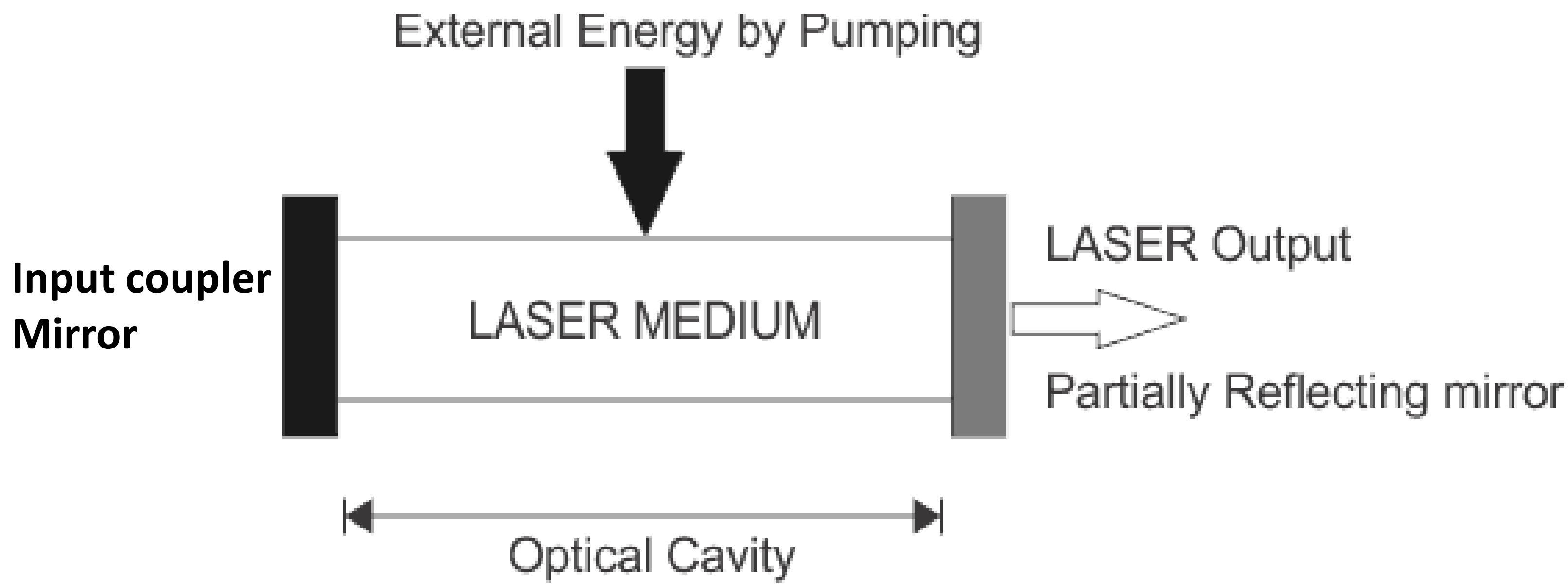


Components of LASER

Essential components of a laser system :

Active medium or Gain medium : It is the system in which population inversion and hence stimulated emission (laser action) is established.

Active Medium → Pumping Mechanism → Optical resonator

Pumping mechanism : It is the mechanism by which population inversion is achieved.
i.e., it is the method for raising the atoms from lower energy state to higher energy state to achieve laser transition.

DIFFERENT PUMPING MECHANISMS :

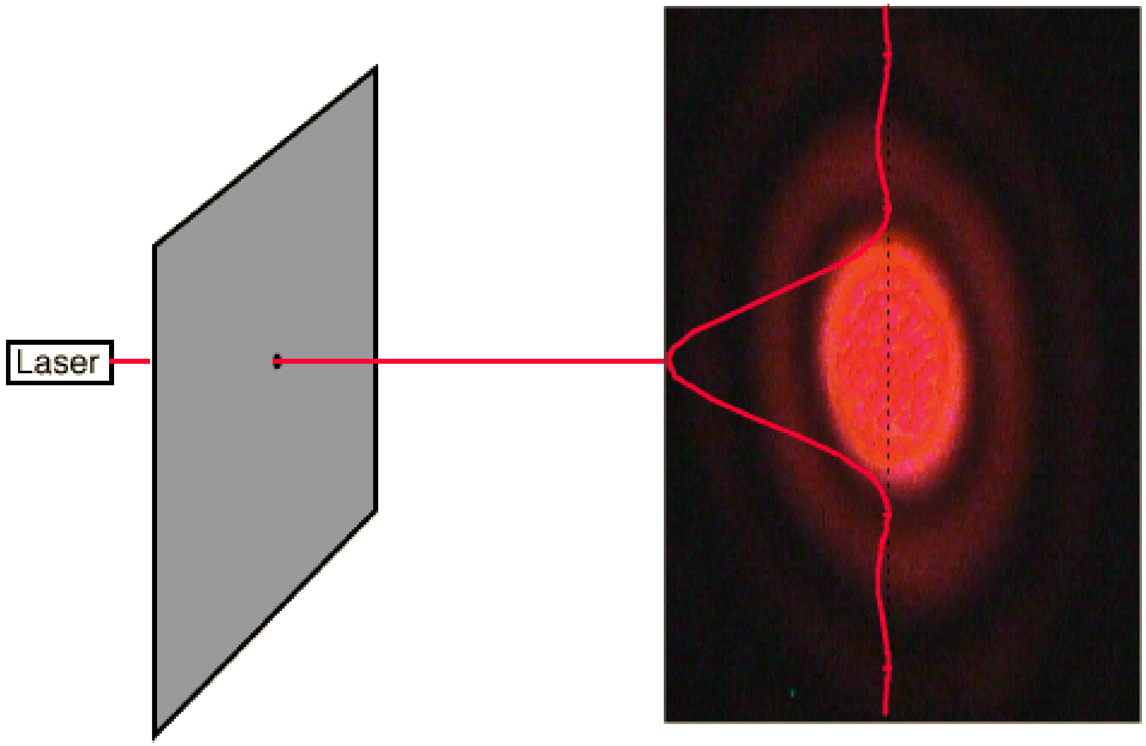
i. ***Optical pumping*** ***:*** Exposure to electromagnetic radiation of frequency $\upsilon = (E_2 - E_1)/h$ obtained from discharge flash tube results in pumping Suitable for solid state lasers.

ii. ***Electrical discharge*** ***:*** By inelastic atom-atom collisions, population inversion is established.

Suitable for Gas lasers

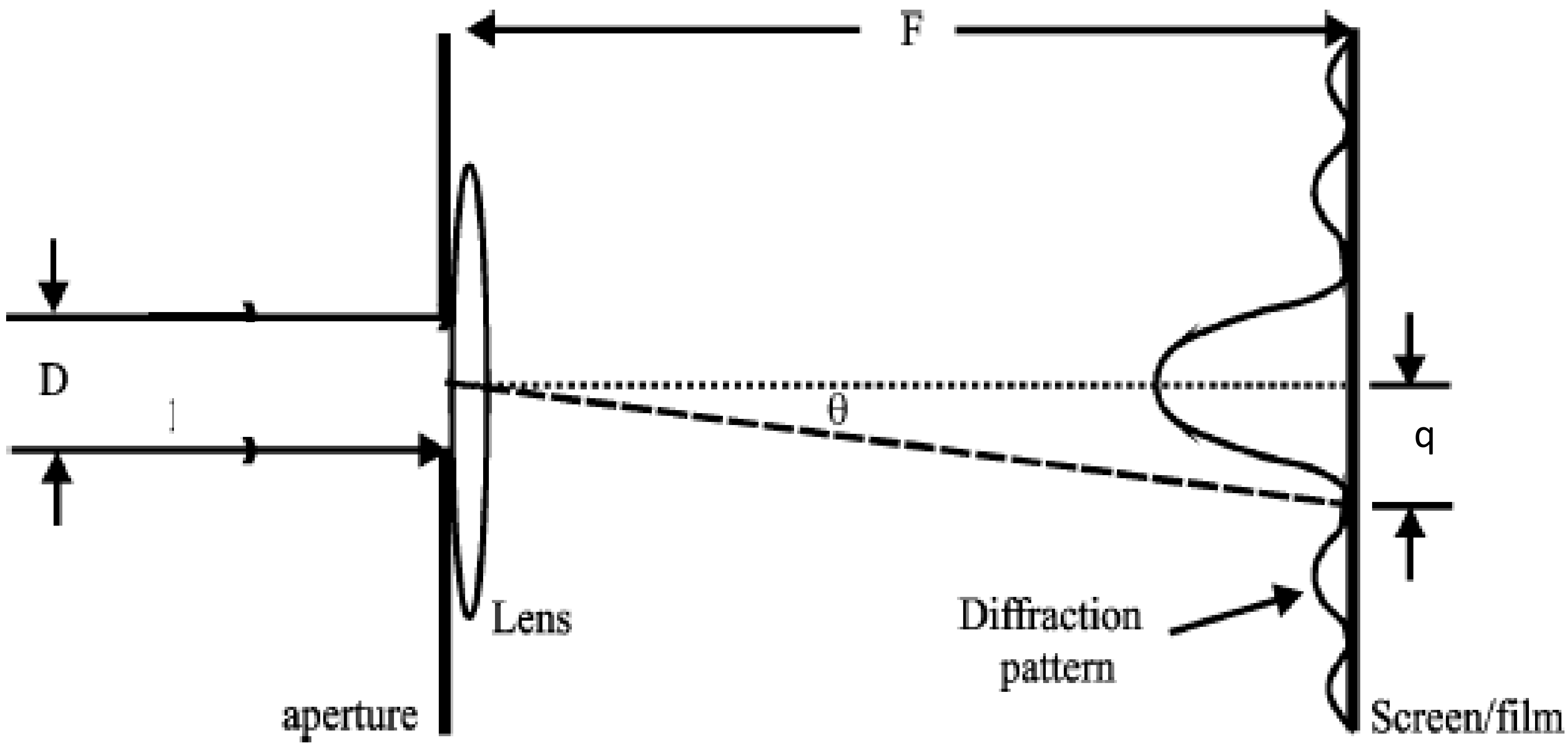
iii. ***Chemical pumping*** ***:*** By suitable chemical reaction in the active medium, population of excited state is made higher compared to that of ground state Suitable for liquid lasers.

iv. ***Optical resonator*** ***:*** A pair of mirrors placed on either side of the active medium is known as optical resonator. One mirror is completely silvered and the other is partially silvered. The laser beam comes out through the partially silvered mirror.



Airy disk : high irradiance circular spot

Diffraction limit of Camera



Two point sources cannot be resolved if their separation is less than the radius of the Airy disk.

According to Rayleigh's criterion

Angular limit of resolution :

$$\Delta\theta = \frac{1.22\lambda}{D}$$

Limit of resolution :

$$\Delta l = \frac{1.22F\lambda}{D}$$

Δl=centre to centre separation between images

Round trip gain with losses

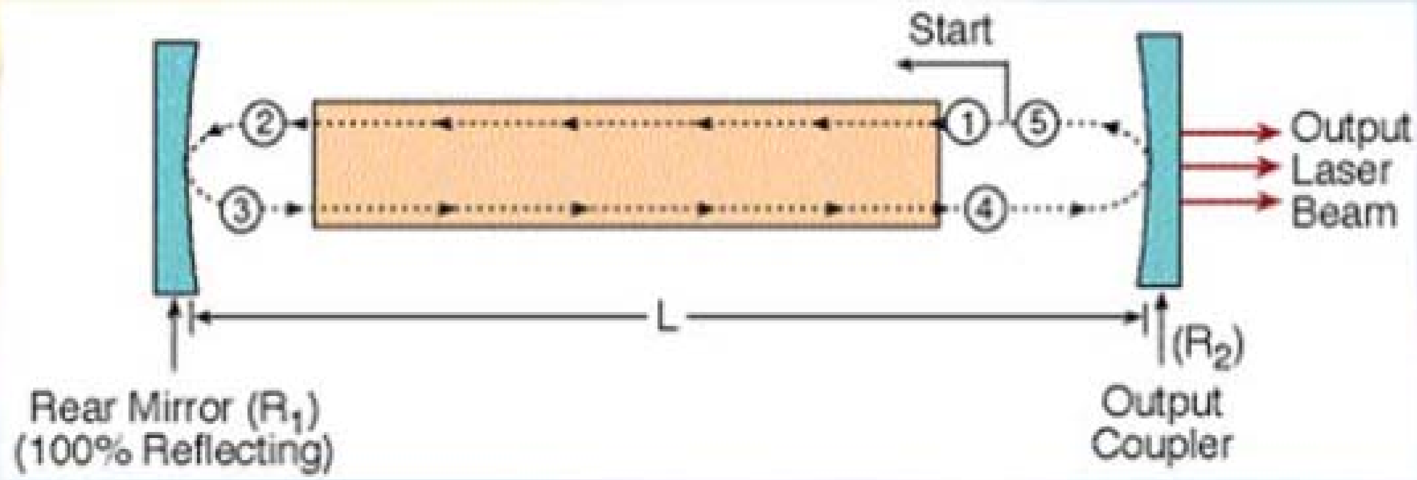
The total losses of the laser system is due to a number of different processes these are:

1. Transmission at the mirrors
2. Absorption and scattering by the mirrors
3. Absorption in the laser medium
4. Diffraction losses at the mirrors

All these losses will contribute to reduce the effective gain coefficient to (γ_o- k)

Round trip Gain (G)

Figure below show the round trip path of the radiation through the laser cavity. The path is divided to sections numbered by 1-5, while point "5" is the same point as "1".



Round trip path of the radiation through the laser cavity.

By definition, Round trip Gain is given by:

$$G = I_5 / I_1$$

G = Round trip Gain.

I_1 = Intensity of radiation at the beginning of the loop.

I_5 = Intensity of radiation at the end of the loop.

Gain (G) Without Losses

$$I_5 = R_1 * R_2 * G^2 * I_1$$

Gain (G) With Losses

We assume that the losses occur uniformly along the length of the cavity (L). In analogy to the Lambert formula for losses, we define loss coefficient (α), and using it we can define absorption factor k:

$$k = \exp(-2\alpha L)$$

k = Loss factor, describe the relative part of the radiation that remain in the cavity after all the losses in a round trip loop inside the cavity.

All the losses in a round trip loop inside the cavity are 1-k (always less than 1).

α = Loss coefficient (in units of 1 over length).

2L = Path Length, which is twice the length of the cavity.

Adding the loss factor (k) to the equation of I_5:

$$I_5 = R_1 * R_2 * G_A{}^2 * I_1 * k$$

From this we can calculate the round trip gain:

$$G = I_5/I_1 = R_1 * R_2 * G_A{}^2 * k$$

As we assumed uniform distribution of the loss coefficient (α), we now define gain coefficient (γ), and assume active medium gain (G_A) as distributed uniformly along the length of the cavity.

$$G_A = \exp(+\gamma L)$$

$$\boxed{G(\nu) = e^{\gamma_0(\nu)l}}$$

Substituting the last equation in the Loop Gain:

$$\boxed{k = \exp(-2\alpha L)}$$

$$G = R_1 * R_2 * \exp(2(\gamma - \alpha)L)$$

$$G = R_1 * R_2 * \exp(2(\gamma - \alpha)L)$$

When the loop gain (G) is greater than 1 ($G > 1$), the beam intensity will *increase* after one return pass through the laser.

When the loop gain (G) is less than 1 ($G < 1$), the beam intensity will *decrease* after one return pass through the laser. laser oscillation decay, and no beam will be emitted.

Conclusion:

There is a threshold condition for amplification, in order to create oscillation inside the laser.

$$G_{th} = 1$$

This Threshold Gain is marked with index "th".

For continuous laser , the threshold condition is:

$$\boxed{G_{th} = 1 = R_1 R_2 G_A^2 k = R_1 * R_2 * \exp(2(\gamma - \alpha)L)}$$

Example

Active medium gain in a laser is 1.05. Reflection coefficients of the mirrors are: 0.999, and 0.95. Length of the laser is 30cm. Loss coefficient is: $\alpha = 1.34*10^{-4}\ cm^{-1}$.

Calculate:

1. **The loss factor k.**
2. **The round trip gain G.**
3. **The gain coefficient (γ).**

Solution

1. The loss factor k:

$$k = \exp(-2\alpha L) = \exp[-2(1.34*10^{-4})*30] = 0.992$$

2. The Loop gain G:

$$G = R_1 R_2 G_A{}^2 k = 0.999*0.95*1.052*0.992 = 1.038$$

Since $G_L > 1$, this laser operates above threshold.

3. The gain coefficient (γ):

$$G = \exp(\gamma L)$$

$$\text{Ln } G = \gamma L$$

$$\gamma = \text{Ln } G/L = \ln(1.05)/30 = 1.63*10^{-3}\ [cm^{-1}]$$

The gain coefficient (γ) is greater than the loss coefficient (α), as expected.

Example

Helium Neon laser operates in threshold condition. Reflection coefficients of the mirrors are: 0.999, and 0.97. Length of the laser is 50 cm. Active medium gain is 1.02.

Calculate:

1. The loss factor k.
2. The loss coefficient α.

Solution

Since the laser operates in threshold condition, G = 1.
Using this value in the round trip gain:

$$G = 1 = R_1 R_2 G_A^{\,2} k$$

1. The loss factor k:

$$k = 1/(\, R_1 R_2 G_A^{\,2}) = 1/(0.999*0.97*1.02^2) = 0.9919$$

As expected, $k < 1$.
Since $G > 1$, this laser operates above threshold.

2. The loss coefficient (α) is calculated from the loss factor:

$$k = \exp(-2\alpha L)$$

$$\ln k = -2\alpha L$$

$$\alpha = \ln k/(-2L) = \ln(0.9919)/(-100) = 8.13*10^{-5}\ [cm^{-1}]$$

Attention:

If the loss factor was less than 0.9919, then $G < 1$, and the oscillation condition was not fulfilled.

Example

Reflection coefficients of the mirrors are: 0.999, and 0.95. All the losses in round trip are 0.6%.

Calculate the active medium gain.

Solution

For finding the active medium gain G_A, the loss factor (k) must be found.

All the losses are 1-k.

$$1-k = 0.006$$
$$k = 0.994$$

Using this value in the threshold loop gain:

$$G_{th} = 1 = R_1 R_2 G_A^2 k$$

$$(G_A)_{th} = 1/\mathrm{sqrt}(R_1 R_2 k) = 1/\mathrm{sqrt}(0.999*0.95*0.994) = 1.03$$

The active medium gain must be at least 1.03 for creating continuous output from this laser.

Summary

G = round trip Gain, determines if the output power of the laser will <u>increase, decrease, or remain constant</u>. It include all the losses and amplifications that the beam have in a complete round trip through the laser.

$$G_L = R_1 R_2 G_A{}^2 k$$

R_1, R_2 = Reflection coefficients of the laser mirrors.
G_A = Active medium gain as a result stimulated emission.

$$G_A = \exp(+\gamma L)$$

γ = Gain coefficient.
L = Active Medium length.

k = Optical Loss Factor in a round trip path in the laser cavity.

$$k = \exp(-2\alpha L)$$

α = Loss coefficient.

Summary

When $G = 1$, The laser operate in a **steady state mode**, meaning the output is at a constant power. This is the **threshold condition for lasing**, and the **active medium gain** is:

$$(G_A)_{th} = 1/\mathrm{sqrt}(R_1 R_2 k)$$

The **round trip Gain** is:

$$G_L = R_1 * R_2 * \exp(2(\gamma - \alpha)L)$$