The Beam Characteristics of High Power Diode Laser Stack

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Abstract. Direct diode lasers have some of the most attractive features of any laser. They are very efficient, compact, wavelength versatile, low cost, and highly reliable. However, the full utilization of direct diode lasers has yet to be realized. However, the poor quality of diode laser beam itself, directly affect its application ranges, in order to better use of diode laser stack, need a proper correction of optical system, which requires accurate understanding of the diode laser beam characteristics. Diode laser could make it possible to establish the practical application because of rectangular beam patterns which are suitable to make fine bead with less power. Therefore diode laser cladding will open a new field of repairing for the damaged machinery parts which must contribute to recycling of the used machines and saving of cost.

1. Introduction

Various concepts for providing solutions for scaling up power in the application focus for high power diode lasers have been investigated and realized in industrial solutions in the past years. This task is specified in relatively simple terms in bringing the optimum beam quality and power transfer efficiency from the high-power diode laser to the application focus. High-power single-mode diode laser arrays provide a scaling solution based on the inherent high beam quality of the individual single mode emitter source and the assembly with high quality micro-optics with two micro-optical elements per array in fast and slow axis direction. Thus, very high power laser systems with stringent demands on the beam quality rely on one additional active laser cavity and, in some cases, additional power amplifying stages to improve the beam quality of the diode lasers, with fiber lasers and disk lasers being the two most prominent examples [1-4]. Laser systems with high powers at moderate beam quality can also be obtained by directly combining diode lasers, spatially and spectrally into a fiber. Such a direct diode laser system is very compact, very efficient and it can be modulated from dc to the GHz range by solid state electronics. Thus, direct diode lasers can be easily used in processes with an active feedback loop to regulate the laser power. Free space beam shaping with precision micro-optics is a key element to access the size, the quality and stability needed in commercial applications. Aspheric cylindrical lenses in high index precision glass can be tailor-made in micro to macro dimension for optimum form accuracy of the aspheric surface and optimized to the respective task of the applications. Micro-optical cylindrical slow-axis lens arrays in standard quartz glass material are available in high precision in pitch and form accuracy by reflow lithography [5].

2. Astigmatism of Diode Laser Stack

Astigmatism is a kind of aberration. When using the optical system imaging of near field on the surface of the diode laser cleavage, Astigmatism would be found, as a result of the existence of astigmatism, there would appear on the focal line two image point. Diode lasers are used on both sides of the active layer in transverse refractive index difference of optical waveguide which is formed by the effect of active area to restrict the photons. There are two types of optical limiting including gain
and refractive index waveguide. Early diode laser is gain waveguide laser bar. For the lateral refractive index of waveguide, they are widely used in the direction perpendicular to the junction plane of the Gaussian beam waist in the cleavage plane, and in front of the waist in the plane wave, as shown in figure 1 (a). When the lateral waveguide structure was gain waveguide, then the light field distribution as shown in figure 1 (b), there was the waist inside the cavity apart from the cavity surface for D (called a amount of astigmatism), which is also the minimum width of the near field, the real waist in the center of the cavity observed by external observer. Therefore, looked from the propagation direction, the direction of the two synthesis of wave front is a cylinder, the output light is astigmatism. Its influence is spherical lens imaging of the cleavage cavity surface, the virtual image plane and the cavity of the waist like the surface of the waist (that is, the transverse optical field like surface) is not correct, which should be in the same place. The consequence is far field distribution in "rabbit ear", in the early days of oxidation strip laser has appeared the situation in the far field. At the same time, the existence of the aberration would cause the aberration of the lateral mode increased and widen the spectrum width. This has done a lot of difficulties to the application, unless the aberration of the elimination measures, otherwise difficult to general optical system focus is very small spot, focal spot polishing, uneven distribution of field is difficult to make the laser and single mode fiber coupling efficiency. Even lateral refractive index waveguide limitation, it is hard to make the size of the above characterization of astigmatism value is zero, be in commonly 2 μm above.

![Image](image_url)

(a) Perpendicular to the junction plane (the direction of fast axis divergence angle)  
(b) Divergence angle of Parallel to the junction plane (slow axis) direction

**Figure 1.** The divergence angle junction plane in fast and slow axis direction.

In the application, generally, there are two ways to eliminate assignation, adopts a diode laser without astigmatism, or by optical system to correct it.

### 3. Divergence Angle of Diode Laser Stack in Far-Field

If the diode laser emission is the ideal of Gauss beam, the intensity distribution should be as follows formula

$$I(r) = I_{\text{max}} \exp\left[-2\left(\frac{r}{\omega}\right)^2\right]$$  \hspace{1cm} (1)

where \(I(r)\) is the intensity which radius is \(\omega\) apart from the gauss beam waist size with \(r\), \(I_{\text{max}}\) is the maximum intensity at the waist. Obviously, when \(r=\omega\), the intensity is the \(I_{\text{max}}/e^2\), as shown in figure 2. The divergence of the Gauss peak beam is

$$\theta = \frac{4\lambda}{\pi\omega} = \frac{1.27\lambda}{\omega}$$  \hspace{1cm} (2)
Diode laser far field is not strictly the Gauss distribution, the beam in the horizontal and lateral asymmetry has large divergence angle. Due to the thinner active layer of the diode laser, the transverse with large divergence angle can be expressed as

$$\theta_\perp = \frac{4.05 \left( \frac{n_2^2}{n_1} - 1 \right) d/\lambda}{1 + \left[ 4.05 \left( \frac{n_2^2}{n_1} - 1 \right) / 1.2 \right] (d/\lambda)^2}$$  \hspace{1cm} (3)$$

In the formula, $n_2$ and $d$ are active layer of laser refractive index and the thickness, respectively. $n_1$ is the layer limited refraction index, is the lasing wavelength. Apparently, when $d$ is very small, this can be neglected for second in the denominator.

$$\theta_\perp \approx \frac{4.05 \left( \frac{n_2^2}{n_1} - 1 \right) d}{\lambda}$$  \hspace{1cm} (4)$$

From the formula, $\theta_\perp$ increased with the increase of $d$ and Ga$_{1-x}$Al$_x$As/GaAs, the diode laser and $d$ curve in the first half was consistent. This can be interpreted as decrease with increasing $d$, the optical field to both sides of the active layer, equivalent to the thickening of the active layer, and reduce the $\theta_\perp$. When the active layer thickness is comparable with the wavelength, but still work in fundamental transverse mode, can ignore 1 in the denominator approximately.

$$\theta_\perp \approx \frac{1.2\lambda}{d}$$  \hspace{1cm} (5)$$

The consistency in style show in the active thickness within a certain range, the transverse optical field has a good characteristic of Gauss beam. Within this range, and reduce with the increase of $d$, which can be explained by the theory of diffraction. As diode laser with active layer width $W$ is larger in the lateral, the divergence angle $\theta_\parallel$ is small, which can be expressed as the follow formula.

$$\theta_\parallel \approx \frac{\lambda}{W}$$  \hspace{1cm} (6)$$

Hence, although the slow axis of the active region is large in size, the divergence angle is relatively small, about 8-10 degree of the active region, and the smaller size of the fast axis direction, the divergence angle is large about 25-40 degree. The far field spot is an elliptical. The long and short axes are corresponding to the fast axis and slow axis. In many applications, optical systems need to shape the far field beam of the non-circular symmetrical circular.
4. Beam Parameter Product (BPP) Evaluation Method

According to the ISO-11146 standard, laser beam quality is described by the beam parameter product (BPP) through the following equation [6].

\[
BPP = w_0 \cdot \theta / 2
\]  

(7)

where, \( w_0 \) is the beam waist radius of lasers, \( \theta \) is far-field divergence angle of laser.

The beam parameter product (BPP) is used to measure the beam quality of diode optical parameter. The minimum value of product is called the diffraction limit, to a certain wavelength of lambda \( \lambda \), the diffraction limit as shown in follow equation.

\[
BPP_d = \lambda / \pi
\]  

(8)

Beam parameter product is defined as follow

\[
BPP = w_0 \times \theta_0 / 2
\]  

(9)

where \( w_0 \) is the beam waist radius, \( \theta_0 \) is the far field divergence angle. Beam parameter product with another expression for the beam quality parameter \( M^2 \)

\[
M^2 = \frac{BPP}{\lambda / \pi} = \frac{w_0 \cdot \theta_0}{\lambda / \pi}
\]  

(10)

5. Conclusion and Outlook

The characteristic of diode laser stack beam is introduced through astigmatism, based on two order moments of the intensity of laser diode stack divergence angle, beam radius and beam quality evaluation methods, mainly focuses on the relationship between the concept of factor and beam parameter product between BPP and \( M^2 \). At present, we plan to make polarization coupling experiment for the laser diode laser stacks which contain more diode laser bars and try other kinds of beam coupling methods. We continue to bend ourselves to improve the coupling efficiency. In addition, we are also studying on the diode laser beam shaping, expecting the consistent beam quality of fast axis and slow axis by rearrangement of beam and focusing the beam into single fiber.

References

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