High-Power 638-nm Red Laser Diode with Built-in Lens for Display Applications

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A red semiconductor laser diode (LD) with small built-in lens was developed by applying the principle of the optical beam expander in the slow axis (horizontal) direction where three emitters (emitting point) are lined up. In this product, a pulsed 2.5W collimating beam with divergence angle of 3.6°×0.5° (typical value) was realized.

1. Background

In contrast to the high-pressure mercury lamp which is widely used as a light source for projectors, a semiconductor laser with good color reproduction, high efficiency, low power consumption and high brightness is attracting attention. We have developed a high output red semiconductor laser, ML562G84, with a pulse light output of 2.5 W, for display application.

In this product, the output laser light has a large divergence angle. To radiate the laser light on the display efficiently, an external collimating lens is required. However, since the design has a large divergence angle in the fast axis (vertical) direction and three emitters in one LD chip, the optical design is difficult and the application range is limited.

Therefore, we developed the lens by applying the principle of the optical beam expander in the slow axis direction where three emitters are lined up. This paper describes the design of the collimating lens and various characteristics of the product.

2. Design Review of Lens for Red Pulse LD

Our red pulse LD uses an AlGaInP based material mounted on the TO-CAN package of 9.0 mm diameter. After studying the optical output characteristics and reliability, a multi-emitter design having three emitters consisting of a broad stripe LD of 60 μm width was selected. The divergence angle full widths (FW1/e^2M), which make the optical output 1/e^2 of the peak value in the far field, are 8.0° and 69.0° (typical values), respectively. In particular, the divergence angle of the vertical direction is relatively larger.

When designing a collimating lens which is suitable for these LD device designs and far-field characteristics, the following problems are encountered. First, the width of three emitters in the LD horizontal direction is 270 μm, which is rather wide. To make the divergence angle small, it is necessary to increase the focal length of the lens, but this makes it necessary to increase the effective opening of the lens to improve the light use efficiency because the divergence angle in the LD vertical direction is large. Thus, in a general axisymmetric lens, the desired lens performance has a trade-off relationship with a compact lens size.

Therefore, we designed a lens by applying the principle of the optical beam expander in the horizontal direction having three emitters lined up. The beam expander enlarges the beam diameter of the laser light and makes the divergence angle of the beam small. Figure 1 shows a schematic of the collimating functions for each direction.

The principle of the beam expander is as follows. When lenses with focal lengths of f_1 and f_2 are placed at the distance of d, the beam is enlarged with magnitude m (= −f_2/f_1) determined by the ratio of the focal lengths. The relationships between the incident beam (divergence angle θ_0, beam diameter ω_0) and the generated beam (convergence angle θ_1, beam diameter ω_1) and between distance d and focal lengths f_1 and f_2 are as follows:

$$\omega_1 = (-f_2/f_1)\,\omega_0 = m\omega_0 \qquad (1)$$

$$\theta_1 = (-f_1/f_2)\,\theta_0 = \theta_0/m \qquad (2)$$

$$d = f_1 + f_2 \qquad (3)$$

The parameters of each lens were optimized by applying this principle to the horizontal direction and considering the limitations of lens manufacturing. On the other hand, in the vertical direction, we collimate at output surface by employing the conventional way. The lens position for the LD in the optical axis direction is the constant beam divergence angle in the horizontal direction, which is independent of the distance between the LD and the lens. Therefore, lenses were placed at the position of the focal length in the vertical direction. Figure 2 shows the calculated beam pattern at each

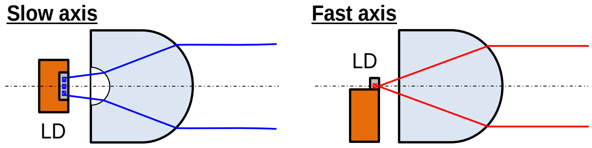

Fig. 1 Collimating functions for each axis

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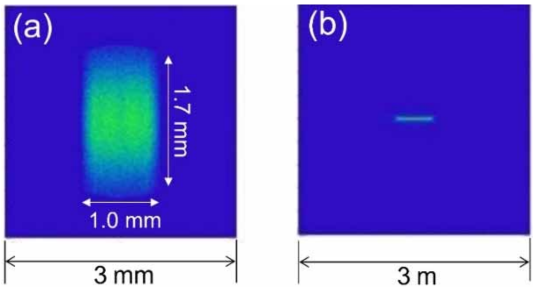
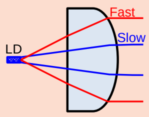
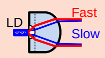


(a) Lens output surface (b) Far field pattern

Fig. 2 Calculated results of beam profile

Table 1 Comparison of lens configuration

Item	Conventional (Axisymmetric)	This work
Configuration		
Size	Large	Small
Divergence angle in slow axis	Equivalent	
Cost	Equivalent	

position after emission from the lens. The beam diameter immediately after the lens is 1.0 mm in the horizontal direction and 1.7 mm in the vertical direction. The divergence angle (FW1/e^{2}M) in the far field is 3.5° in the horizontal direction and 0.2° in the vertical direction.

Table 1 shows a comparison of the axisymmetric lens configuration and the developed lens configuration. In this development, the principle of the beam expander in the horizontal direction was used and a compact projector light source was achieved. With the optimum design and small lens diameter based on the lens manufacturing conditions, costs equivalent to those for normal lenses were achieved.

3. Laser Characteristics

Figure 3 shows the optical output vs. current characteristics of the developed product. The operating conditions are pulse operation with the duty ratio of 30% and pulse frequency of 120 Hz. The temperature in the figure is the temperature (case temperature) at the bottom of the package. The figure shows a photo of the appearance of the developed product. At 25°C and 2.5 W output, the operating current was 2.77 A, the operating voltage was 2.35 V and the slope efficiency was 1.17 W/A. The transmittance of the lens was 98% or more, and the pulse light output of 2.5 W was achieved with the operating current equivalent to that of the conventional pulse product. By using a large package with high heat dissipation, operation in the range from 0 to 45°C was confirmed. The peak wavelength was about 638 nm and the full width at half maximum of the spectrum was about 1.0 nm. Figure 4 is the far field pattern of the developed product in the horizontal direction (FFP//) and vertical direction (FFP⊥). The full width when the optical output is 1/e^2 of the peak value is 3.6° in the horizontal direction and 0.4° in the vertical direction. Considering the assembly tolerance of capping, a reasonable divergence angle was obtained as a result of the design.

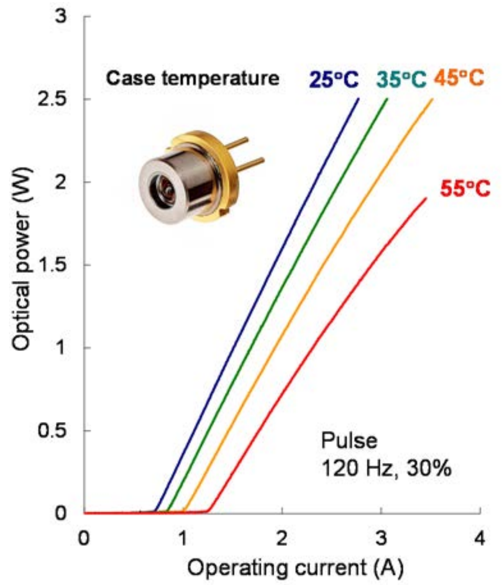


Fig. 3 P-I characteristics

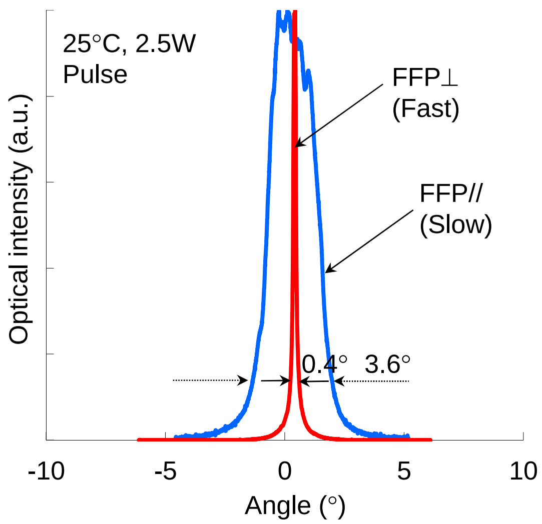


Fig. 4 FFP characteristics

4. Conclusion

In this study, we developed a high output red LD with lens which can be easily applied to projector systems. By applying the principle of the optical beam expander for the slow axis direction, a compact light source for projectors was achieved. As a result, parallel light of 3.6°×0.5° with a divergence angle full width (FW1/e^{2}M) which makes the light output 1/e^2 of the peak value was achieved.

This product can be used to simplify the optical design of projectors and to develop compact, low-cost optical devices. This red LD is expected to be increasingly used for projector light sources.

5. References

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