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ScienceDirect
Optik 121 (2010) 1708–1711
Optik Optics
www.elsevier.de/ijleo

Design of aspheric collimation system for semiconductor laser beam

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Received 28 December 2008; accepted 22 April 2009

Abstract

In this paper, semiconductor laser beam collimation lenses system has been optimum simulated and designed. The new design methods for aspheric cylinder lenses collimation system have been discussed in detail and the system parameters are calculated and optimized by using a geometrical ray optics approximation. The optical system has been further simulated by software MATLAB, and the simulation results showed that the emergence angle can be collimated effectively, and the output beam can be expanded to a circular spot in centimeter level beam radius.

Keywords: Semiconductor laser; Aspheric lens; Collimation system; Simulation optimum

1. Introduction

Because of the rapid development of the optoelectronic devices, semiconductor lasers have been widely used in many fields such as laser processing, medical applications and optical communication. However, the edge emitting semiconductor lasers have different origins and angles of divergence in the two transverse directions [1], as shown in Fig. 1, resulting in the inherent astigmatism and elliptical beam shape. This characteristic of output beam of the edge-emitting semiconductor laser is a drawback for many applications requiring laser sources. How to improve the quality of the edge-emitting semiconductor laser beam becomes a widely concerned problem.

There are two kinds of technique to improve the beam quality of the semiconductor laser. The first one is to alter the beam quality internally, such as adding external cavity to the LD or optimizing the structure of the LD cavity [2]. The second one is to improve the beam quality exteriorly, the common method is to add optical elements in front of the laser beam, which is the approach discussed in this paper. In general, lenses or prisms are mostly employed to reshape the beam [3,4]. Because of simple structure and easy fabricating, the cylindrical lenses have been used in many practical applications for beam collimating of LD [5,6]. The aspheric lens is another shaping system that is used to collimate the beam of LD, and the theoretic performance could be perfect [7,8].

In this paper, an optical system comprising two aspheric cylindrical lenses is designed to collimate the elliptical semiconductor laser beam using analytical equations and MATLAB simulation.

2. Collimation system design

2.1. Geometrical ray optics versus physical optics

Optical design of beam shaping systems can be achieved using either physical or geometrical optics.

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doi:10.1016/j.ijleo.2009.04.002

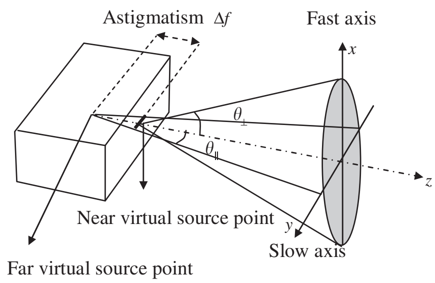

Fig. 1. Free-space radiation pattern of a semiconductor laser with an elliptical beam profile.

For single-mode Gaussian beams, calculating the parameter β_0 will help determining whether geometrical or physical optics methods should be used, the parameter β_0 is defined [9]

$$\beta_0 = \frac{2\sqrt{2\pi} r_0 D_{out}}{f\lambda} \tag{1}$$

where $\lambda = 870\,\text{nm}$ is the wavelength of semiconductor, r_0 is the beam radius or waist, D_{out} is half-width of the desired output dimension, and f is the focal length of the focusing optic system, or the working distance from the optical system to the target plane. In general, if $\beta_0 < 4$, a beam shaping system will not produce acceptable results. When $4 < \beta_0 < 32$, diffraction effects are significant and should be part of design of beam collimation system. When $\beta_0 > 32$,geometrical methods should be adequate for design of beam collimation systems [10].

In this paper, we calculated β_0 values for all the surfaces, and based on these values, we will discuss collimation system by geometrical optical principle.

2.2. Theory for collimation system design

This design method employs two aspheric cylindrical lenses, the input surface S_1 and the output surface S_2 are both aspheric surfaces and the two surfaces between them are planes, as shown schematically in Fig. 2.

The surface S_1 has refractive power in the x–z plane and is flat in the y–z plane so as to collimate the beam in perpendicular transverse directions. Meanwhile, the S_2 surface is flat in the perpendicular direction allowing the beam to propagate through with no refraction in this direction, while the surface in parallel direction collimates the beam. As a result, the output beam has the desired circular, collimated, and expanded beam shape.

2.3. Equations for the input surface S_1

The input surface S_1 is an aspheric cylindrical surface, and the calculations in x–z plane are shown in this section. The variables used to calculate lens parameters

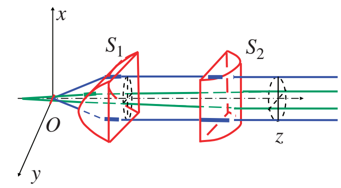

Fig. 2. Schematic of the collimation system.

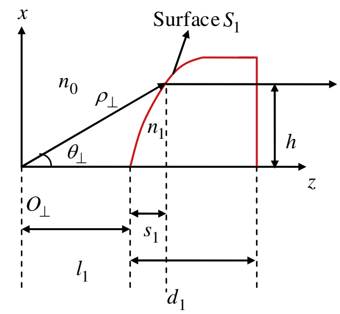

Fig. 3. Schematic of aspheric lens in the perpendicular direction (x–z plane).

in x–z plane are presented in Fig. 3.

$$n_0 \rho_\perp = n_0 l_1 + n_1 s_1 \tag{2}$$

From a trigonometric relation, we have

$$\cos\,\theta_\perp = \frac{l_1 + s_1}{\rho_\perp} \tag{3}$$

Simultaneously solving Eqs. (2) and (3), we obtain

$$\rho_\perp = \frac{l_1(n_1 - n_0)}{n_1 \cos\,\theta_\perp - n_0} \tag{4}$$

According to the theory of analytic geometry, Eq. (4) is a polar equation of hyperbola. And transforming it into rectangular coordinates form, we obtain the equation of the surface S_1

$$\frac{(z - n_1 l/n_1 + n_0)^2}{a_1^2} - \frac{x^2}{b_1^2} = 1 \tag{5}$$

where the hyperbola parameters $a_1 = n_0 l/(n_1 + n_0)$, $b_1 = l\sqrt{n_1 - n_0/n_1 + n_0}$, $e_1 = n_1/n_0$, and the near virtual source lies on the outer focus of a hyperbola plane.

2.4. Equations for the output surface S_2

The output surface is also an aspheric cylindrical surface, and the y–z plane calculations are shown in this section. Fig. 4 shows the schematic of the surfaces in the parallel transverse direction (y–z plane) and the variables used to calculate lens parameters. We use Fermat's principle and trigonometric relationships to determine the surface equation. The parallel transverse direction divergence angle $\theta_\parallel$, the final output beam radius h (h is equal to the same height as the output ray in