



Gaussian Beam Optics

Introduction

In most laser applications it is necessary to focus, modify, or shape the laser beam by using lenses and other optical elements. In general, laser-beam propagation can be approximated by assuming that the laser beam has an ideal Gaussian intensity profile, corresponding to the theoretical TEM₀₀ mode. Coherent Gaussian beams have peculiar transformation properties that require special consideration. In order to select the best optics for a particular laser application, it is important to understand the basic properties of Gaussian beams.

Unfortunately, the output from real-life lasers is not truly Gaussian (although helium neon lasers and argon-ion lasers are a very close approximation). To accommodate this variance, a quality factor, M^2 (called the "M-square" factor), has been defined to describe the deviation of the laser beam from a theoretical Gaussian. For a theoretical Gaussian, $M^2=1$; for a real laser beam, $M^2>1$. Helium neon lasers typically have an M^2 factor that is less than 1.1. For ion lasers, the M^2 factor is typically between 1.1 and 1.3. Collimated TEM₀₀ diode laser beams usually have an M^2 ranging from 1.1 to 1.7. For high-energy multimode lasers, the M^2 factor can be as high as 25 or 30. In all cases, the M^2 factor, affects the characteristics of a laser beam and cannot be neglected in optical designs.

In the following section, *Gaussian Beam Propagation*, we will treat the characteristics of a theoretical Gaussian beam ($M^2 = 1$); then, in the section *Real Beam Propagation* we will show how these characteristics change as the beam deviates from the theoretical. In all cases, a circularly symmetric wavefront is assumed, as would be the case for a helium neon laser or an argon-ion laser. Diode laser beams are asymmetric and often astigmatic, which causes their transformation to be more complex.

Although in some respects component design and tolerancing for lasers are more critical than they are for conventional optical components, the designs often tend to be simpler since many of the constants associated with imaging systems are not present. For instance, laser beams are nearly always used on axis, which eliminates the need to correct asymmetric aberration. Chromatic aberrations are of no concern in single-wavelength lasers, although they are critical for some tunable and multiline laser applications. In fact, the only significant aberration in most single-wavelength applications is primary (third-order) spherical aberration.

Scatter from surface defects, inclusions, dust, or damaged coatings is of greater concern in laser-based systems than in incoherent systems. Speckle content arising from surface texture and beam coherence can limit system performance.

Because laser light is generated coherently, it is not subject to some of the limitations normally associated with incoherent sources. All parts of the wavefront act as if they originate from the same point, and consequently the emergent wavefront can be precisely defined. Starting out with a well-defined wavefront permits more precise focusing and control of the beam than would otherwise be possible.

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