Al-Mustaqbal University

College of Engineering & Technology

Biomedical Engineering Department

Subject Name: Medical Lasers in Engineering

Third Class, Second Semester

Subject Code: [Insert Subject Code Here]

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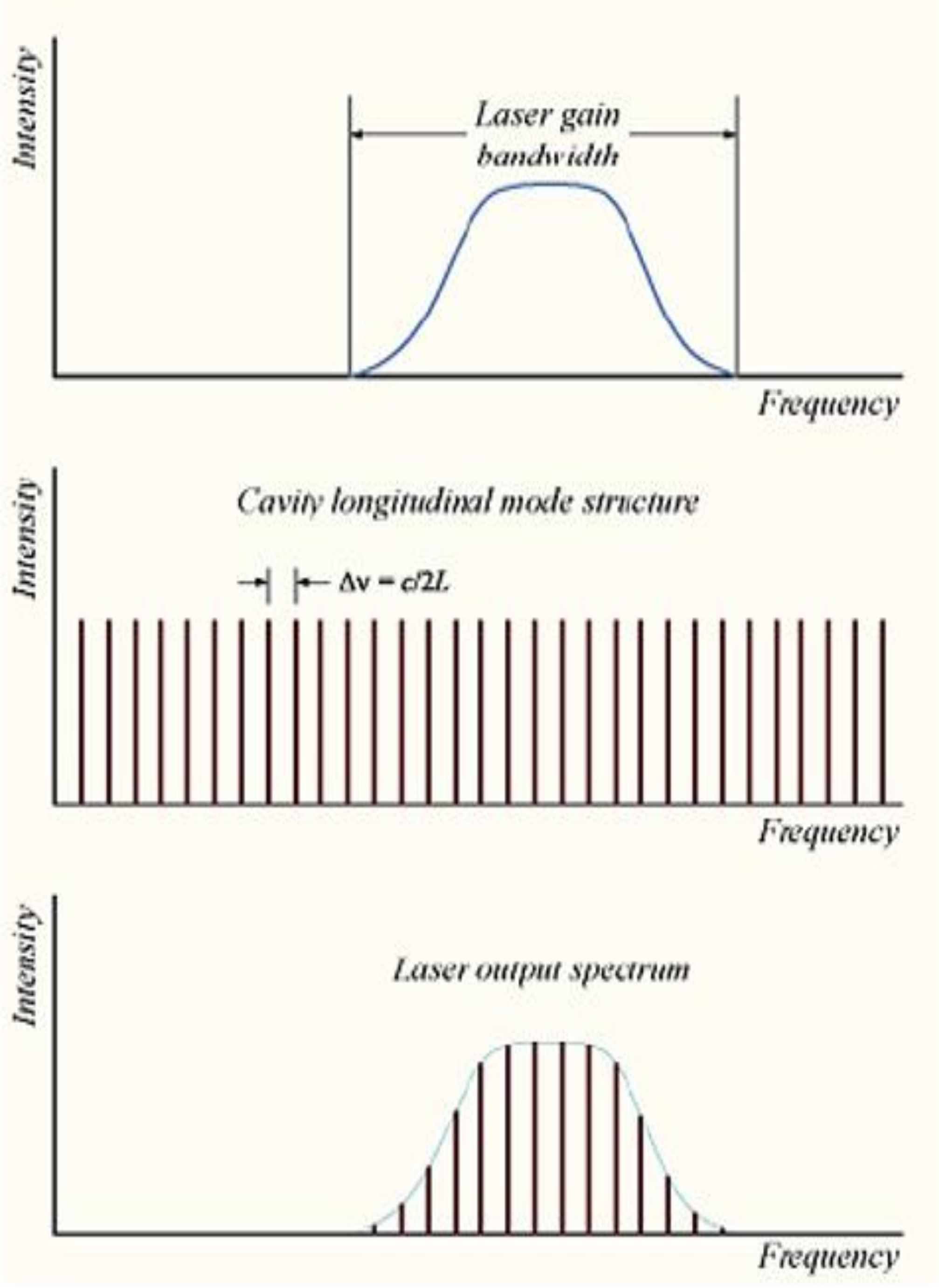
Lecture No.:-3

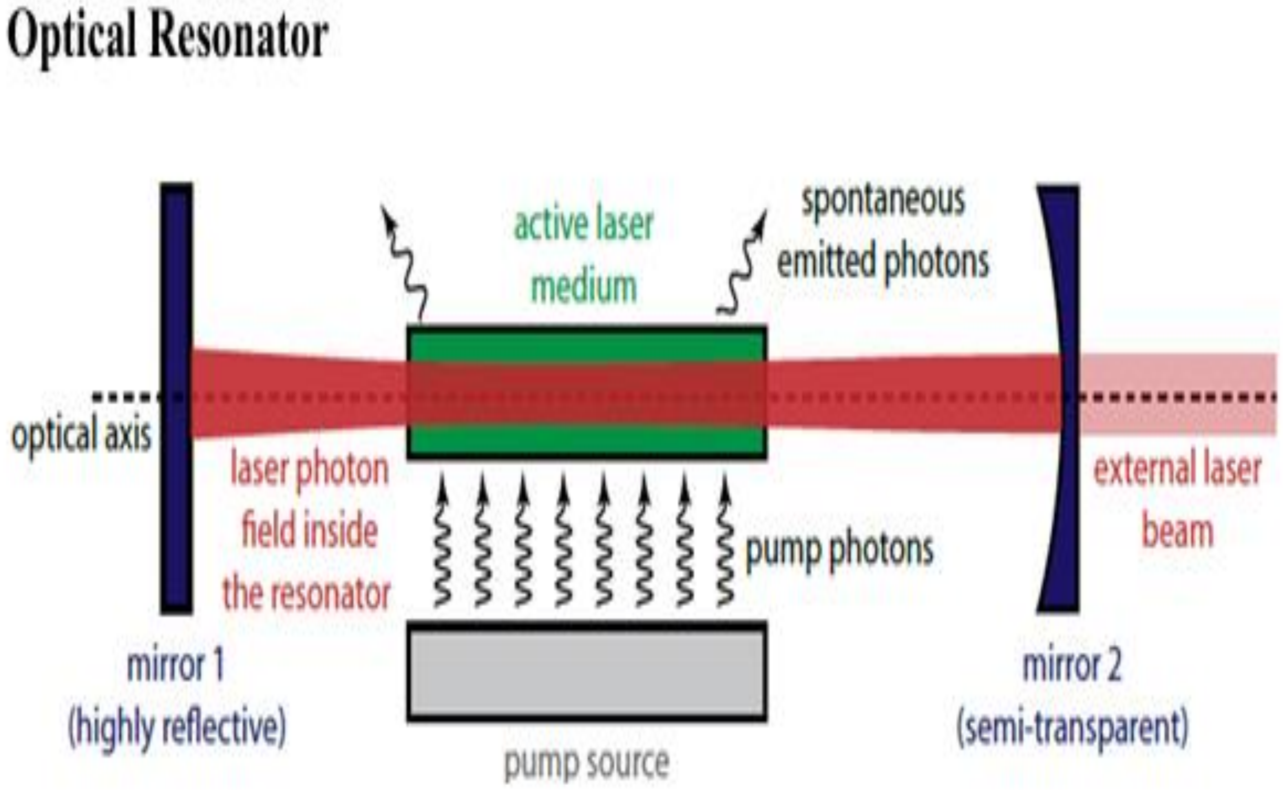
Lecture Title: [Laser beam characteristics]

Laser Modes

The output of a laser consists of several very closely spaced, discrete frequency components (that is very narrow spectral lines) covering a moderately broad spectral range. The discrete components are called laser modes and the spectral range they occupy is approximately the fluorescent linewidth of the atomic transition produce the laser output. It is obvious that the laser medium will only exhibit gain over the range of frequencies of the fluorescent line. The precise frequencies within this range that
are amplified by stimulated emission depends on;

- The nature of the mirrors and their separation.
- The losses in the system.
- The broadening mechanism.


Intensity
Laser gain
bandwidth
Frequency
Intensity
Cavity longitudinal mode structure
Δv = c/2L
Frequency
Intensity
Laser output spectrum
Frequency


Optical Resonator
active laser
medium
spontaneous
emitted photons
optical axis
laser photon
field inside
the resonator
pump photons
external laser
beam
mirror 1
(highly reflective)
pump source
mirror 2
(semi-transparent)

An optical cavity or optical resonator is an arrangement of mirrors that forms a standing wave cavity resonator for light waves. Optical cavities are a major component of lasers, surrounding the gain medium and providing feedback of the laser light. Light confined in the cavity reflect multiple times producing standing waves for certain resonance frequencies, and due to the effects of interference, only certain patterns and frequencies of radiation will be maintained by the resonator, with the others being suppressed by destructive interference. In general, radiation patterns which are reproduced on every round-trip of the light through the resonator are the most stable. The standing wave patterns produced are called modes of the resonator.

Resonator modes can be divided into two types:

- Axial or longitudinal modes, which differ in frequency from each other.
- Transverse modes, which may differ in both frequency and the intensity pattern of the light across the cross section of the beam. The basic, or fundamental transverse mode of a resonator is a Gaussian beam.

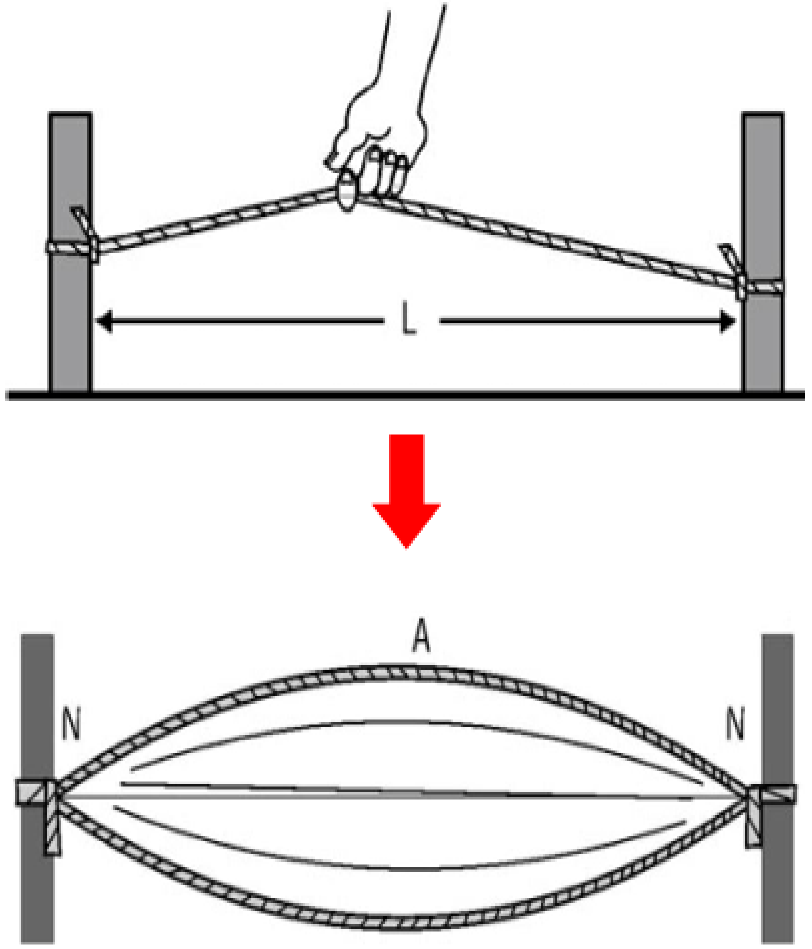
Laser mirrors serve two goals:

1. Increase the length of the active medium, by making the beam pass through it many times.

2. Determine the boundary conditions for the electromagnetic fields inside the laser cavity.

Standing Wave Patterns

The diagram below shows one of the natural patterns of vibrations for a string. In the pattern, there are certain positions along the string (the medium) that appear to be standing still (don’t move at all). These positions are referred to as nodes (N). In between each nodal position, there are other positions that appear to be vibrating back and forth between a large upward displacement to a large downward displacement (move up and down with the greatest amplitude). These points are referred to as antinodes (AN). There is an alternating pattern of nodal and antinodal positions in a standing wave pattern.



Standing Waves

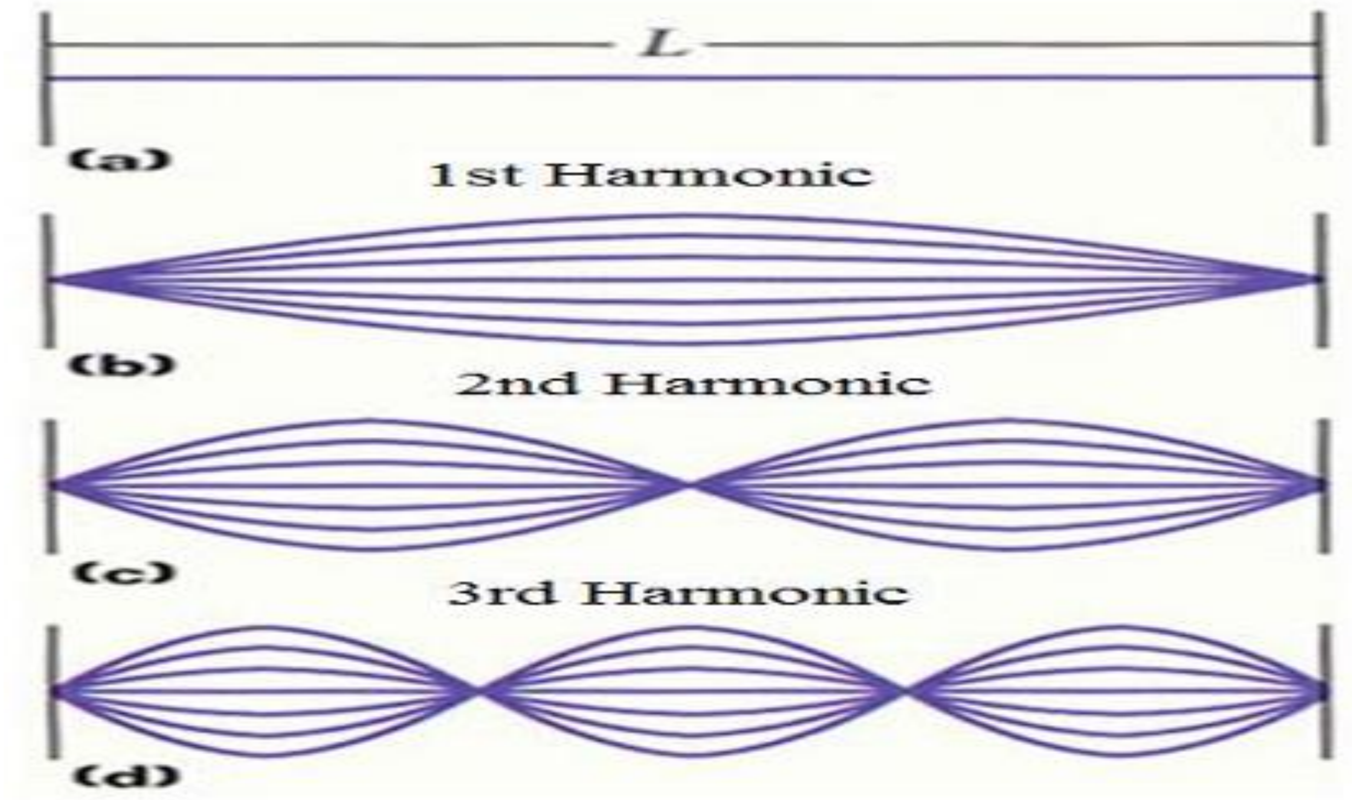
Wave pattern that results when two waves of the same frequency, wavelength and amplitude travel in opposite directions and interfere. Also known as a stationary wave – is a wave in a medium in which each point on the axis of the wave has an associated constant amplitude. The locations at which the amplitude is minimum are called nodes, and the locations where the amplitude is maximum are called antinodes.

Node: point in a standing wave that always undergoes complete destructive interference.

Antinode: point in a standing wave, halfway between two nodes, at which the largest amplitude occurs. Because the antinodal positions along the string are vibrating back and forth from a large upward displacement to a large downward displacement, the standing

wave pattern is often depicted by a diagram such as that shown below;

- **Fundamental Frequency** is the lowest frequency of vibration which produces a standing wave. There are a variety of patterns by which the string could naturally vibrate. Each pattern is associated with one of the natural frequencies of the strings. Three other patterns are shown in the next Figure. Each standing wave pattern is referred to as a harmonic of the string (first, second, and third harmonics). All represent the standing wave patterns for the string.



Axial (longitudinal) modes

For laser oscillations to occur a wave within the cavity must replicate itself after two reflections so that the electric fields add in phase. In other words, the mirrors form a resonant cavity and standing-wave patterns are set up in exactly the same way as standing waves develop on a string. For creating a standing wave;

1. The optical path from one mirror to the other and back must be an integer multiplication of the wavelength.

2. The wave must start with the same phase at the mirror.

3. The Length between the mirrors is constant (L).

4. If any phase changes which might occur on reflection at the mirrors is ignored, the phase change experienced by a wave in a round trip is;