Simple Optics For A Laser Diode

Most commercially available laser diodes project an elliptical beam due to the diode junction having a rectangular shape. The divergence is typically specified in both the x & y axes separately. The axis with the larger divergence is called the fast axis & the axis with the smaller divergence is called the slow axis. This elliptical beam can create difficulties for many applications & lowers the efficiency of fibre coupling. A number of techniques exist to circularize laser beams, such as anamorphic lenses, anamorphic prism pairs, micro-optics, & beam truncation.

Anamorphic Lenses

The first surface of the lens collimates the fast axis of the laser while letting the slow axis continue to diverge. The second surface of the lens collimates the slow axis of the laser while passing the already collimated fast axis through. By collimating the fast axis of the diode before the slow axis, it allows the slow axis light to catch up to the beam diameter of the fast axis, resulting in a collimated & circular beam in a very elegant & compact package. Diode to single-mode fiber coupling can be increased to over 90% in some cases.

Anamorphic Prism Pair

Anamorphic prism pairs are the most frequently used method for achieving good beam quality & circularization of laser diodes. Although this method achieves approximately 50% energy throughput, it is often difficult to align the prisms, the prisms are expensive, & the exit beam is not collinear with the laser diode - all of which make packaging difficult. An additional collimating optics is needed as well, adding to the cost & complexity.

Micro-Optics

One approaches utilizes a small cylindrical lens mounted in the laser diode, which slows down the diverging fast axis beam. This does not produce a fully collimated beam & an external collimating lens is still needed. The value-added benefit of this approach is its compact size, low cost & high-energy throughputs of approximately 75-80%.

Beam Truncation

Beam truncation is the least efficient method, & is accomplished by masking the beam with an aperture or lens. It produces a circular beam, but only 10%-30% of the beam is transmitted.

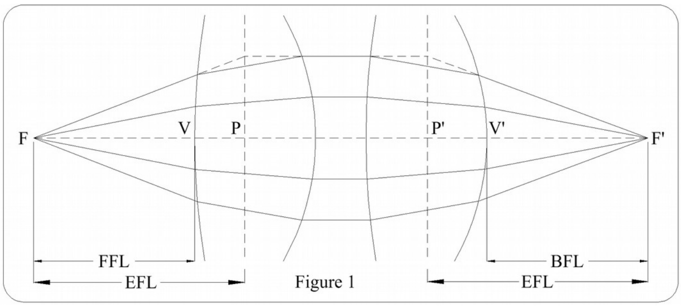

Figure 1

Some TO canister laser diodes have a window, which causes spherical aberration. Some collimating lenses compensate for this. Use the correct type.

Front focal length (FFL) is the distance from the front focal point to the first surface vertex.

Back focal length (BFL) is the distance from the last surface vertex to the rear focal point.

Effective focal length (EFL) is the distance from the focal point to the principal point.

Collimating lenses are designed to work at a specific wavelength. Use with other wavelengths affects the EFL, BFL & the RMS wavefront error (WFE). Example:

| | EFL mm | BFL mm | WFE |
|---|---|---|---|
| Design wavelength, 780nm | 1•452 | 0•876 | < 0•07 |
| 532nm | 1•424 | 0•851 | < 0•11 |
| 1550nm | 1•479 | 0•901 | < 0•08 |

## Numerical Aperture

The NA of a lens is a measure of the maximum divergence that the lens can capture from the laser. It is important to note that φ is the *half* angle of the divergence cone and is given at the *marginal ray* (not $1/e^2$ or half max).

Some laser manufacturers give the NA of the source in different terms, such as half max (50% point) or $1/e^2$ (87% point). Whatever type of number is entered into the formula for the NA of the source will be the same type of number given for the beam diameter. For example, if the half max NA for a laser is used with the above formula, you will get the half max beam diameter. There is no simple way to convert from a half max number or a $1/e^2$ beam diameter to a full beam diameter for a specific source

because it depends on the intensity profile of the source itself. A reasonable approximation, though, for most edge emitting diode lasers is to assume a gaussian beam profile. Using this beam profile, you can convert the beam diameters as follows:

1. To convert a half max beam diameter to a full beam diameter, multiply the

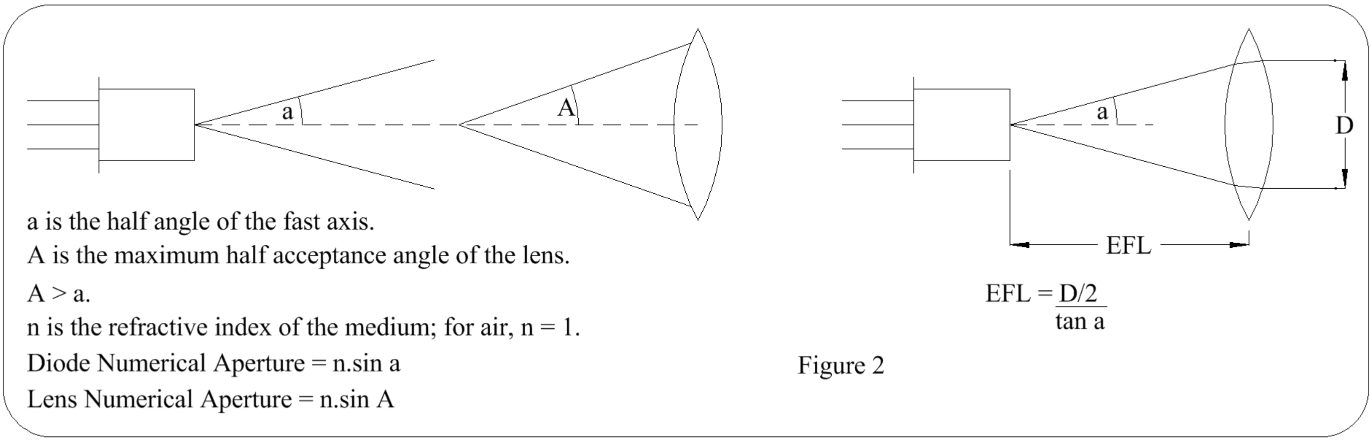

Figure 2

diameter by 2•576.

2. To convert a $1/e^2$ beam diameter to a full beam diameter, multiply the diameter by 1•517.

## Choosing A Lens

Ideally, a lens should be used that has an NA higher than the NA of the laser's fast axis. If not, the lens will mask the beam causing some of the light to be wasted.

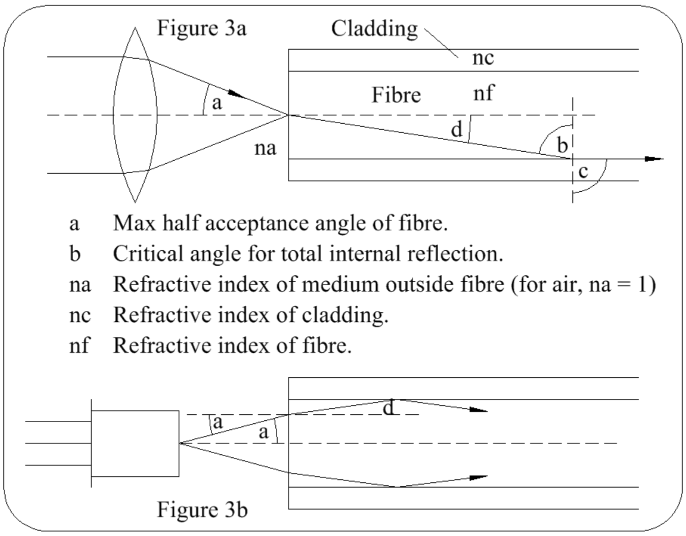

Figure 3a

Figure 3b

## Fibre Optics

Referring to Figure 3a:

When b = critical angle:

$\sin b / \sin c = nc / nf$

$c = 90°$ so $\sin c = 1$

$\sin b = nc / nf$

$\sin b = \cos d = nc / nf$

$nc / nf = \sqrt{(1 - \sin^2 d)}$

$nc^2 = nf^2(1 - \sin^2 d)$

$\sin a / \sin d = nf / na$

$\sin^2 d = na^2.\sin^2 a / nf^2$

$nc^2 = nf^2(1 - na^2.\sin^2 a / nf^2)$

$nc^2 = nf^2 - ns^2.\sin^2 a$
$\sin^2 a = (nf^2 - nc^2) / na^2$

$$\sin a = \sqrt{[(nf^2 - nc^2) / na^2]} = NA$$

For air: $\sin a = \sqrt{(nf^2 - nc^2)} = NA$
So for total internal reflection $a < \sin^{-1}\sqrt{(nf^2 - nc^2)}$