A presentation on

Cavity optics

Presented by:
Md. Shahadat Hasan Sohel
Student No.: 0412062252

Supervised by:
Dr. Md. Nasim Ahmed Dewan
Associate Professor, EEE, BUET

Lasing Condition

- Stimulated emission rate >> Spontaneous emission rate
- The ratio between the two rates is given by

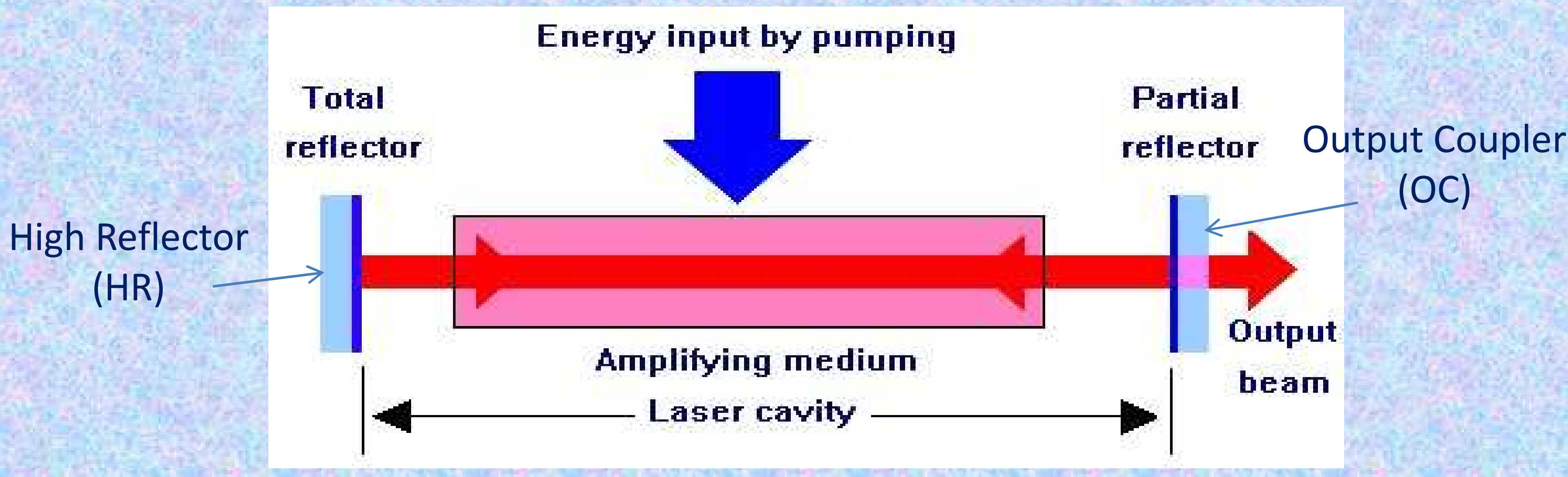
$$\frac{r_{\text{stimulated}}}{r_{\text{spontaneous}}} = \frac{c^3 \rho}{8\pi h \nu^3}$$

Variable

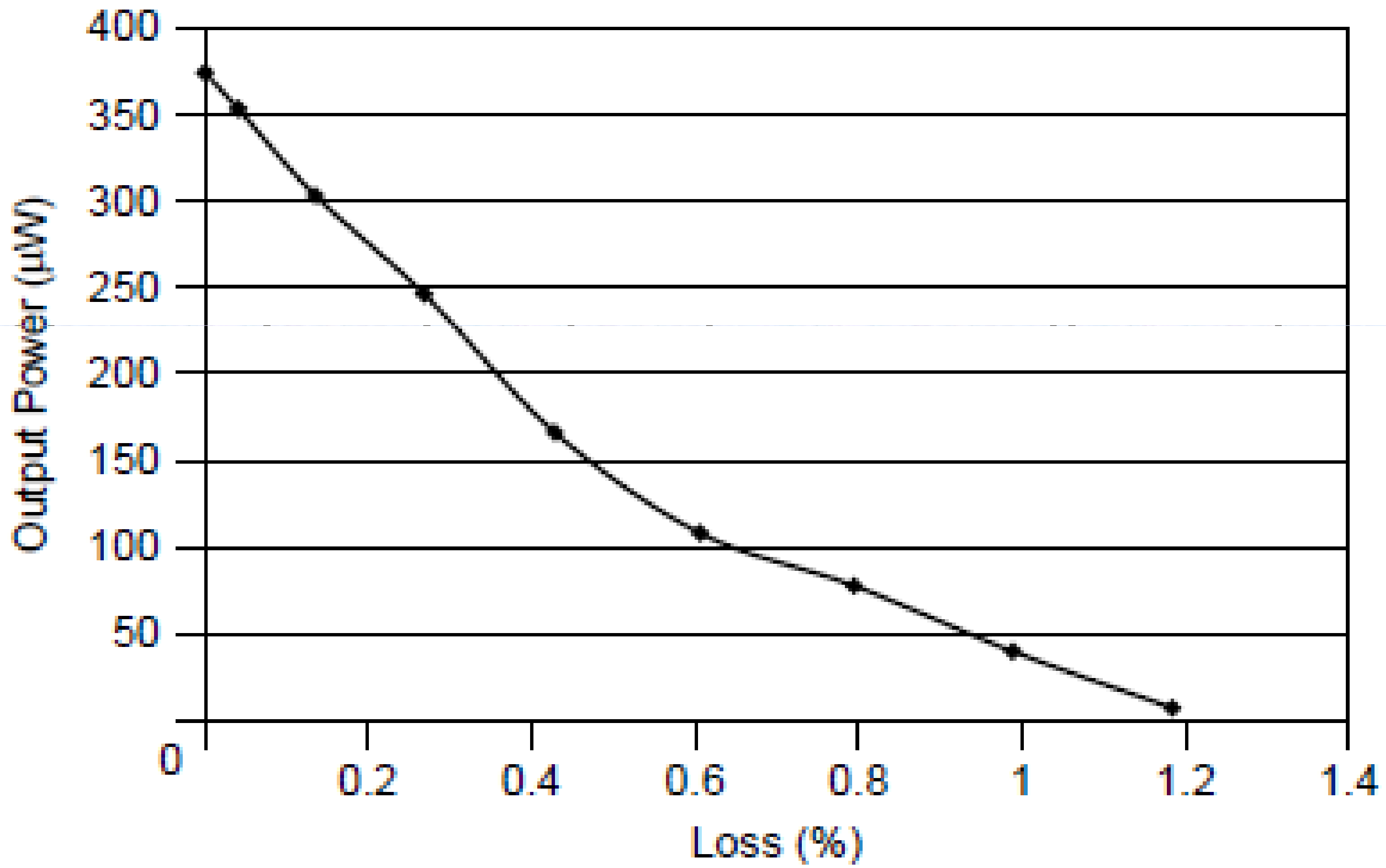
For sustained lasing, photon energy density must be very high!

Resonator

- An arrangement of mirrors that forms a standing wave cavity resonator for light waves
- Surrounds the gain medium and provides feedback of the laser light to compensate the loss and increase photon energy density

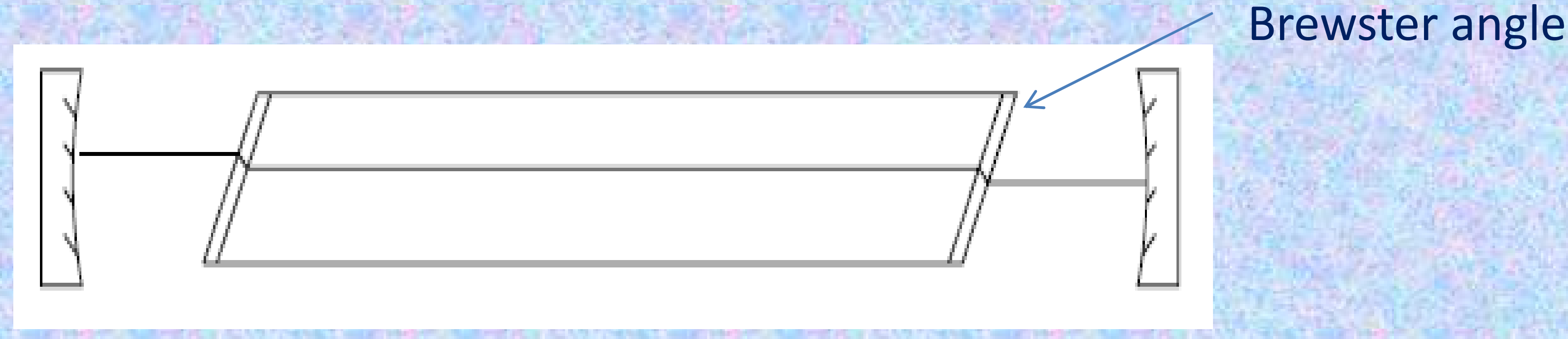


Loss mechanisms



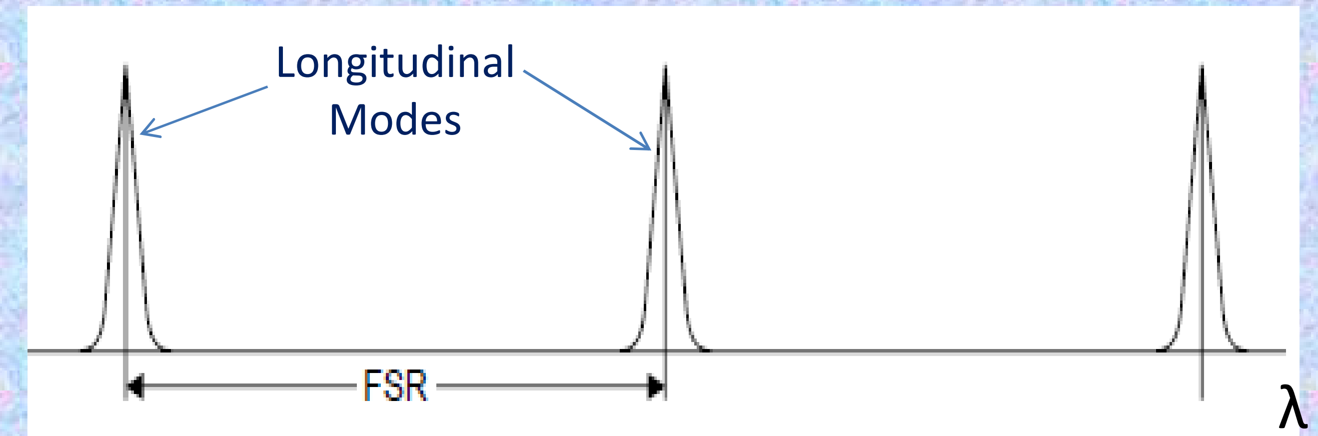
Minimizing losses

- Mirrors may be sealed directly into the ends of the tube so that there were no windows in the optical path to increase loss.
- Optical windows are angled at the Brewster angle, which polarizes the output of the laser to reduce the loss in the cavity.

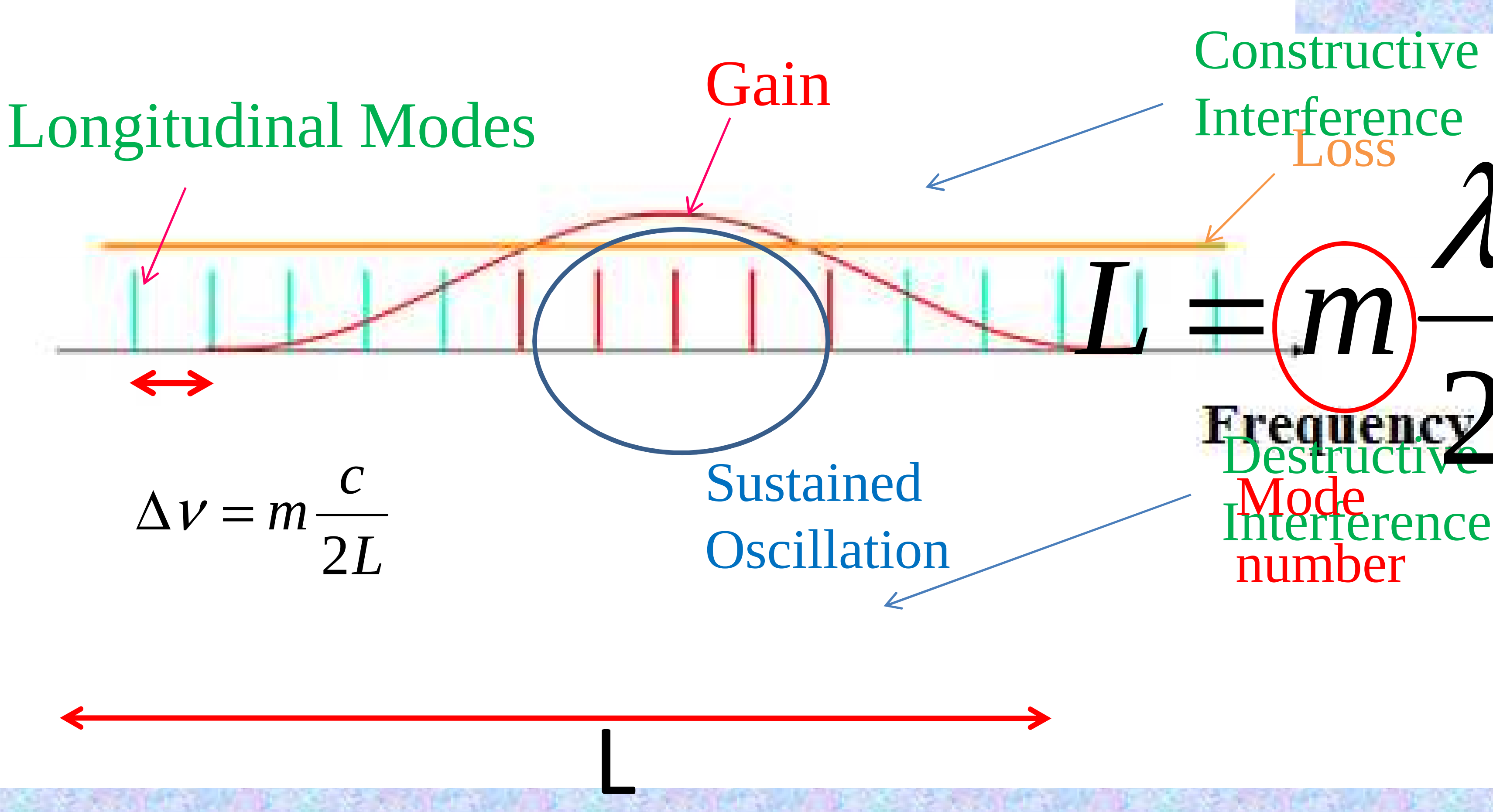


Interferometer

- Optical, acoustic, or radio frequency instruments that use interference phenomena between a reference wave and an experimental wave or between two parts of an experimental wave



Resonator - As An Interferometer



$$L = m\frac{\lambda}{2}$$

Mode number

$$\Delta\nu = m\frac{c}{2L}$$

Resonator parameters

- Free spectral range (FSR): Frequency difference between two modes

$$\Delta\nu = m\frac{c}{2L}$$

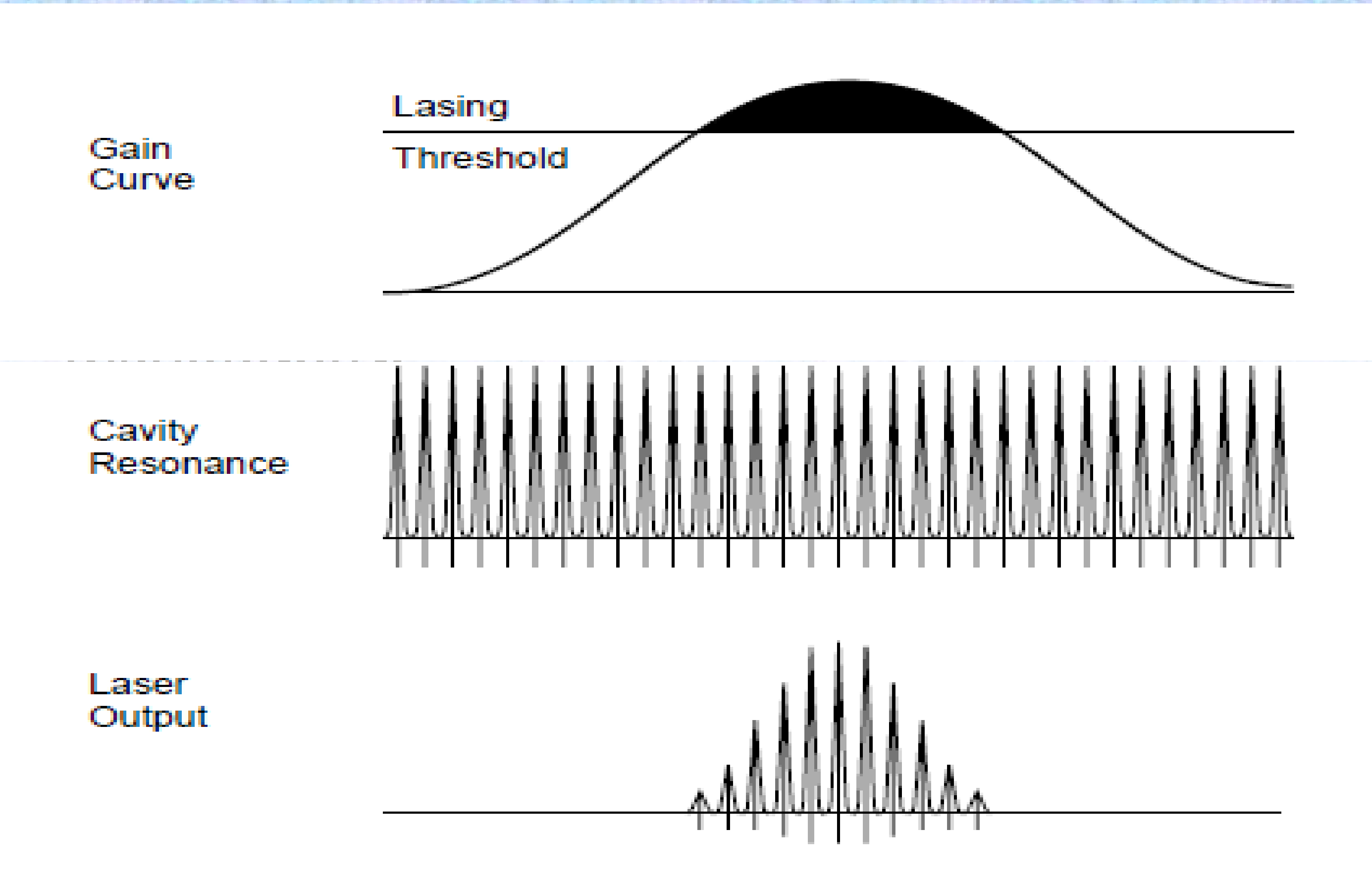
- Spectral width: Full Width at Half Maximum

$$\delta = \frac{\nu_f}{F}$$

- Finesse: Ratio of the FSR to the spectral width. It’s a function of the reflectivity of cavity mirrors.

$$F = \frac{\pi\sqrt{R}}{1-R}$$

Longitudinal Modes - Conditions

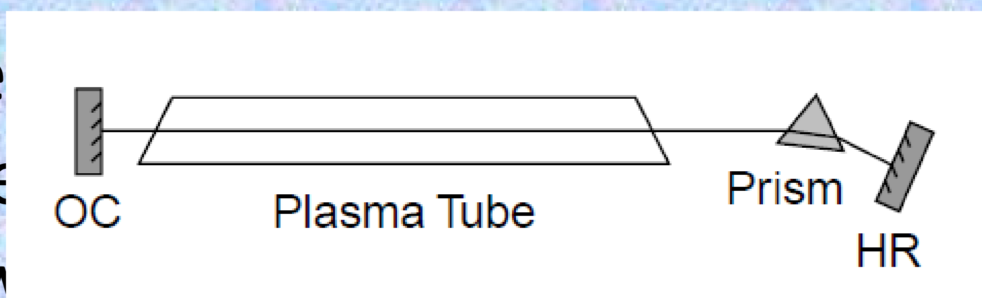


Wavelength Selection

1. To de

reflective

chosen w



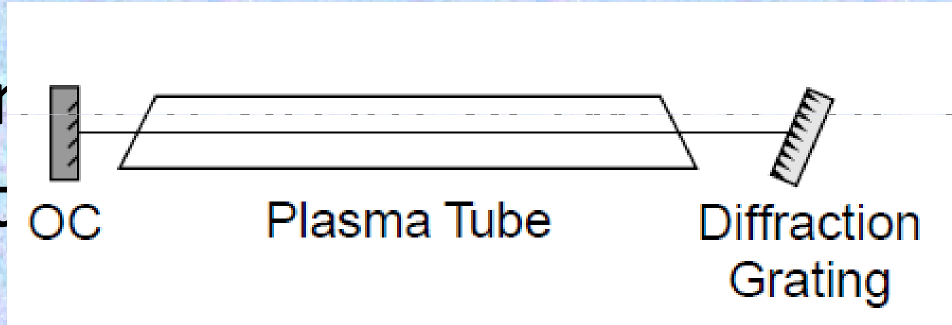
e highly

a set of

2. Additior

tube and t

line

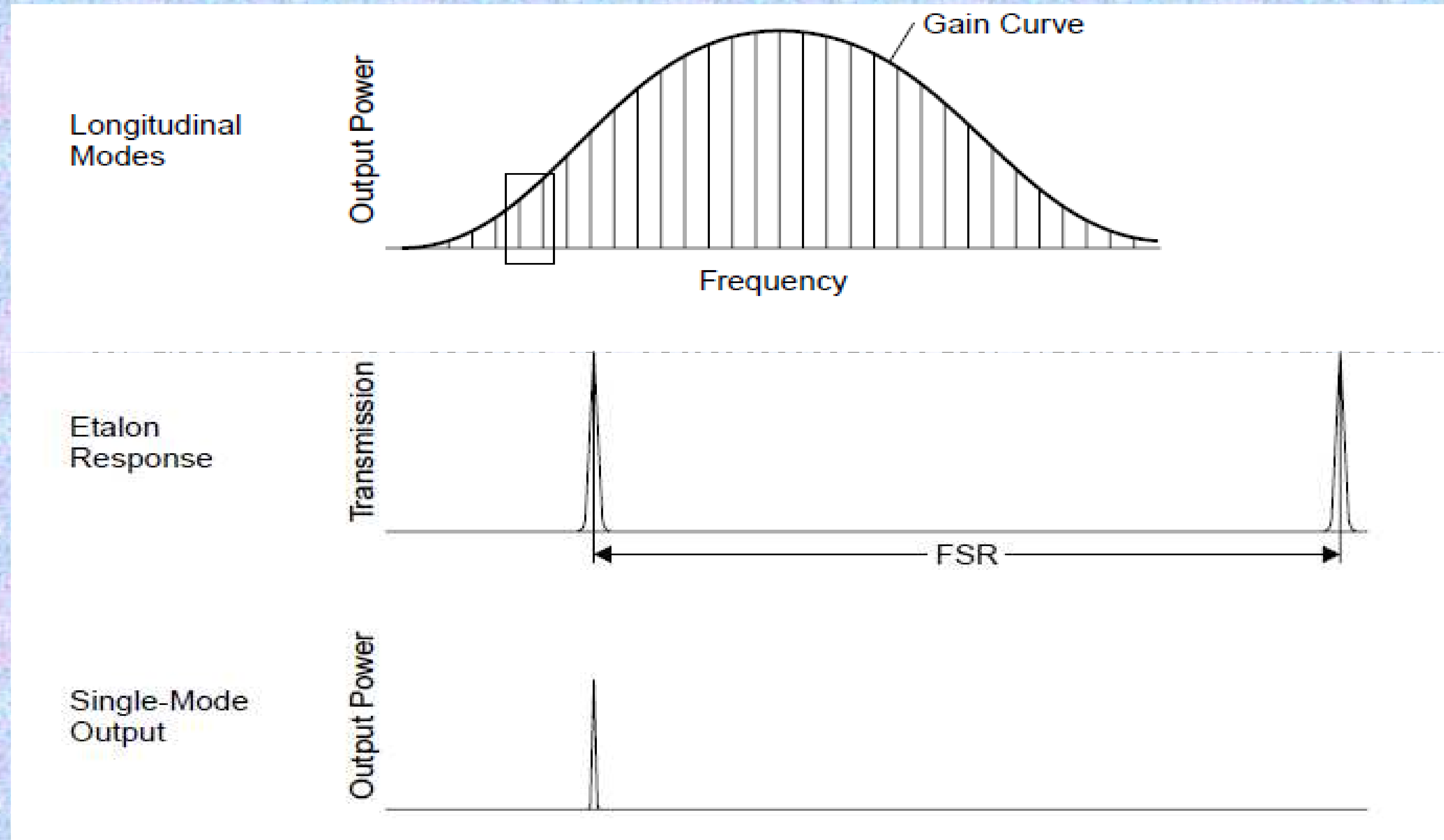


plasma

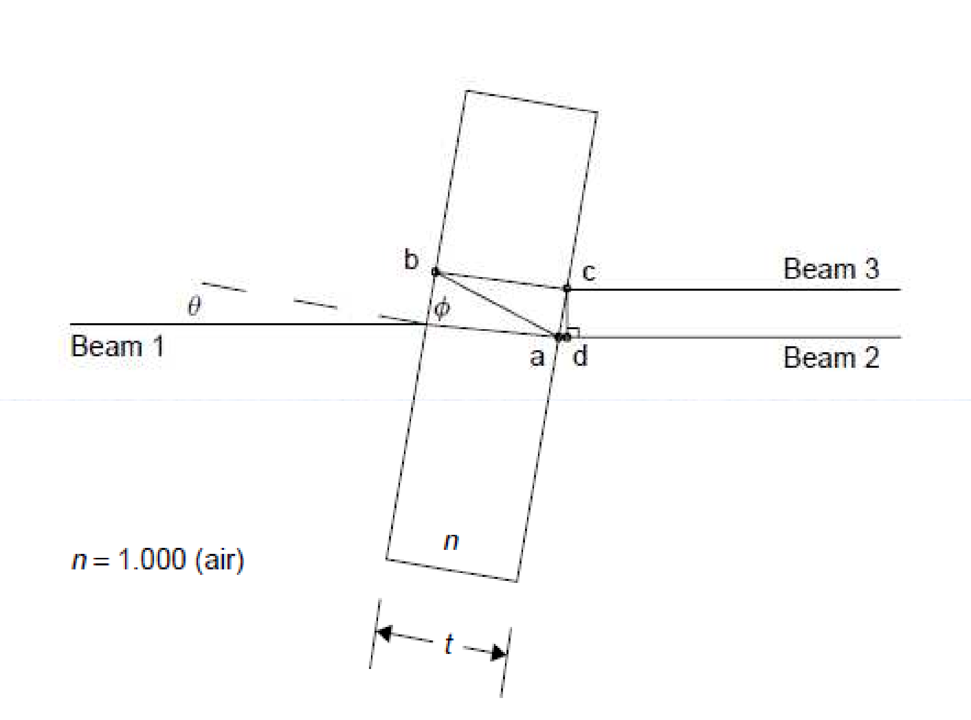
single

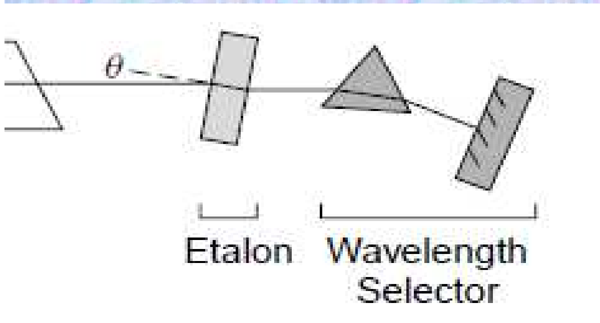
3. Addition of a diffraction grating between the plasma tube and the HR

Single-Frequency Operation Using Etalon



Intracavity Etalon





$$N\lambda = 2nt\cos\phi$$

$$\mathrm{FSR} = \frac{c}{2nt}$$

$$N\lambda = n(\text{distance a–b} + \text{distance b–c}) + \text{distance a–d}$$

Characterization of a Resonator

- Total loss coefficient: Sum of all the loss components $\gamma_r = \gamma_a + \gamma_1 + \gamma_2$

- Mirror loss: Loss at cavity mirror $$\gamma_1 = \frac{\ln \frac{1}{R_1}}{2l}$$

- Absorption loss: Absorption due to transitions other than lasing $$\gamma_a = \frac{(2^* \gamma^*_{\text{rod}} l_{\text{rod}})}{2l}$$

Lifetime broadening

- Photon lifetime: Refers to the average time that a photon spends in the cavity of a laser

$$\tau_c = \frac{1}{c\gamma_r}$$

- Lifetime broadening: Linewidth broadening due to ‘Photon lifetime’

$$\Delta\nu = \frac{1}{2\pi\tau_c}$$

Gaussian Beam

- The Gaussian output beam (also called a TEM_{00} beam) has the lowest electromagnetic mode structure possible.
- It is spatially the purest laser beam possible and is characterized by the lowest divergence of any mode.

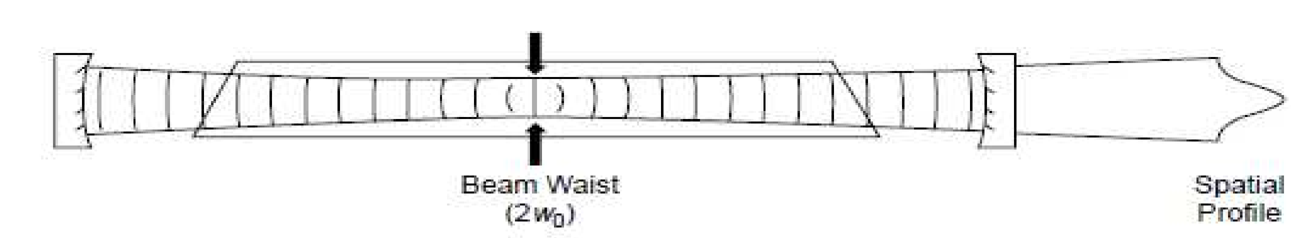
$$I(y) = I_0 \exp\left(-\frac{2y^2}{w^2}\right)$$

Distance from the center of the beam

Maximum intensity

Radius of the beam

Gaussian Beam parameters



- Beam Waist: Inside a cavity consisting of two concave mirrors with radius of curvature equal to exactly the distance between them the beam converges at the center of the gain medium in what is called the beam waist denoted as w_0.

$$w_0 = \left(\frac{\lambda L}{2\pi}\right)^{1/2}$$

Gaussian Beam parameters

- Beam divergence: At the beam waist wavefronts are plane, but as they move toward the cavity mirrors the shape changes to match that of the radius of curvature of the mirrors essentially that of a spherical wave.
- Wavefronts exiting through the OC diverge at an angle of

$$\theta = \frac{\lambda}{\pi w_0}$$

Half-angle of the divergence (θ)

Wavelength (λ)

Beam waist (w_0)

Resonator Stability

- A resonator is stable if a beam inside reflects perfectly back on itself and is completely trapped within the cavity.
- Any ray within the cavity can retrace itself exactly after one round trip through the stable cavity.
- Stability parameter: Stability of a laser cavity can be mathematically determined from resonator 'g' parameters, one representing each mirror.

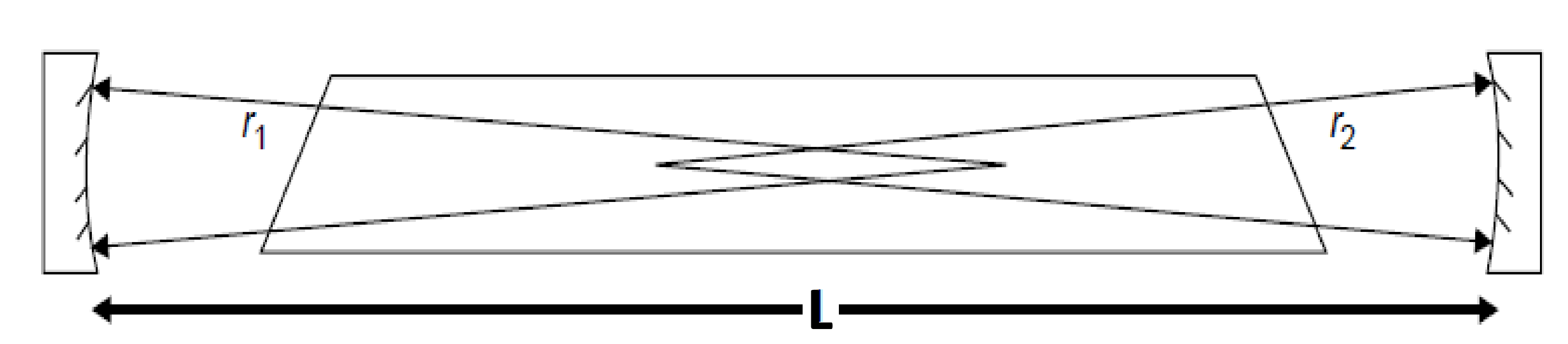
Resonator 'g' parameter

- Defines the beam path relative to the entire cavity. Given by -

$$g = 1 - \frac{L}{r}$$

L — Cavity length

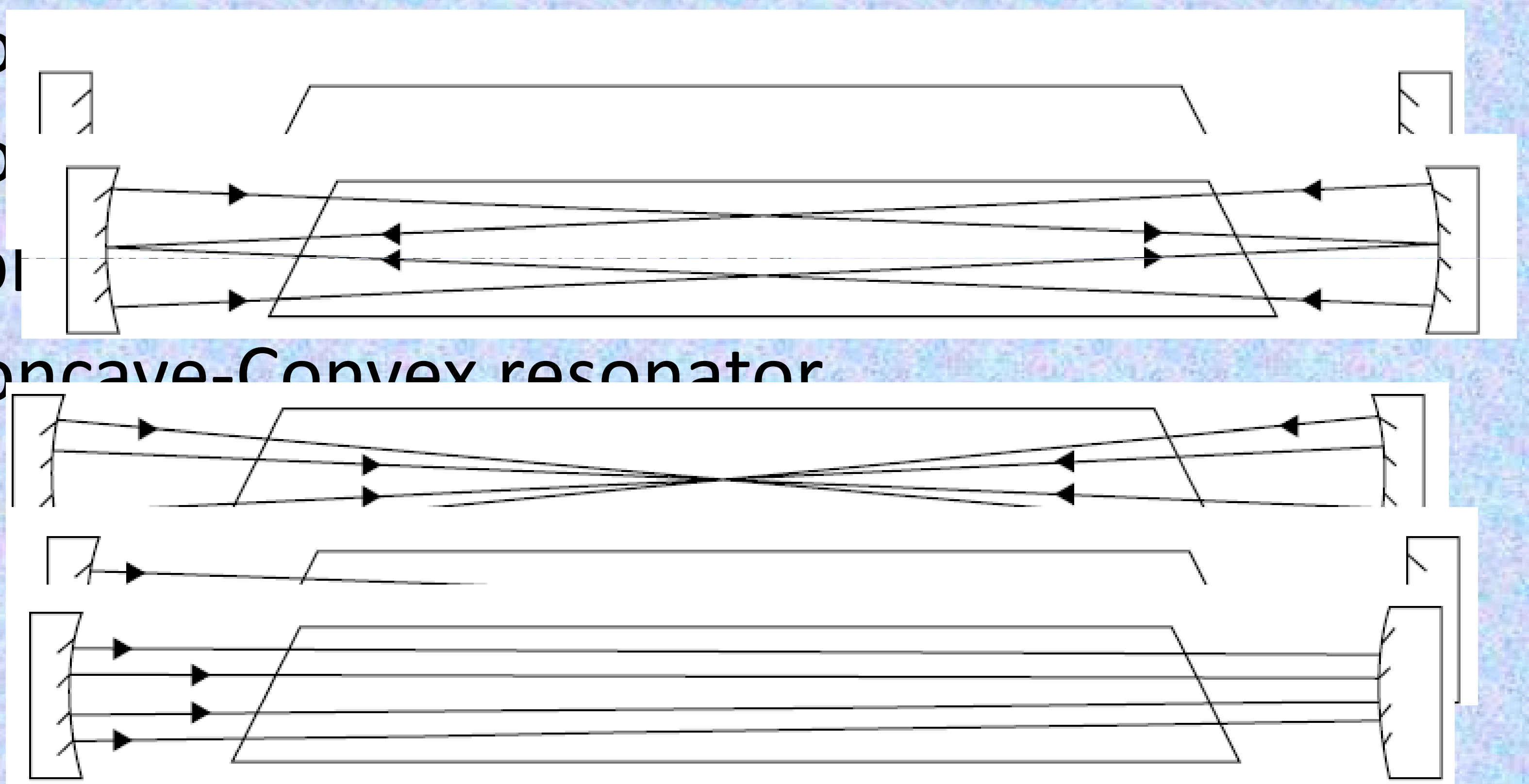
r — Radius of curvature



Stability Condition: $0 \le g_1 g_2 \le 1$

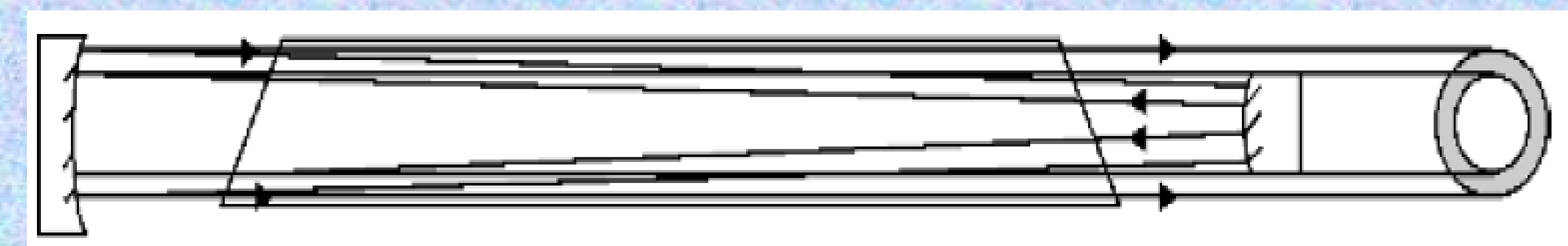
Common Stable Cavity Configurations

1. Plane mirror resonator
2. Co
3. Co
4. Sp
5. Concave-Convex resonator



Unstable resonator

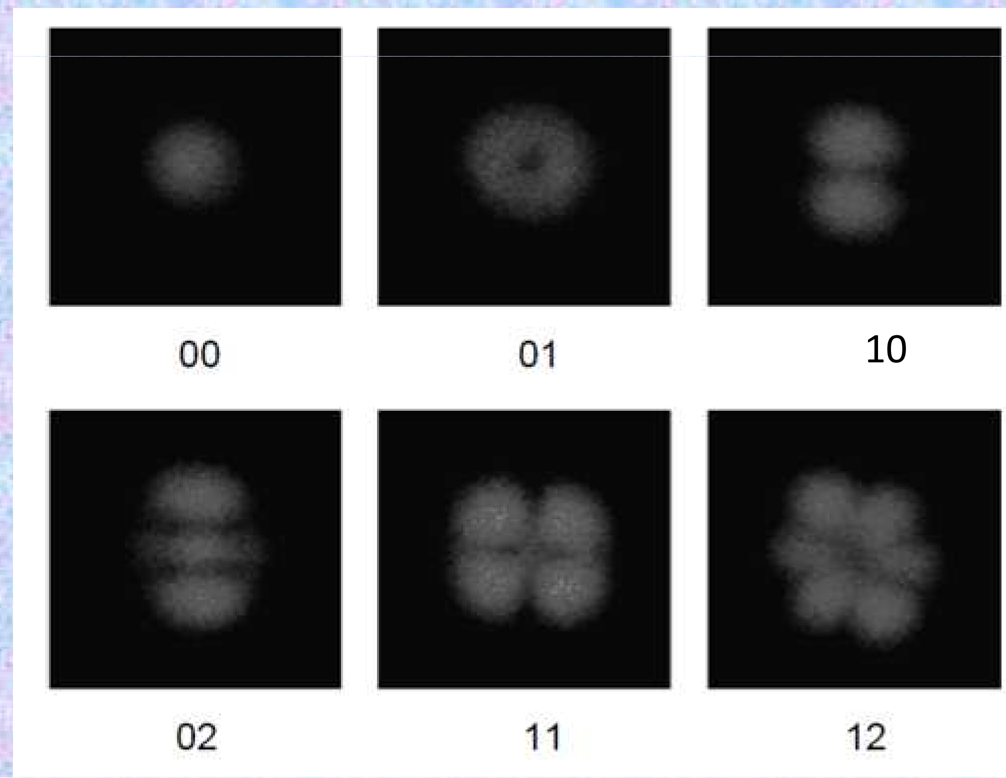
- For certain high-power lasers such as excimer and carbon dioxide TEA lasers, unstable resonators are a popular option.
- Because these resonators are not stable, light is not trapped in the cavity, at least for many round trips, so this arrangement is suitable only for use with high-gain lasers.



Transverse mode

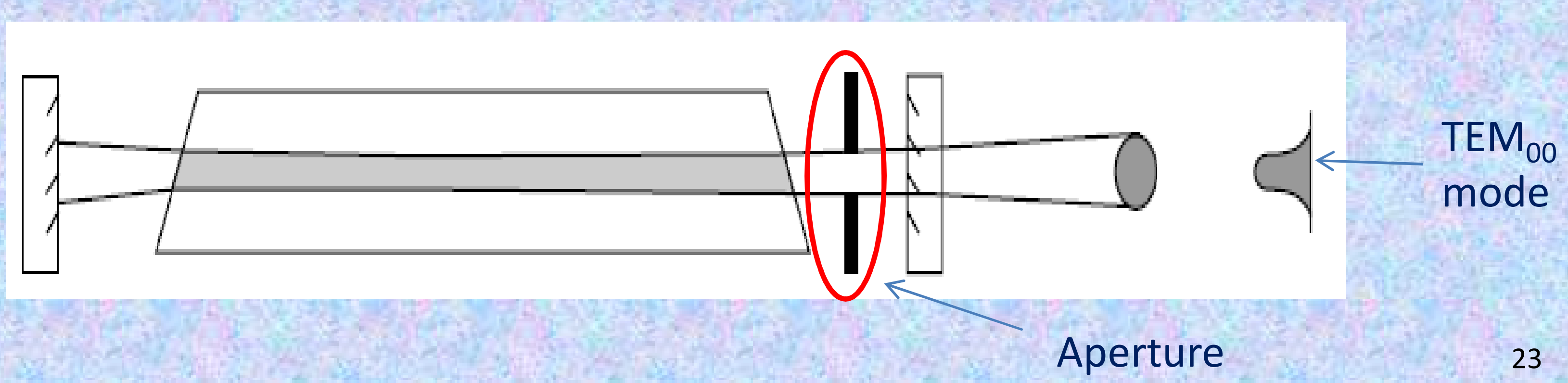
- Particular electromagnetic field pattern of radiation measured in a plane perpendicular (i.e., transverse) to the propagation direction of the beam.

TEM modes



Limiting Modes

- Many small-bore lasers often operate exclusively in TEM_{00} mode.
- To prevent a laser from oscillating in higher-order modes an aperture of the proper size inside the cavity can be placed so that only the TEM_{00} mode will fit through it.

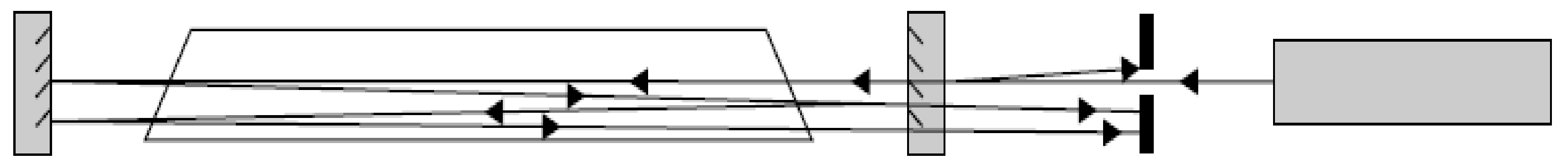


Resonator Alignment

- Mirrors have to be aligned with respect to the cavity to ensure stability.
- Depending upon the diameter (bore) of the laser gain medium, different processes are used for alignment.
  - Large-bore lasers > Visible alignment laser
  - Small-bore lasers > Autocollimator alignment

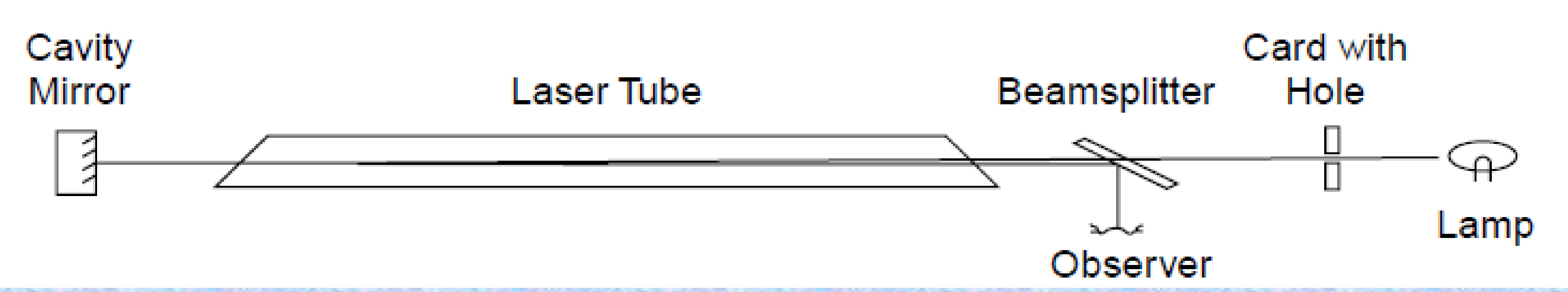
Visible alignment laser

- Used in carbon dioxide laser, YAG laser
- Steps:
  1. Alignment of the high reflector (HR)
  2. Alignment of the output coupler (OC)

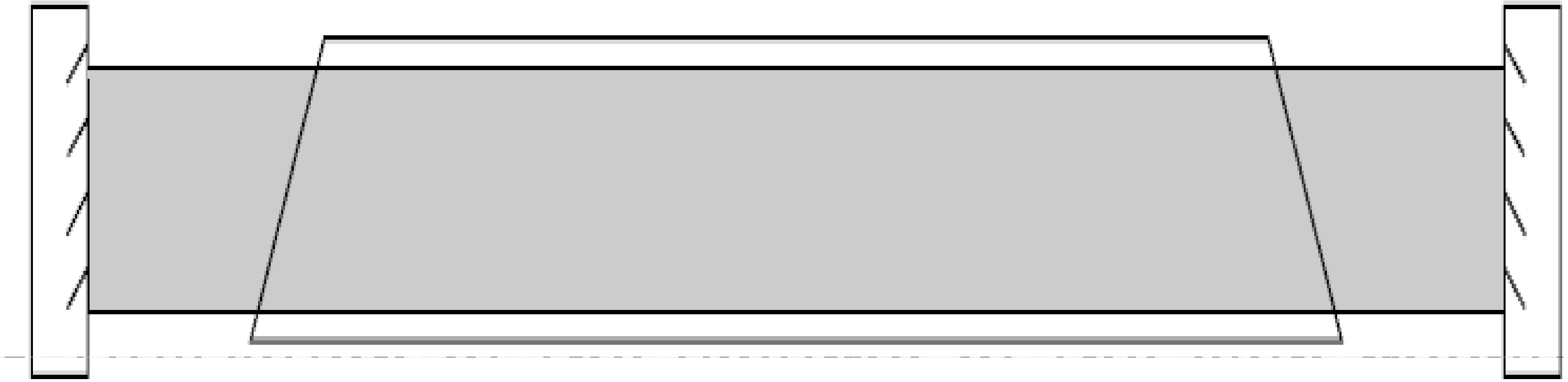


Autocollimator alignment

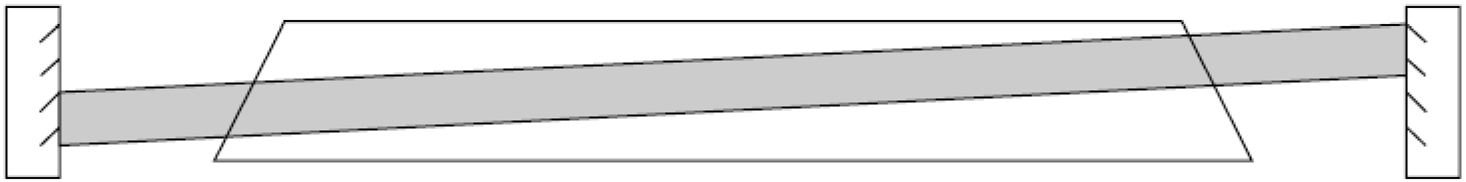
- Used in HeNe laser, argon laser
- Steps:
  1. Alignment of the high reflector (HR)
  2. Alignment of the output coupler (OC)
  3. Adjustment for maximum output



Misalignment



Properly Aligned Cavity



Misaligned Cavity

Thank you all.....