R. Milkowski
C. Morrow
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Interfacing Optical Systems with Iradion CO_2 Lasers

Scope

This Paper is intended to give some background on CO_2 Laser Technology, a basic description of laser beam performance characteristics, and describe the correct method of characterizing the beam of an Iradion CO_2 Laser. This paper is intended for practitioners who have some experience in laser systems, and want to understand how to optimize spot quality when using Iradion Ceramic CO_2 lasers.

Not all CO_2 laser-beams are the same…

CO_2 lasers are available in a variety of technologies, i.e., Glass Tube, SLAB, Waveguide, Free-space, DC-driven, or RF-Driven. Each technology has beneficial attributes for its intended market, but each will most likely have attributes that are less desirable for some applications. It is the job of the System Designer and Product Manager to weigh the cost and performance benefits of each, and select the best solution for the target market and application.

Each CO_2 Laser Technology will produce a laser-beam with different characteristics. These differences can be subtle, or can vary greatly and require optical system modifications and/or redesign. The technology used for the laser's resonator is one of the primary contributors to laser-beam disparity from one technology to another.

Resonator Design Basics

The *classic* CO_2 laser resonator is a sealed cavity containing a CO_2 gas mixture. At each end of this cavity there are optical elements with reflective properties; one end has an optical element with little-to-no optical transmission – a mirror. The other end an element with some optical transmission – the "Output Coupler". The gas in the cavity is excited electrically, causing the electrons in the gas molecules to change energy level and emit photons. The photons travel back-and-forth between the optical elements gathering optical power from the gain while some of the inter-cavity flux leaks out of the output coupler. At least one mirror in the cavity will have some curvature to provide mode stability and promote a near Gaussian spacial mode to the laser beam.

The prior paragraph describes a "stable" resonator. A stable resonator is one that has the photon propagation entirely confined between the cavity mirrors and photons escape by leaking through a partially transmissive optical element. Stable resonators have laser beams that compare well to Gaussian propagation equations, and typically can have a better Mode in both the near and far fields due to the beam being formed as a natural Gaussian within the cavity. However, because the mode is formed as a natural Gaussian, power scaling this design to high powers requires large packages and very long distances between mirrors. This limitation has led to more compact cavity designs and to beams formed by non-Gaussian means within the cavity… Unstable, Slab cavities are one prominent variety.

Iradion Laser, Inc.
51 Industrial Drive
N. Smithfield, RI 02896 USA
+1 401 762-5100
www.iradionlaser.com

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“Unstable” resonators share some common methods with Stable resonators. They both have a sealed cavity with a CO_2 gas mixture, the gas is excited by electrical means between two (maybe more) optical elements, and the changing energy levels emit photons providing optical gain. However, the major difference between Stable and Unstable resonators is the method for allowing the photons to escape from the cavity. Where photons escape a Stable resonator by leaking through the Output Coupler, Unstable resonators allow photons to escape the cavity by spilling off the edge of a cavity mirror. Unstable resonators also comprise a slab, planar discharge so there are 2 different axis dimensions leading to elongated beams and beam diffraction effects from the edge of the mirror that the beam spilled off of. Beam correction is used either in the cavity, or externally to make the beam round. Using a slab configuration allows area scaling for increased power per unit volume. This is a critical improvement that allows very high powers in a very small package. However, there are side effects to this method where higher order modes can become superimposed on the main Gaussian beam. Since these higher order modes will diverge much more rapidly than the fundamental Gaussian mode, they will not impede the performance of the laser beam at the focus (Far-Field image). For this reason, the beam of a Slab laser must be examined in its Far Field and NOT close to the laser in the Near Field.

Beam Waist, Divergence

The laser Beam Waist is where the beam is narrowest, or has the smallest diameter. The Beam Waist is typically near, or at the output aperture of the laser; this is the case with Iradion products.
As photons exit the resonator cavity, they will diverge. The divergence angle is a direct function of the number of wavelengths across the beam diameter. In the figure below, as the photons move away from the output aperture $2w_0$, 2w grows bigger in diameter along Propagation Axis. This is the beam divergence. Beam divergence becomes a near linear function in the far field only.

Far-Field, Near-Field

The near field of a laser beam is a region at or very close to the output aperture that is characterized by ***disordered phase fronts***. In the near field, beam shape, size, profile and divergence can vary rapidly with distance. How far the near field extends depends greatly on laser beam diameter.

At greater distances from the laser, the phase fronts become ordered, leading to stable beam characteristics along the propagation path. This is known as the Far-Field. A very rough approximation of the distance to the onset of the far-field region can be obtained by taking the square of the beam diameter divided by the wavelength:

$$F = 2w_0^2/\lambda$$

Where:
F = the beginning of the far field (meters)
w_0 = the beam radius (meters) ($2w_0$ = the $1/e^2$ diameter of the beam)
$\lambda = 10.6 \times 10^{-6}$ (meters)

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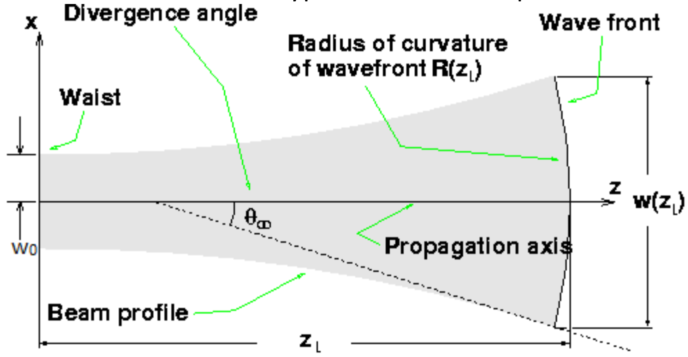
Using this equation, we can see that for a 2.5mm beam, the Iradion laser has a far field that starts at ≈ 600 mm from the laser. Iradion typically images beams at 1 meter to be conservative. Closer than 600mm will result in beam distortions that will not be typical of the beam profile at the focus of the beam.

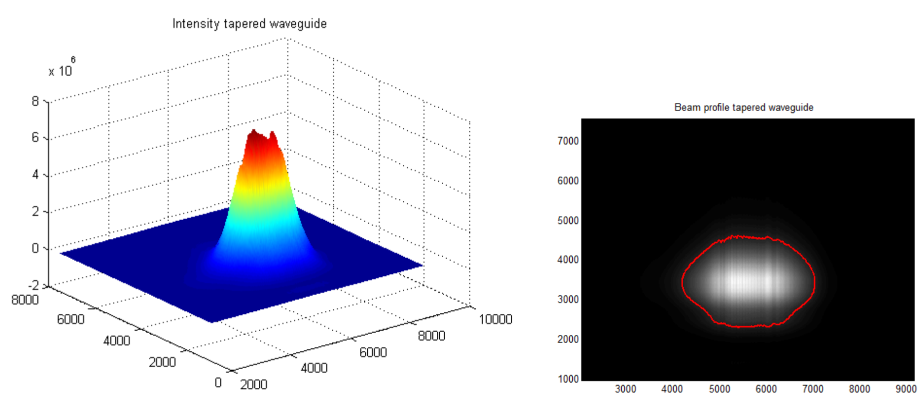


Remember that at the focus of a lens, the focal spot image will be a tiny duplicate of the Far Field image.

Wavefront Pictorial, Near-Field, Far-Field

Shown below is an example of an Iradion Laser Beam wavefront imaged in the Near, and Far-Field. Notice the improvement in Wavefront profile and spot quality as you move from the Near, into the Far-Field.

<u>Near Field, 10cm from Waist</u>



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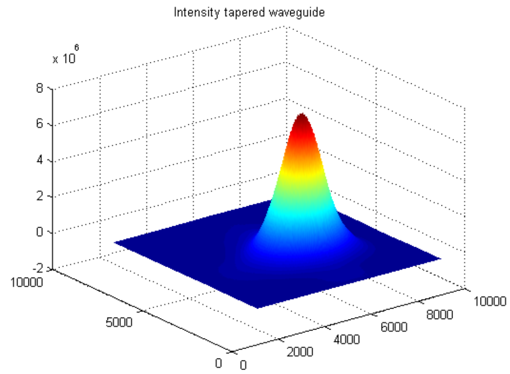
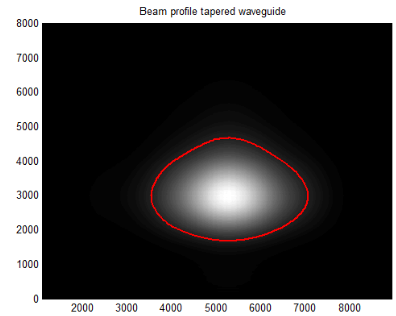
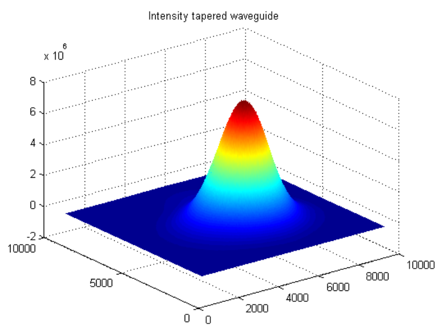
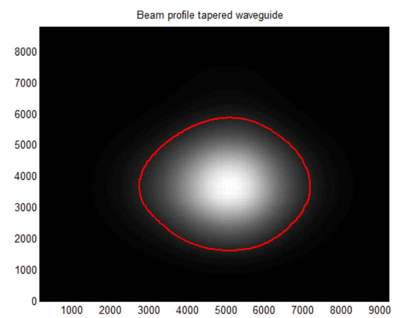
Near Field, 30cm from Waist



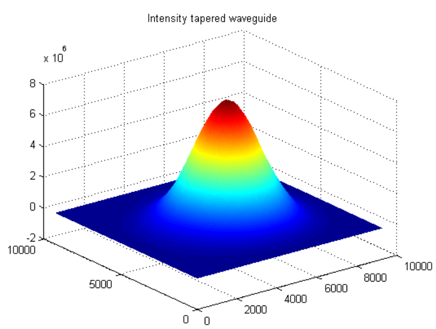


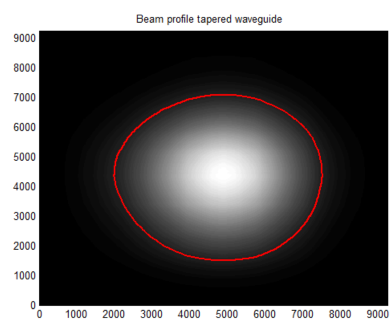
Near Field, 50cm from Waist





Far Field, 70cm from Waist





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The roundness of a beam in the Far Field is a function of the correction method used and alignment of the laser. A slab resonator has 2 different propagation axes. One is a result of the waveguide dimension. The other is determined by the product of the Out-Coupling Ratio times the width of the slab (Free-Space dimension). With Iradion lasers, the resulting divergence ratio of the two axes is ≈ 2:1. That is, the waveguide axis beam is ½ the dimension of the free-space dimension. This beam ellipse is created by the 2 different divergences of the waveguide and free-space axes. Iradion uses two different methods to correct the beam to near round. One method uses a cylinder lens placed at the point where the two divergences cross and the beam is round. Only the waveguide divergence is reduced to match the Free-Space divergence. This method is used in the above mode examples and achieves roundness
< 1.2:1.

Iradion also uses an internal method (patent 8,295,319) where the waveguide is matched to the Free-Space divergence before the beam leaves the cavity window. Generally, the roundness and mode is slightly better using this method however, the laser beam mode must still be viewed in the Far-Field for accuracy.

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