Mode Selection

In general, the spot size of the TEM_{00} mode is relatively small. For example, a symmetric resonator with R = 2 m and L = 1 m has a radius of the TEM_{00} mode of w_0 = 0.5 mm at a wavelength of 1.06 μm. If the transverse dimension of the gain region of the active material is larger than the TEM_{00} mode dimension, a laser oscillator will typically operate in an incoherent superposition of several modes.

Many applications of solid-state lasers require operation of the laser at the TEM_{00} mode since this mode produces the smallest beam divergence, the highest power density, and hence the highest brightness. Furthermore, the radial profile of theTEM_{00} mode is smooth.

A large amount of research has been devoted to the design of optical resonator configurations that maximize energy extraction from solid-state lasers at the TEM00 mode. One finds that a resonator designed for TEM00 mode operation will represent a compromise between the conflicting goals of large mode radius, insensitivity to perturbation, good mode discrimination, and compact resonator length.

Insertion of an Intracavity Aperture.

With a properly sized intracavity aperture higher order modes can be suppressed and the laser can be forced to operate at the TEM00 mode but at the cost of substantially reduced output power and efficiency.

The diffraction losses caused by a given aperture and the transverse mode selectivity achievable with an aperture of radius (a) is illustrated in Fig. 1.

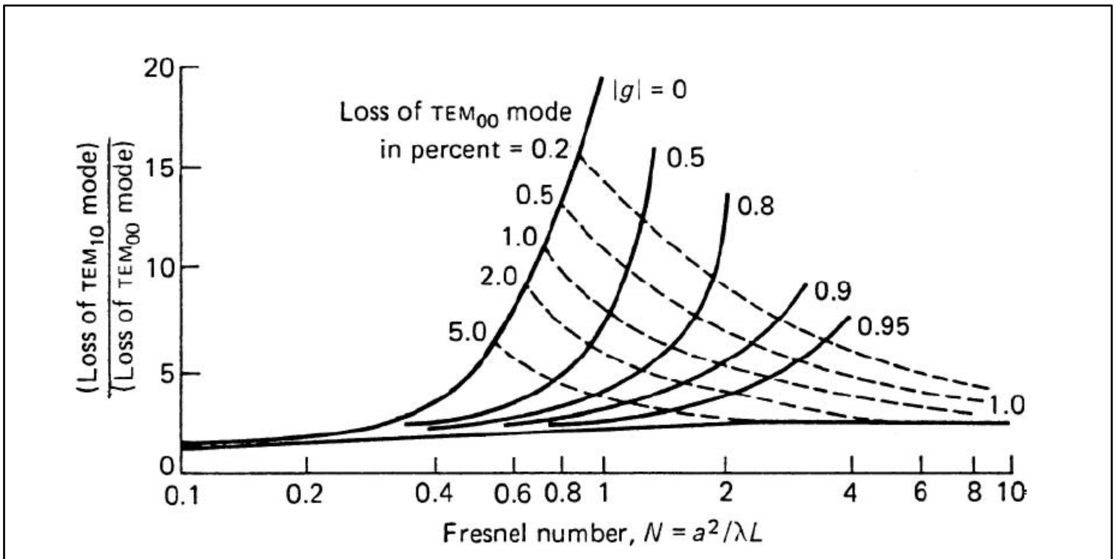


Fig.1. Ratio of the losses per transit of the two lowest order modes for the symmetrical resonator. The dashed curves are contours of constant loss for the TEM00 mode

Increasing Mode Size: Because the TEM00 mode has the smallest beam diameter of all the resonator modes, a number of techniques have been developed to increase the TEM00 mode volume in the active material, which is normally considerably larger in diameter than the mode size. One obvious solution to increase the TEM00 mode volume is to make the resonator as long as physical constraints permit, since for a given Fresnel number, the mode cross-sectional area increases proportional with length. Another approach is to utilize resonators, such as the concentric and hemispherical configuration. These resonators, owing to their focusing action, support large mode size differences along the axis. For example, in a hemispherical cavity the spot size in the limit can theoretically become zero at the flat mirror and grow to infinity for L = R. Location of the laser rod close to the curved mirror permits utilization of a large active volume as indicated in Fig.2.

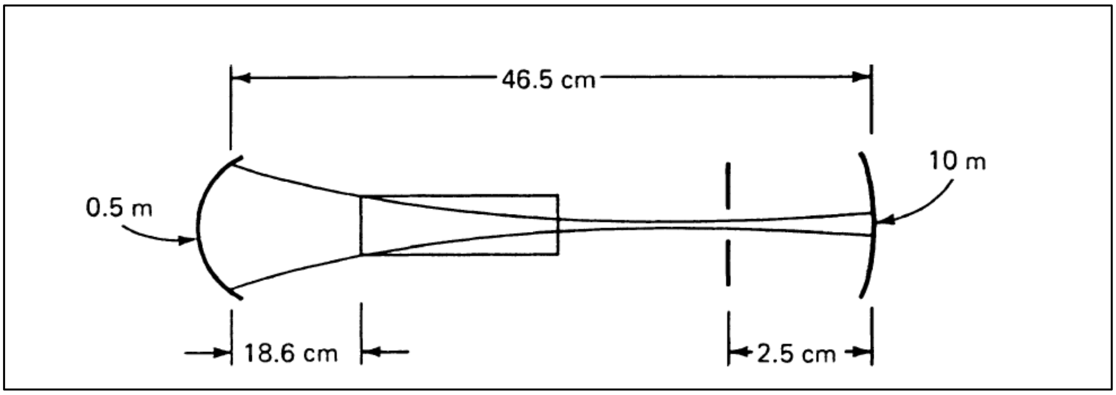
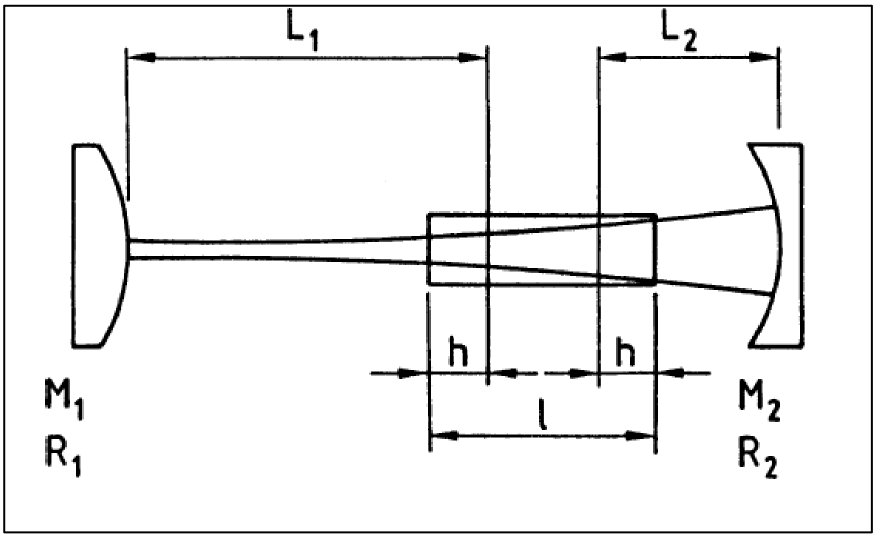


Fig.2 Focusing resonator geometry

Spatial Match of Gain Region and TEM00 Mode. In the end-pumped lasers the most elegant solution to the problem of mode selection can be implemented, namely a spatial match between the pump beam and the resonator TEM00 mode. Because the beam characteristics of diode lasers allow for tight focusing of their output radiation into the active material, a near-perfect overlap between the pump or gain region and the TEM00 mode volume can be achieved. Typically, the pump beam and resonator axis are oriented collinear within the active material. This way highly efficient TEM00 mode operation can be achieved.

Concave–Convex Resonator for a Weakly Focusing Laser Rod:
We concluded that with a convex mirror at one end of the resonator one can achieve $g1/g2 > 1$ and independently set $g1g2 = 0.5$. The first condition provides a large spot size $w2$ on mirrorM2, and the second condition minimizes the resonator sensitivity to changes of focal length. Another advantage of a concave resonator is its compactness in comparison with other resonators. Figure (4) illustrates a typical configuration consisting of a short-radius convex mirror at one end of the resonator, and a concave mirror at the other end of the laser rod close to it.



Concave–convex resonator containing a Nd:YAG rod

As an example we will calculate the parameters for a concave–convex resonator that has been used for a high repetition rate Nd:YAG laser. The laser rod, with a diameter of 5 mm, was measured to have a focal length of 6 m for a particular input. The length of the cavity was restricted to about 0.8 m. The optimum value of $w2$ has been found empirically to be equal to one-half the laser rod radius. With the rod as close as possible to the output mirror, the following design parameters are obtained for the equivalent resonator

$$w_2 = 1.25 \text{ mm}, \quad f = 6 \text{ m}, \quad L_1 = 0.7 \text{ m}, \quad L_2 = 0.1 \text{ m}.$$

We obtain a value of $g1 = 2.9$, and $g2 = 0.17$. The spot size on the concave mirror has a value of $w1 = 0.31$ mm. The curvatures of the mirrors can be as follows: The radius of the convex mirror is $R = -0.41$m and the concave mirror has a radius of $R = 1.1$m. The physical length of the resonator will be 82.25 cm for a 5-cm-long Nd:YAG crystal.

The design parameters for this particular laser cavity illustrate one disadvantage of the concave-convex resonator, namely, a very small spot size at the concave mirror.
This small spot size, which could lead to mirror damage, effectively precludes the use of this resonator in high-power Q-switched lasers.