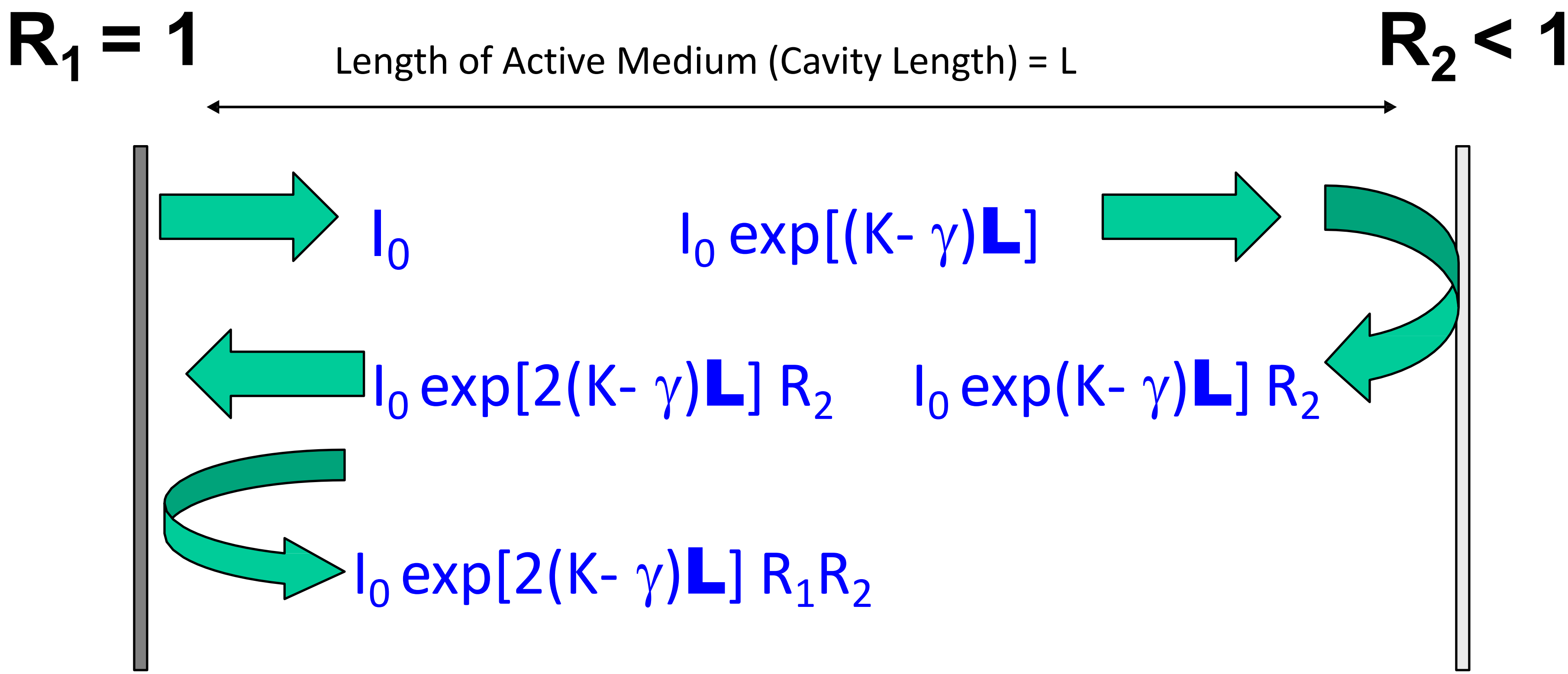
$$I_1 = I_0 \exp(kL)$$

  where k – the gain coefficient

- Let if γ is the coefficient of practical losses . This reduces the effective gain coefficient to $(k - \gamma)$. Then

$$I_1 = I_0 \exp[(k - \gamma)L]$$

Growth of Power Through Cavity



Gain Coefficient = K Loss Coefficient = γ

$$\text{Roundtrip Gain (G)} = \frac{I_0 \exp[2(K-\gamma)\mathbf{L}]\, R_1 R_2}{I_0}$$

Threshold Gain Coefficient

$$\text{after reflecting at mirror } M_2, \qquad I_1 = I_0 R_2 \exp[(k - \gamma)L]$$

$$\text{just before reaching } M_1 \text{ again}, \qquad I_1 = I_0 R_2 \exp[2(k - \gamma)L]$$

$$\text{after refelcting from } M_1, I_1 = I_0 R_1 R_2 \exp[2(k - \gamma)L]$$

$$G = \frac{\text{Final irradiance}}{\text{Initial irradiance}} = R_1 R_2 \exp[2(k\text{-}\gamma)L]$$

- We can determine the k_{th} from the condition that G must be at least unity
- To sustain the laser oscillations, the minimum intensity amplified should be equal to the initial intensity I_0.

$$\text{initial intensity} = \begin{cases} \text{final amplified intensity} \\ \quad \text{in one round trip} \end{cases}$$

$$\text{so} \quad I_0 = I_0 R_1 R_2 \exp[2(k_{th} - \gamma)L]$$

$$k_{th} - \text{threshold gain coefficient}$$

Threshold Gain Coefficient

$$\mathrm{k_{th}} - \text{threshold gain coefficient}$$

$$\cancel{\mathrm{I_0}} = \cancel{\mathrm{I_0}}\mathrm{R_1 R_2 exp[2(k_{th} - \gamma)L]}$$

$$1 = \mathrm{R_1 R_2 exp[2(k_{th} - \gamma)L]}$$

$$\ln 1 = \ln \mathrm{R_1 R_2 exp[2(k_{th} - \gamma)L]}$$

$$2\mathrm{k_{th}L} = 2\gamma\mathrm{L} + \ln\left(\frac{1}{\mathrm{R_1 R_2}}\right)$$

Threshold gain coefficient, $\mathrm{k_{th}} = \gamma + \frac{1}{2\mathrm{L}}\ln\left(\frac{1}{\mathrm{R_1 R_2}}\right)$

$$\gamma - \text{practical or volume losses}$$

$$\left.\frac{1}{2\mathrm{L}}\ln\left(\frac{1}{\mathrm{R_1 R_2}}\right)\right\} - \text{useful laser output}$$

- Product R_1 R_2 represents the losses at the mirrors, whereas α_s includes all the distributed losses such as scattering, diffraction and absorption occurring in the medium.
- Losses are balanced by gain, when $G \geq 1$ or $I(2L) \geq I_0$. It leads to the condition that

$$R_1 R_2 e^{(K-\gamma)2L} \geq 1 \quad \text{or} \quad e^{(K-\gamma)2L} \geq \frac{1}{R_1 R_2}$$

Taking logarithms on both sides, we get

$$2L(K-\gamma) \geq \ln(R_1 R_2)$$

$$(K-\gamma) \geq \frac{1}{2L} \ln(R_1 R_2)$$

$$\boxed{K \geq \gamma + \frac{1}{2L} \ln\left(\frac{1}{R_1 R_2}\right)} \Rightarrow \textbf{Condition for Lasing}$$

- Shows that the **initial gain must exceed the sum of losses in the cavity**. The condition is used to determine the threshold value of pumping energy necessary for lasing action.

  - As the pump power is slowly increased, a value of **'K_{th}' called threshold value** will be reached and the laser starts oscillating.

Threshold value **'K_{th}'** is given by

$$K_{th} = \gamma + \frac{1}{2L}\ln\left(\frac{1}{R_1 R_2}\right)$$

- For the laser to oscillate, $K > K_{th}$ $\Rightarrow$ **Threshold condition for lasing**

  - This states the criterion when the net gain would be able to counteract the effect of losses in the cavity