Transverse Modes and Mode Control

The fundamental TEM_{00} mode is only one of many transverse modes that satisfies the condition that it be replicated each round-trip in the cavity. Figure 10.9 shows examples of the primary lower-order Hermite-Gaussian (rectangular) modes.

Note that the subscripts m and n in the mode designation TEM_{mn} are correlated to the number of nodes in the x and y directions. The propagation equation can also be written in cylindrical form in terms of radius (ρ) and angle (ϕ). The eigenmodes ($E_{\rho\phi}$) for this equation are a series of axially symmetric modes, which, for stable resonators, are closely approximated by Laguerre-Gaussian functions, denoted by $TEM_{\rho\phi}$. For the lowest-order mode, TEM_{00}, the Hermite-Gaussian and Laguerre-Gaussian functions are identical, but for higher-order modes, they differ significantly, as shown in figure 10.10.

The mode, TEM_{01}*, also known as the “bagel” or “doughnut” mode, is considered to be a superposition of the Hermite-Gaussian TEM_{10} and TEM_{01} modes, locked in phase and space quadrature. (See W.W. Rigrod, “Isolation of Axi-Symmetric Optical-Resonator Modes,” *Applied Physics Letters*, Vol. 2 (1 Feb. ‘63), pages 51–53.)

In real-world lasers, the Hermite-Gaussian modes predominate since strain, slight misalignment, or contamination on the optics tends to drive the system toward rectangular coordinates. Nonetheless, the Laguerre-Gaussian TEM_{10} “target” or “bulls-eye” mode is clearly observed in well-aligned gas-ion and helium neon lasers with the appropriate limiting apertures.

MODE CONTROL

The transverse modes for a given stable resonator have different beam diameters and divergences. The lower the order of the mode is, the smaller the beam diameter, the narrower the far-field divergence, and the lower the M^2 value. For example, the TEM_{01}* doughnut mode is approximately 1.5 times the diameter of the fundamental TEM_{00} mode, and the Laguerre TEM_{10} target mode is twice the diameter of the TEM_{00} mode. The theoretical M^2 values for the TEM_{00}, TEM_{01}*, and TEM_{10} modes are 1.0, 2.3, and 3.6, respectively (R. J. Freiberg et al., “Properties of Low Order Transverse Modes in Argon Ion Lasers”). Because of its smooth intensity profile, low divergence, and ability to be focused to a diffraction-limited spot, it is usually desirable to operate in the lowest-order mode possible, TEM_{00}. Lasers, however, tend to operate at the highest-order mode possible, either in addition to, or instead of, TEM_{00} because the larger beam diameter may allow them to extract more energy from the lasing medium.

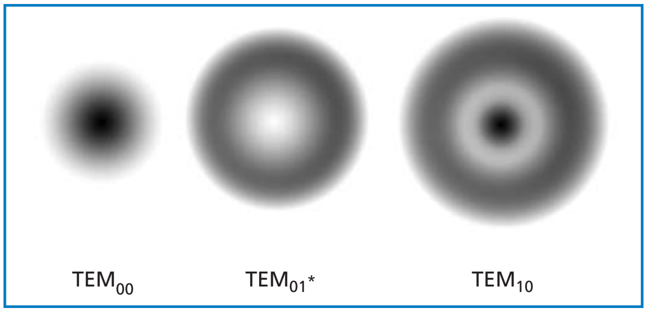

Figure 10.10 **Low-order axisymmetric resonator modes**

The primary method for reducing the order of the lasing mode is to add sufficient loss to the higher-order modes so that they cannot oscillate without significantly increasing the losses at the desired lower-order mode. In most lasers this is accomplished by placing a fixed or variable aperture inside the laser cavity. Because of the significant differences in beam diameter, the aperture can cause significant diffraction losses for the higher-order modes without impacting the lower-order modes. As an example, consider the case of a typical argon-ion laser with a long-radius cavity and a variable mode-selecting aperture.

When the aperture is fully open, the laser oscillates in the axially symmetric TEM_{10} target mode. As the aperture is slowly reduced, the output changes smoothly to the TEM_{01}* doughnut mode, and finally to the TEM_{00} fundamental mode.

In many lasers, the limiting aperture is provided by the geometry of the laser itself. For example, by designing the cavity of a helium neon laser so that the diameter of the fundamental mode at the end of the laser bore is approximately 60 percent of the bore diameter, the laser will naturally operate in the TEM_{00} mode.

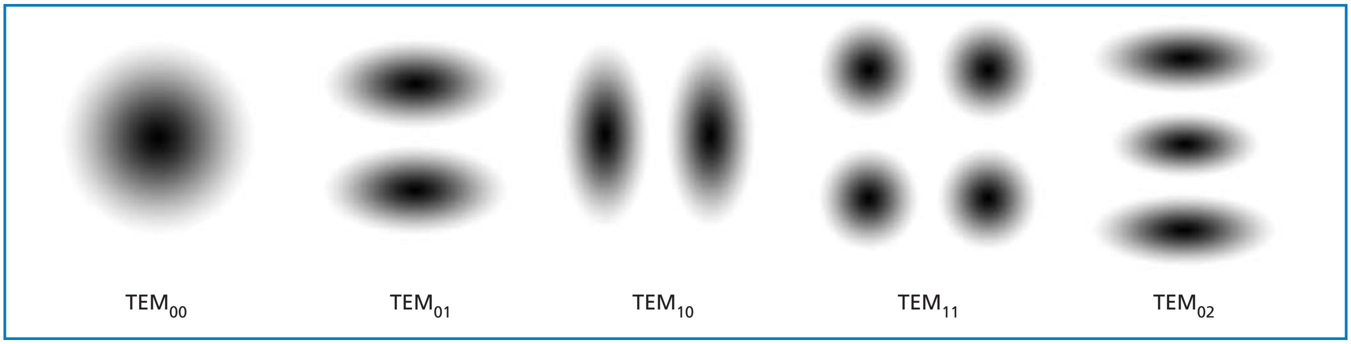

Figure 10.9 **Low-order Hermite-Gaussian resonator modes**