An Experimental Research of Beam Correcting for A Semiconductor Laser Diode*

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Abstract An experimental beam correcting optical system for laser diode is established for compensating astigmation and circulating the elliptical beam. The system is combined by two prisms, a cylindrical lens and a collimating lens. The results show that the divergence angle of the laser beam can be corrected to less than 1 mrad, and even reach diffraction limited. This system possesses the advantages of low cost, low power loss, simple structure, and it is convenient to operate.

Key words laser diode; laser beam correcting; elliptical beam; astigmatism

For the advantages of contract structure and convenience of utilization, semiconductor laser diodes have found acceptance in a wide range of applications, such as optical communication, optical storage and precise measurement systems et al. However, laser diodes have also certain shortcomings. For the asymmetry of the activate passageway, the laser beam has elliptical cross section and intrinsic astigmatism. The average divergence angles in the direction of parallel and vertical are $10^\circ\sim30^\circ$ and $30^\circ\sim60^\circ$ respectively. This low quality beam must be corrected before it can be applied practically.

There are many methods to improve the quality of the laser diode′s beam, such as micro Fresnel lens[1], binary diffraction optics[2] and refractive gradient-index elements[3]. Though they can correct the beam of laser diode very well, in present, there are some critical demands in their manufacture. This is the reason why there are few products of LD with beam correcting optics avliable, also the reason why the technology of beam correcting for laser diode is taken seriously attention by many researchers all over the world.

In this paper, a laser beam correcting optical system combined with a pair of anamorphic prisms, a very weak cylindrical lens and a collimating lens is presented. There are many advantages. First, low power loss. The only loss is caused by surface reflection of the prisms and the lens. If the surafaces are antireflection coated, total loss is less than 30%~50%. Second, low cost. Since there is low power loss, a low power and less expensive laser diode can be used. Third, no complex adjustment is required. The system established here can correct the laser diode′s beam to rather good quality. The angle of divergence can be reduced to less than 1 mrad in both directions of parallel and vertical.

1 Optical Feature of Laser Diode

There are two main optical features for a laser diode.

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Firstly, because of the rectangular shape of the beam emission facet, the beam of laser diode has elliptical cross section. This characteristic prevents the beam from being entirely collimated, allowing for quasi-collimation only. Based on the optics theory, a beam output from a tiny aperture has in one certain direction a full divergent angle θ given by

$$\theta = 4\lambda/\pi d \tag{1}$$

where λ is the wavelength and d is the size of the emitting facet in this direction. The difference between the angles of x-direction and y-direction causes the beam of laser diodes to have an elliptical cross section, as shown in Fig. 1.

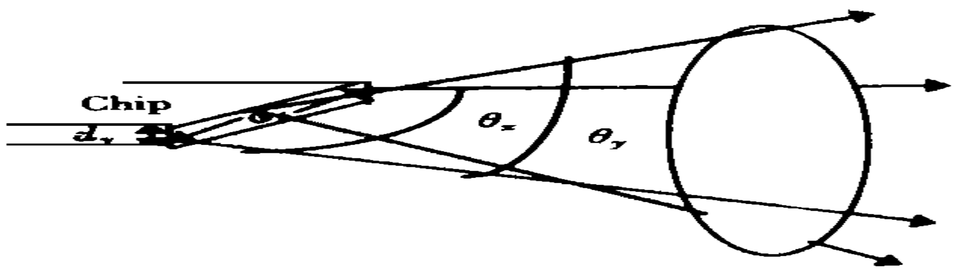

Fig. 1 The diagram of the optical features of a LD: elliptical cross section and astigamatism

A universal characterization of this problem is made impassable by the differences between index-guided and gain-gained diodes as well as by the individualistic nature of the laser diode.

For an index-guided, low power laser diode, the rectangular emission facet has an approximate size of $d_x \approx 3\ \mu$m and $d_y \approx 1\ \mu$m. From Eq. (1) we can find that θ_y is approximately three times larger than θ_x.

For a gain-guided, wide-stripe, high power laser diode, d_x can be tens or even one hundred microns while d_y is still approximately one micron. Therefore, unlike an index-guided laser diode, the difference between θ_y and θ_x is unpredictable and can be much lager than 1/3. To make matters worse, the difference between θ_x and θ_y is not consistent even between two laser diodes of the same type. Thus, the shape of the elliptical cross section varies from diode to diode.

Secondly, the rectangular facet of the laser diode can result in another shortcoming, astigmatism. As shown in Fig. 2.

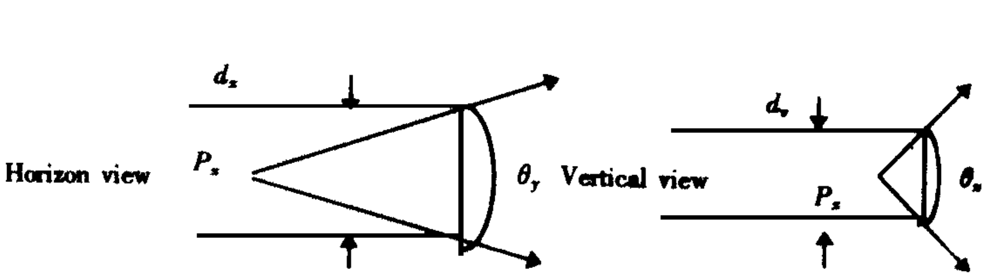

Fig. 2 Illustration of the variation between lasers and the cause of astigmatism

A small facet is equivalent to the beam emitted by an imaginary point P, whose position can be located by tracing the beam backwards. It can be seen obviously that P_x is located behind P_y of the reason that θ_x is smaller than θ_y. When d_x is much larger than d_y, θ_x is much smaller than θ_y, therefore the distance between P_x and P_y is much larger. This phenomenon is called astigmatism, and the distance between P_x and P_y is the numerical description of astigmatism.

Because of the existence of astigatism, when using a single, standard aspheric lens, the beam of laser diode can only be corrected in one direction, for P_x and P_y can not simultaneously converge at the focal point of the collimating lens.

Because of the two optical characteristics of laser diodes, when correcting the beam of laser diode, there are two matters we must consider, the circularity and astigmatism.

3 Principal of the Beam Correcting Method

The most common method to correct astigmatism is to use a very weak cylindrical lens after the collimating lens, as shown in Fig. 3. When the orientation and focal length of the cylindrical lens are right, this method can collimate the beam in the direction of vertical(θ_y), without changing the beam in the direction of horizon(θ_x). The collimating lens can not fulfill this alone due to the astigmatism.

The most common method to circularize the elliptical beam is to use a pair of anamorphic correcting prisms, as shows in Fig. 4.

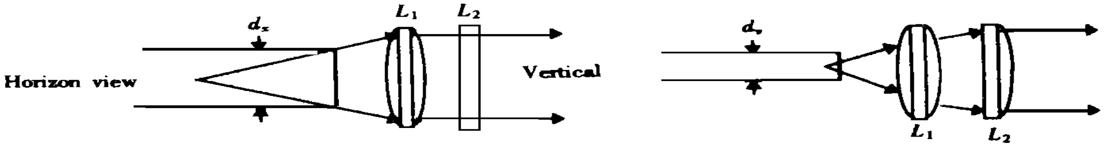

Fig. 3　The astigmatism correction by a cylindrical lens

L_1: Collimating lens L_2: Cylindrical

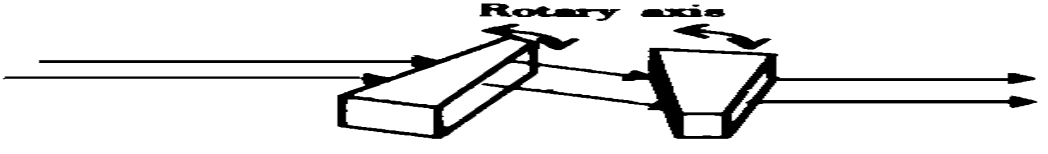

Fig. 4　Beam circularizing of a laser diode by a pair of anamorphic prisms

Because the transmission of the laser elliptical beam can be theoretically resolved as horizon partial and vertical partial[4], the two partials can be treated separately without inferencing each other. Thus the prisms can enlarge or reduce the beam size in one direction while keeping the beam size in another direction unchanged. The enlargement or reduction rate can be adjusted by adjusting the angles of the two risms. By properly adjusting the angles of the prisms and using a circular aperture, it is easy to circularize an elliptical beam.

So, a complete system for the correcting of a laser diode should be an elliptical beam circularizing subsystem following by an astigmatism correcting subsystem.

4 Results of Experiment

Following the method discussed above, an experimental optical laser diode beam correcting system has been established, which is shown in Fig. 5. The wavelength of the laser diode we used is 790±5 nm, the angles(θ_x, θ_y) of the laser diode are measured to be approximately 8° and 25°, and the spot of the laser beam was detected by a piece of infrared detection card.

By adjusting the angles of the prisms carefully, we have seen that the beam can be circularized quite well, even can't be distinguished by eyes and manual measurements. For the lack of precise instruments, we can't get out the exact values of the angles of the prisms.

After the beam circularizing optics, a spherical lens and a cylindrical lens were adopted for the astigmatism collecting of the beam. After carefully adjusting the positions of the two lens, the measured data are illustrated in Table 1.

Table 1 Data of the experiment

Distance L/cm	Diameter of beam spot R/mm	Divergence angle θ/mrad
50	7.8	0.80
100	8.2	0.10
500	8.6	0.12
1 000	9.2	

From Table 1, it can be seen that in the near-field, the beam divergence angle was calculated to be about 0.8 mrad, while in the far-field, the average beam divergence angles were calculated to be about 0.1 mrad.

In the process of the measurement, we have observed that the spot of the beam is always a perfect circle combined with bright and dark annular belts, the diameter of the first dark annular is about 0.35 mm. That is to say, the optical system circularizeds the beam very well, and the collimating of the beam has reached the near diffraction limited.

Though the data are not very precise limiting to the method of measurement, the results of this experiment have demonstrated that the method applied in this paper can fulfill the jobs of beam correcting and collimating perfectly.

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半导体激光器光束修正实验研究*

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【摘要】 采用棱镜、准直透镜和柱面镜组成一个光束修正系统，可对半导体激光器的光束进行整型准直。实验结果表明，其光束发散角可压缩到 1 mrad 以下，并接近衍射极限。该系统具有成本低，光功率损耗小，结构简单、易于操作等优点。

关　键　词　半导体激光器；　光束修正；　椭圆光束；　像散

中图分类号　TN203；　TN243

编辑　叶　红

◦科研成果介绍◦

智能高速瞬态检测仪关键技术研究

主研人员：郭戍生　王树菁　陈长龄　王子斌　江建尧　金　卫

智能高速瞬态检测仪关键技术研究项目完成了实时取样/量化技术，宽带信号实时高速分相多路数字化，采集与存储，数字内插重信号波形技术及可编程高速数字时基技术，借助于样机内高性能微算杨系统辅助测试/处理无论对单次或重复信号均可自动测试与分析处理。

该成果处于国内领先水平，并达到 90 年代初国外同类技术先进水平。

◦科　卞◦

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