Lecture 7

Laser resonator Longitudinal and Transverse Modes

An intensity distribution not only along the resonator axis but also in the plane perpendicular to the direction of the laser beam propagation was observed. This intensity distribution was classified to two modes longitudinal and transverse modes.

a) Longitudinal mode

When the beam is developing within the mirror cavity, traveling back and forth, certain wavelengths within the gain bandwidth of the laser tend to be more enhanced than others. These are wavelengths (or frequencies) in which the light beam in the cavity forms a standing wave. Longitudinal modes are standing waves along the optical axis of the laser see figure 18.

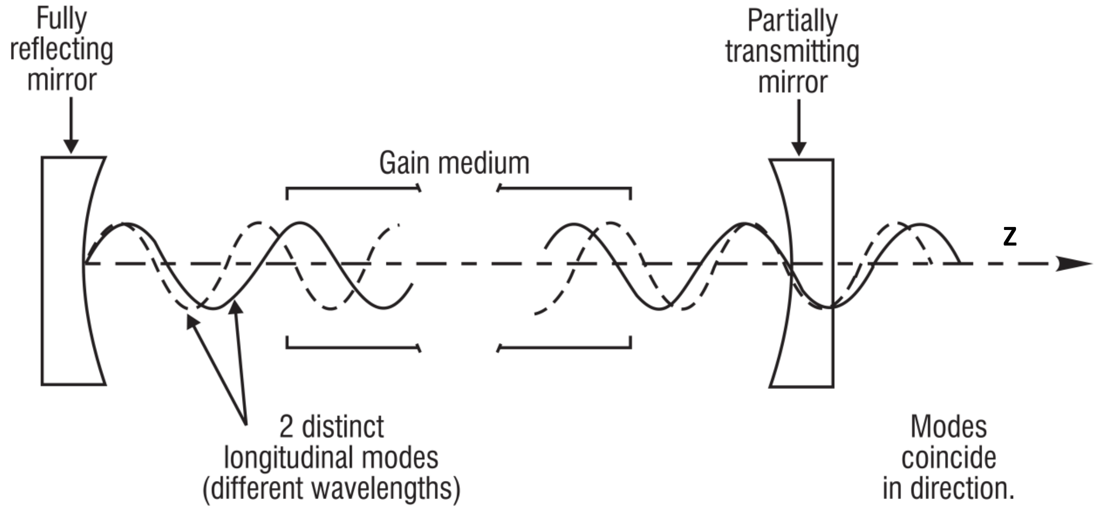

Figure 18: Two distinct longitudinal modes operating simultaneously in the same laser cavity

The condition of the standing wave, undergo amplification.

$$m\frac{\lambda}{2} = L \ldots\ldots..(32)$$

The standing wave arising along the resonator axis, characterized by the wavelength λ and the integer number, *m*, is called the longitudinal mode *m*.

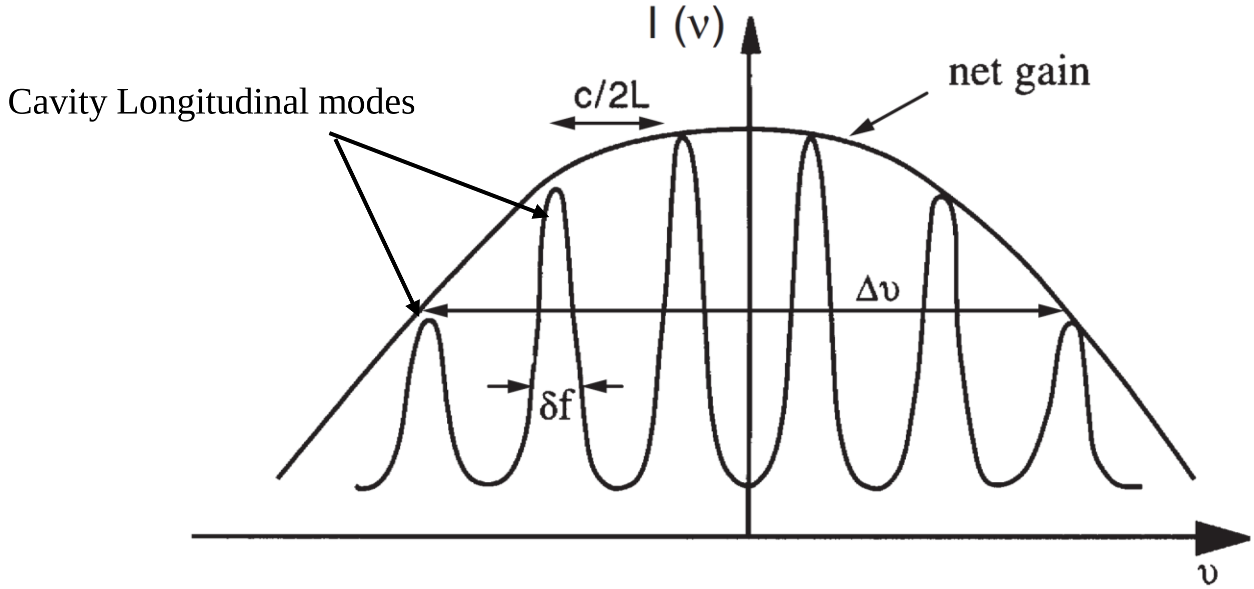

Figure 19: Schematic emission spectrum of a laser

The cavity has a specific period a round-trip time of flight *T* = *2L/c*. The frequency separation between the two modes is:

$$\delta\upsilon = c/2L \ldots\ldots(33)$$

Moreover, the bandwidth of the net gain $\Delta\upsilon$.

$$\Delta\upsilon = \frac{c}{2nL}.m \ldots\ldots..(34)$$

Where *n* is the refractive index of the material.

b) Transverse Modes

The specific transverse intensity distribution depends on the resonator configuration because the beam size *w(z)* depends on the resonator parameters such as curvature of the mirrors R and the resonator length L. Therefore, the shape of the mode changes as it propagates along the resonator axis.

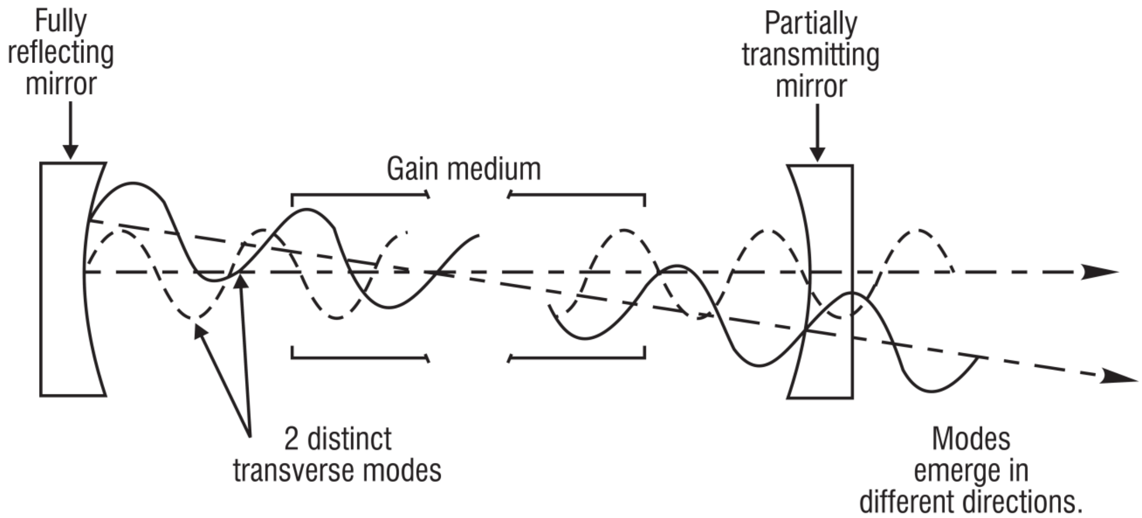

Figure 20: Two transverse modes occurring simultaneously within a laser cavity.

Different transverse modes involve slightly different optical paths through the amplifier and thus have slightly different directions when they emerge from the laser as shown in Figure 18. Because of the different optical path lengths, they also have slightly different frequencies. Each transverse mode traveling over its unique path might also consist of several longitudinal modes separated in frequency.

The distributions characterized by the integers n and m are called the transverse mode and are designated as TEM_{mn} (TEM stands for the Transverse Electromagnetic Mode). The m and n refer to the number of intensity nodes of the resonator mode pattern along the y and x-axis, respectively. That is, in Cartesian coordinates, the x and y-axes are orthogonal to each other and to the resonator propagation, or z, axis.

The optical intensity distribution of such a mode (Figure 18) shows the transverse modes.

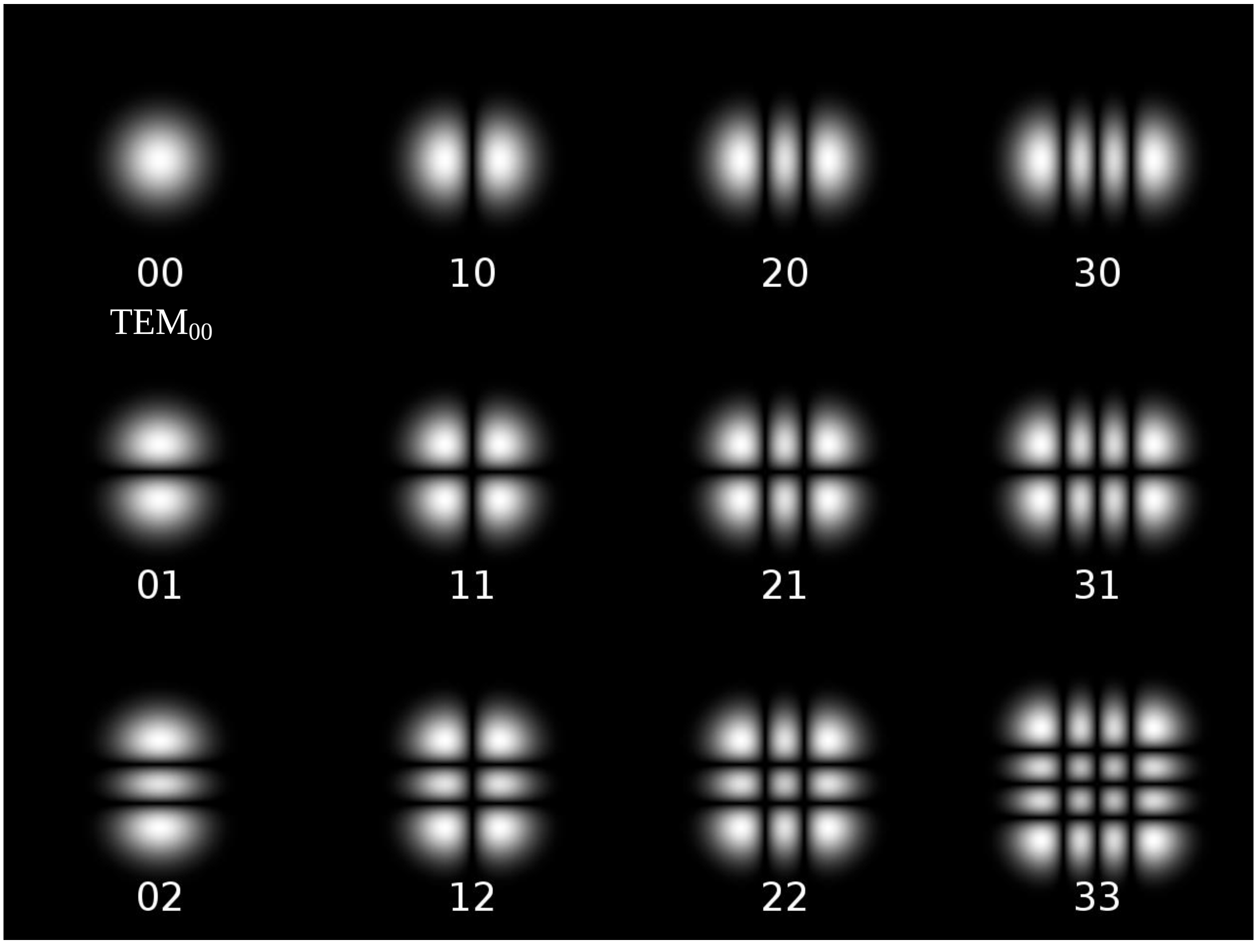

Figure21. Transverse Gaussian mode patterns with m, n indicated.

Control of the Transverse Modes of the Laser

When a laser operates in several transverse modes, the total intensity profile is a superposition of all existing transverse modes.

The lower transverse modeTEM$_{00}$ have the smallest diameter compared to other modes.

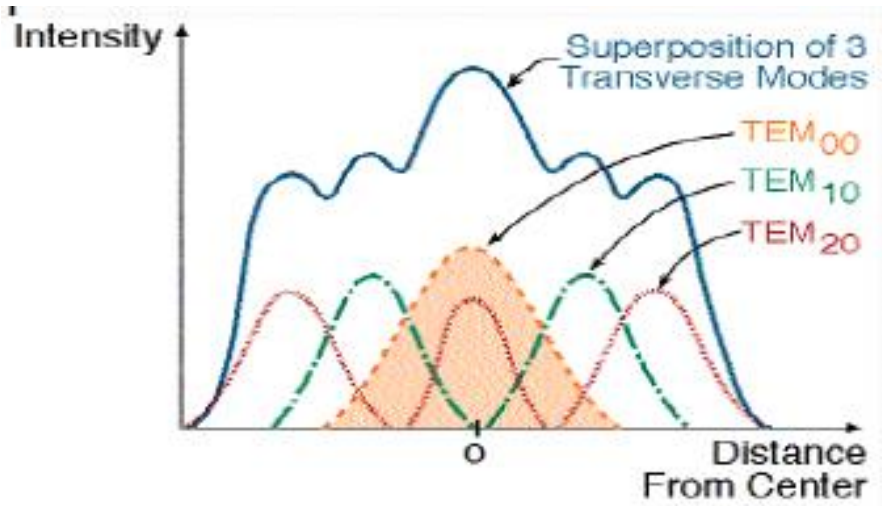

Figure 22: superposition of some of the transverse modes

How to make a laser operate in a single basic transverse mode?

By installing and choosing a pinhole diameter inside the optical cavity equal to the diameter of the lower transverse mode TEM_{00}, only this mode can pass through the pinhole, and all higher modes are attenuated.

Problems15:

Calculate the wavelengths of the following longitudinal modes where the distance between the cavity mirrors is 25 cm:

m =1.
m = 10.
m = 100.
m = 10^6

Problem 16:

The length of the optical cavity in a He-Ne laser is 30 [cm]. The emitted wavelength is 0.6328 [mm]. Assuming the refractive index for effective medium $n \approx 1$

Calculate

1. The number of the emitted longitudinal mode at this wavelength

2. The bandwidth of the net gain $\Delta\upsilon$:

Problem 17:

The length of the optical cavity in He-Ne laser of a wavelength of 632.8 nm is 55 [cm]. Find the approximate number of longitudinal laser modes. :

Problem 18:

A Ruby laser contains a crystal length (4cm) with a refractive index of (1.78). The peak emission wavelength from the device is (0.55μm). Determine the number of longitudinal modes and the bandwidth of the net gain: