HeNe Lasers

HeNe lasers are the preferred light sources for a variety of metrological, alignment, and control tasks. HeNe lasers allow performing tasks that would be extremely difficult, or even impossible, to perform using conventional light sources.

HeNe lasers emit intense, monochromatic, spatially coherent, highly collimated light beams.

The most prominent features of our HeNe lasers are:

- they are simple and easy to use
- they mate to our other components and systems
- they provide reliable, dependable operation
- they have long service lives

This brief introduction covers the principles of their operation, plus their basic characteristics to aid in the selection of HeNe lasers for given applications and to make the most of their capabilities.

Principles of HeNe laser operation

Like all other lasers, HeNe lasers consist of a resonator structure enclosing an active, amplifying medium. Their active medium is a helium-neon gas mixture enclosed within a resonator consisting of two mirrors, one of which is partially transmissive in order to allow a small fraction of the energy carried by the electromagnetic waves circulating within the resonator to escape in the form of a laser beam.

Resonator modes and gain curves

Within the resonator, electromagnetic energy will be able to circulate as standing waves at those wavelengths, λ, for which the resonator's length, L, is an integral multiple of half-wavelengths, i.e., at those wavelengths satisfying the relation:

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

where m is an integer. Wavelengths satisfying this relation will be separated in frequency, u, by increments of Du, the resonator's longitudinal mode separation, given by:

$$\Delta\upsilon \approx \frac{c}{2 \cdot L}$$ (c = speed of light in active medium).

The number, N, of longitudinal modes emitted by HeNe lasers is governed by the Doppler-broadened widths of active neon emission lines. Since the full width at half maximum intensity (FWHM) of the 632.8-nm laser line is roughly 1500 MHz, N will be approximately given by:

$$N \approx \frac{1500\ \text{MHz}}{\Delta\upsilon}$$

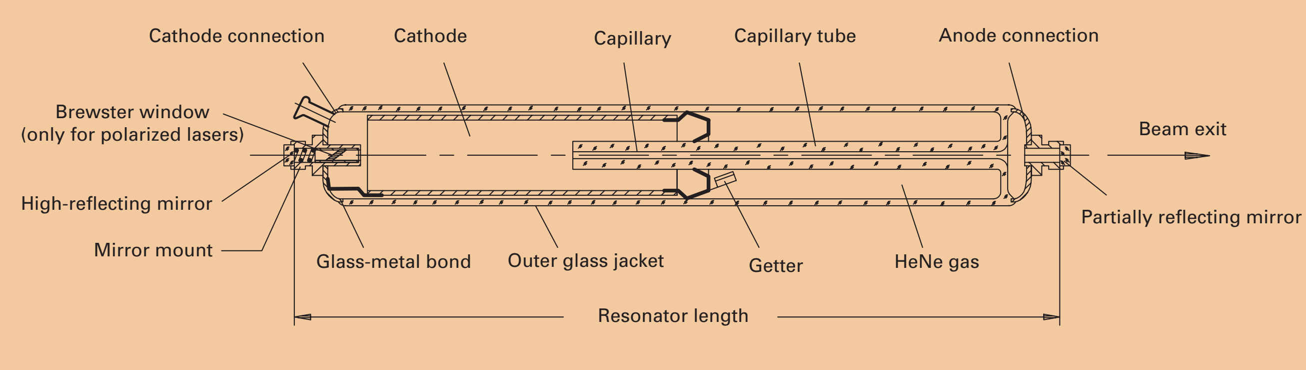
The number of active longitudinal modes will determine the coherence length of emitted laser radiation. Since HeNe lasers typically have resonator lengths of about 0.2 m, yielding longitudinal mode separations of about 750 MHz, only a few of their longitudinal modes will be active, a fact that makes them ideal for use in interferometric work.

Polarization properties

Light is defined to be plane-polarized (or linearly polarized) if its electric-field vector oscillates in a fixed plane containing its direction of propagation. It is defined to be circularly polarized if its electric-field vector describes a helix as the electromagnetic wave advances. Circularly polarized light may be viewed as the superposition of two plane-polarized electromagnetic waves of common wave-length with mutually orthogonal electric-field vectors differing in phase by one-quarter wavelength. Conversely, plane-polarized light may be decomposed into right and left circularly polarized electromagnetic waves.

HeNe lasers lacking polarizing elements in their resonators emit longitudinal modes alternately linearly polarized in mutually orthogonal planes. The total number of longitudinal modes emitted, their relative intensities, and the orientations of their principle planes of polarization vary with their operating conditions. HeNe lasers having resonators lacking polarizing elements, such as Brewster plates or Brewster windows, thus exhibit randomly varying linear polarizations, i.e., their beams are unpolarized, or only weakly polarized.

The discharge tubes of our lineraly polarized HeNe lasers are equipped with internal Brewster plates that provide linear polarizations of 500:1.



Cross section of a HeNe laser tube

Beam geometry

Laser beams do not have sharp boundaries. Most of the LINOS HeNe lasers operate in their lowest-order (TEM_{00}) tranverse modes; i.e., their beams have transverse intensity profiles, I(r), describable by Gaussian distributions:

$$I(r) = I_0 \cdot e^{\frac{-2 \cdot r^2}{w^2}}$$

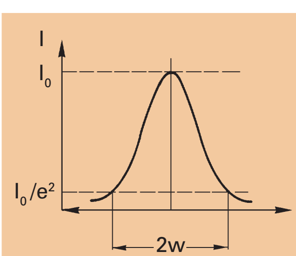
where I_o is the intensity at the beam's symmetry axis, and r is radial distance from this axis. Beam radius, w, or beam diameter, 2w, are defined by the values of r for which beam inten-sity declines to 1/e² (13.5%) of its central maximum.

Beam diameter increases with distance from the laser, i.e., laser beams diverge. Beams of lasers emitting exclusively in their lowest-order modes have divergence half-angles, Θ, given by:

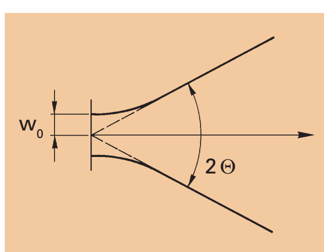
$$\Theta = \frac{\lambda}{\pi \cdot w_0},$$

where λ is laser wavelength, and w_0 is the minimum beam radius, i.e., beam radius at the beam "waist."

The product of beam waist diameter and beam divergence angle is constant for any given laser beam, which implies that the divergence angles of laser beams are inversely proportional to their waist radii. Laser beams having larger waist diameters will thus have smaller divergence angles, and vice versa.



Beam diameter



Beam divergence

Beam radii increase with distance on both sides of beam waists, according to the relation:

$$w(z) = w_0 \cdot \sqrt{1 + \left(\frac{\lambda \cdot z}{\pi \cdot w_0^2}\right)^2} = w_0 \cdot \sqrt{1 + \left(\frac{\Theta \cdot z}{w_0}\right)^2},$$

where w(z) is beam radius at a distance z from the beam waist.

Our HeNe lasers have beam waists coincident with their output mirrors.

At larger distances (several meters or more) from the laser, w(z) may be approximated by:

$$w(z) = \Theta \cdot z$$

Collimating laser beams

Increasing the diameters of laser beams further collimates them, i.e., reduces their divergence angles. The best method for increasing laser beam diameters employs beam-expanding telescopes. If these telescopes are mounted with their exit optics situated at the beam waist, the relationship between beam divergence angles and beam-expansion ratios will be:

Beam divergence angles will be reduced in inverse proportion to telescope beam-expansion ratios.

Focusing laser beams

Due to their small divergence angles, laser beams may be focused down to small spot sizes. Focusing laser beams increases their power densities in proportion to the ratios of their unfocused and focused cross-sectional areas.

The minimum spot radii, w_f achievable by focusing laser beams will be approximately given by:

$$w_f \approx \frac{\lambda \cdot f}{\pi \cdot w_0} = f \cdot \Theta \quad \text{at the point } z' = \frac{z \cdot f^2}{z^2 + \left(\frac{\pi \cdot w_0^2}{\lambda}\right)^2},$$

where w_0 is the radius of the beam entering the focusing lens, and f is its focal length.

Summarizing, we can state that the spot radii of focused laser beams are:

- proportional to the focal lengths of the focusing lenses employed
- proportional to their divergence angles, and inversely proportional to their unfocused radii

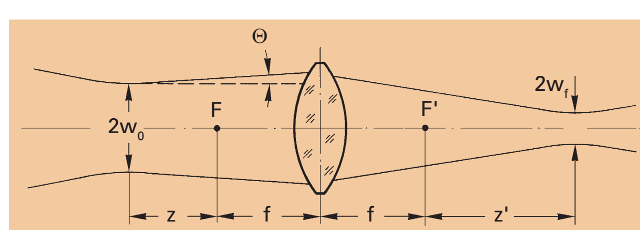
Depth of focus

Depth of focus is defined as the lengths of ranges about beam focal points over which beam spot radii remain within prescribed limits. It may be derived from:

$$\Delta z = \pm \frac{\pi \cdot w_f^2}{\lambda} \cdot \sqrt{\left(\frac{w}{w_f}\right)^2 - 1},$$

where the ratio w/w_f is the tolerated variation in beam spot radii. For $w >> w_f$, the following relation holds true:

$$\Delta z = \pm \frac{\pi \cdot w \cdot w_f}{\lambda}$$



Beam focusing parameters