High Power Red Laser Diode for Projector Light Source

Masato Hagimoto, **Shintaro Miyamoto, Yuki Kimura, Haruki Fukai, Manabu Hashizume, Satoshi Kawanaka**

USHIO OPTO SEMICONDUCTORS, INC. 1-90 Komakado, Gotemba, Shizuoka, 412-0038, Japan

Keywords: red laser, laser projector, speckle reduction, wall plug efficiency, tensile strain

ABSTRACT

We developed 638nm and 642nm red laser diodes with 3.5W pulse / 2.4W CW operation. The 3.5W pulsed operation and wall plug efficiency of 43% are the world's highest in 638nm to the best of our knowledge. The lineups of multiple wavelengths are ideal as red light sources for projector.

1 INTRODUCTION

RGB laser cinema projector system has been developed and been installed in the major cinema chain theaters worldwide over last few years. The lasers as a light source for cinema projector improves its performance in many ways, such as ultra-high brightness, better efficiency, wide color gamut and longer lifetime [1]. One of the key performances that the market continues to request is the higher output power with higher efficiency from the single laser diode. Higher power and higher efficiency lasers enable smaller amounts of lasers, reduce the size of the cooling system, and lower the projector system cost.

One of the issues of laser projectors is speckle, which deteriorates the image quality. Since the projection system uses screen, the main cause of speckle is pattern interference from screen with rough surface. The most effective and commonly used method to reduce speckle is using multiple wavelength lasers [2]. The requirement for laser light source suppler is to lineup lasers with multiple wavelengths.

We have been developing and commercialized high power red laser diode (LD) over the last few years. We introduced two products for laser projector in 2017 [3]. One of them was the single emitter 637nm LD with 1.5W pulse / 1.2W CW operation and the other was the dual emitters 638nm LD with 2.5W pulse / 2.2W CW operation. These LDs contributed the flexibility to projector design by selecting suitable optical output power and emitter size. Furthermore, these LDs were compatible with different types of projectors, pulsed operation was for one panel display device, CW operation was for three panels one. Recently, the world first's, we introduced further high power and high efficiency 638nm LD with 3.5W pulse / 2.4W CW operation for projector [4][5].

In this paper, we report on the characteristics and reliability of newly developed 638nm 3.5W pulse / 2.4W CW LD and multiple wavelengths lineup's 642nm 3.5W pulse / 2.4W CW LD for speckle reduction.

2 LASER DIODE DESIGN

2.1 Laser diode chip structure

We designed the AlGaInP based new chips for 638nm and 642nm 3.5W pulse / 2.4W CW LD based on conventional 2.5W pulse / 2.2W CW LD. The difference of new chip between 638nm and 642nm was only active layer.

Figure 1 shows the schematic view of the developed laser diode chip structure in this study. The developed chip had monolithic, dual emitters. The cavity length was 1500μm, the width of the each emitter was 75μm, and the total width of emitter from the outer end to the outer end was 300μm. Their front and rear facets of the cavity were fabricated with window structures, and were covered by coating films. The waveguides of dual emitters were formed as the ridge structures in the p-cladding layer. The ridge structure has the advantage that reducing the current loss and the optical loss to the outside of the waveguide.

The epitaxial structure both 638nm and 642nm chip was AlGaInP based heterostructures with strained quantum well. The only difference between 638nm and 642nm chip was that the amount of tensile strain in the quantum well to adjust each wavelengths.

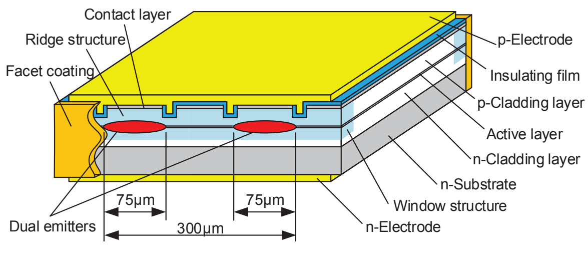

Fig. 1 Schematic view of developed laser diode chip

AlGaInP lasers had been studied by many researchers for a long time [6], the limitation of AlGaInP lasers is the electron leakage from the active layer to the p-cladding layer, because conduction band offset between the active layer and the p-cladding layer is small [7]. In terms of electron leakage, the 642nm chip has advantageous compared to the 638nm chip because of lower quasi-Fermi level in the quantum well.

On the other hand, the strain in the quantum well change band structures, and determines not only the wavelength but also the threshold current and polarization [8]. In case of increasing tensile strain in the quantum well, the splitting between light-hole (LH) band and heavy-hole (HH) band is expand. This enables to decrease the LH density of states and decrease the threshold carrier density [9][10]. In this study, the amount of tensile strain of 642nm was reduced compared to 638nm chip, resulting in increased threshold current. Regarding as the polarization, both 638nm and 642nm chips were designed to be TM-mode which is the electric field perpendicular to the active layer.

These developed chips had been accumulated several improvements of epitaxial growth and heat dissipation to suppress the electron leakage.

2.2 Package outline

The chip was assembled into diameter 9mm TO-CAN package in Figure 2. The TO-CAN package was hermetically sealed to ensure high reliability. In order to improve heat dissipation, the chip was mounted with a junction down configuration. The diameter 9mm package is the standard package of watt class LD for projector, one reason is that, it is easy to take heat dissipation to the external heat sink.

Fig. 2 Photograph of TO-CAN package

3 CHARACTERISTICS

3.1 Optical output power

We measured the temperature dependence of I-L characteristics which was forward current (If) vs optical output power (Po) with both pulsed operation and CW operation. The temperature was defined as the case temperature (Tc), and the measurement position of the temperature was taken as the bottom of the case. Pulse condition was set to frequency of 120Hz with 30% duty cycle.

Figure 3 and 4 show the comparison of I-L between developed 638nm LD (solid line) and conventional 638nm LD (dash line) in each pulse and CW. The developed LD was clearly improved the temperature characteristics both pulse and CW, especially at high temperature. The highest power at 45°C was improved 15% from 3.4W to 3.9W pulse, 30% from 2.3W to 3.0W CW. The highest power at 55°C was further improved 29% from 2.4W to 3.1W pulse, 50% from 1.4W to 2.1W CW. Our target of optical output power 3.5W pulsed operation was achieved with sufficient margin even at high temperature of 45°C. The target of 2.4W CW was also achieved.

We supposed that this remarkable achievement attributed to the improvement of internal loss and heat dissipation by optimizing the chip structure. Furthermore, it was considered that the temperature rise of the active layer was suppressed by the improvement of heat dissipation, the electron leakage from the active layer to the p-cladding layer was reduced, and the internal quantum efficiency was improved.

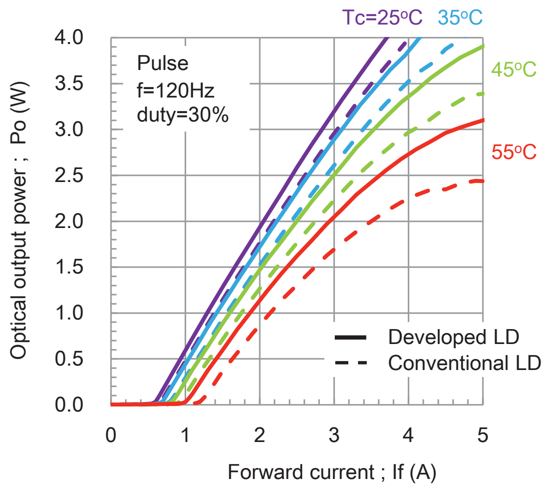

Fig. 3 Comparison of I-L between Developed 638nm LD and Conventional 638nm LD under pulse

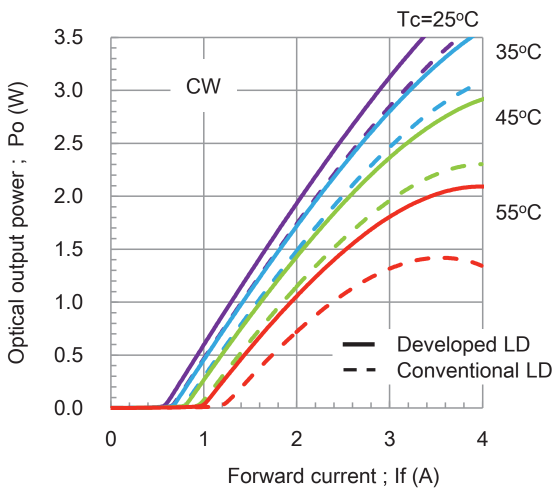

Fig. 4 Comparison of I-L between Developed 638nm LD and Conventional 638nm LD under CW

3.2 Wall plug efficiency

Figure 5 shows the temperature dependence of wall plug efficiency (WPE) with developed 638nm LD in each pulse (solid line) and CW (dash line). In pulse, the highest WPE reached 43% at 25°C, 34% at 45°C and 28% at 55°C. In CW, the highest WPE reached 42% at 25°C, 32% at 45°C and 25% at 55°C. In 638nm LD, WPE 43% at 25°C under pulsed operation is the world's highest to the best of our knowledge. High WPE is highly desirable characteristic for projector, because it can contribute to simplification of cooling system of projector.

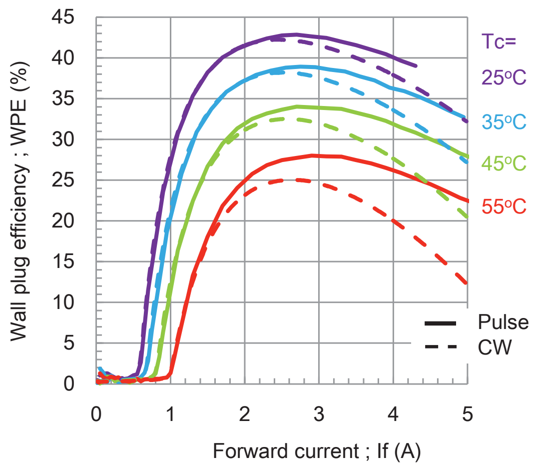

Fig. 5 Temperature dependence of WPE with developed 638nm LD under pulse and CW

3.3 Wavelength effect

Figure 6 and 7 show the comparison of I-L between developed 642nm LD (solid line) and developed 638nm LD (dash line) in each pulse and CW. The 642nm LD was generally improved temperature dependence of I-L than 638nm LD. The threshold current (Ith) at 25°C CW operation for 638nm LD and 642nm LD were 566mA and 614mA, corresponding threshold current density (Jth) was 252A/cm^2 and 273A/cm^2, respectively. Although the threshold current of 642nm LD was 8% larger than 638nm LD at 25°C, the highest power at 55°C was improved 10% from 3.1W to 3.4W pulse, 10% from 2.1W to 2.3W CW. These results were supported by following data that the characteristic temperature (T0) between 25°C and 45°C for 638nm LD and 642nm LD were calculated as 64K and 73K, T0 between 25°C and 55°C were calculated as 56K and 65K, respectively.

We supposed that the reason why the threshold current was higher in 642nm LD was that the split between LH and HH was decreased due to the decrease of tensile strain in quantum well. On the other hand, the reason why T0 was higher in 642nm LD was that electron leakage can be suppressed by lowering the quasi-Fermi level of the quantum well. At high temperatures and high power ranges, the longer wavelength effect was more dominant than the effect of increasing the threshold current due to the decrease of tensile strain.

In case of using red lasers with multiple wavelengths in projector system for speckle reduction, it is necessary to consider differences in I-L characteristics due to differences in wavelength. The developed 638nm and 642nm LDs had similar and good characteristics, and are suitable as projector light sources for speckle reduction.

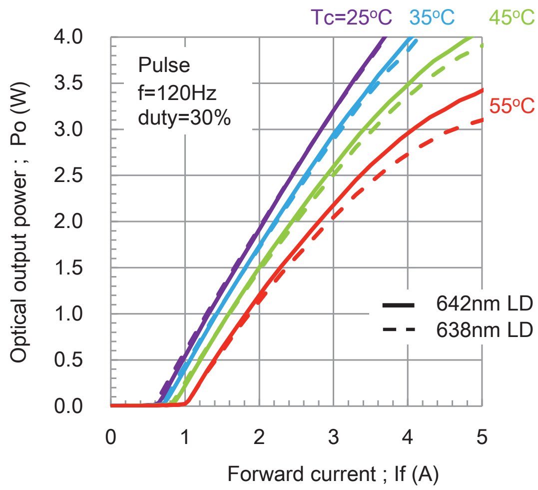

Fig. 6 Comparison of I-L between 642nm LD and 638nm LD under pulse

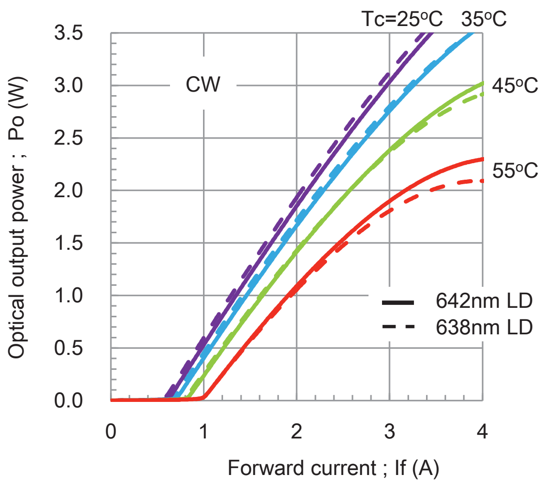

Fig. 7 Comparison of I-L between 642nm LD and 638nm LD under CW

4 RELIABILITY

In the case of high power LDs such as this study, the lifetime is considered two different failure models in which sudden deterioration known as catastrophic optical damage (COD) at high power operation and gradual deterioration at high temperature operation. We calculate the lifetime by two models and the shorter one is defined as the estimated life. Regarding as lifetime of COD, Mean time to failure (MTTF) was equivalent to 28,000hours at pulse 3.5W duty=30%, details were reported in previous paper [5].

Regarding as lifetime of gradual deterioration, Figure 8 shows the life test result of the developed 638nm LD. The test conditions were Tc=45°C, pulse, f=120Hz, duty=35%, If=4.5A (Po=3.5W), automatic current control (ACC). As a result of 1,500hours operation, it showed stable operation. Lifetime was estimated by extrapolation of variation of optical output power with failure criterion of 50% power down. MTTF was calculated to 38,000hours.

From the above results, the estimated life of developed LD was exceeded MTTF 20,000hours under 45°C 3.5W pulsed operation. The life of 642nm LD is estimated to be equal or longer than 638nm LD under the same operating conditions, because 642nm LD has a margin than 638nm LD at high temperature operation as described previous section in this paper. The 3.5W pulsed operation is the world’s highest in 638nm LD to the best of our knowledge. This result satisfies the required lifetime of projector.

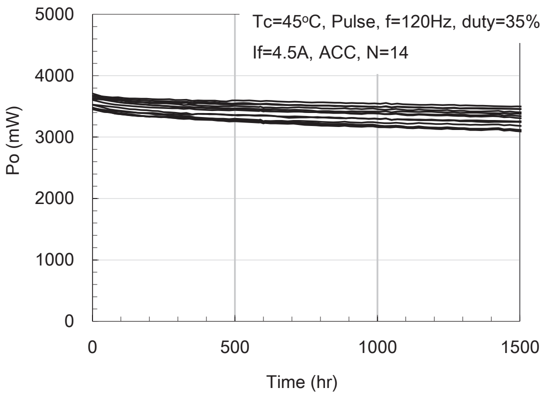

Fig. 8 Life test result of developed 638nm LD

5 CONCLUSIONS

We developed AlGaInP based 638nm and 642nm 3.5W pulse / 2.4W CW red laser diodes. By designing new chips, the developed LDs were achieved high power at high temperature and high efficiency. Our target of optical output power 3.5W pulse with frequency of 120Hz with 30% duty cycle at 45°C was achieved with sufficient margin. The highest WPE reached 43% at 25°C pulse with 638nm LD. The 642nm LD was generally improved temperature dependence of I-L than 638nm LD, although the threshold current of 642nm LD was 8% larger than 638nm LD at 25°C. The estimated life was exceeded MTTF 20,000hours under 45°C 3.5W pulsed operation. The 3.5W pulsed operation and WPE of 43% are the world’s highest in 638nm LD to the best of our knowledge. These newly developed LDs with multiple wavelengths lineups are ideal as red light source for projector.

REFERENCES

[1] H. Hatanaka, and G. T. Niven, “Multi-watt class, red, green, and blue, direct emitting and frequency doubled laser diodes” IDW’11, LIT4/PRJ2-1, 2053-2058 (2011).

[2] H. Yamada, K. Moriyasu, H. Sato, and H. Hatanaka, “Effect of incidence/observation angles and angular diversity on speckle reduction by wavelength diversity in laser projection systems” Optics Express 25, 32132 (2017).

[3] News release from Ushio Opto Semiconductors, Inc. http://www.ushio-optosemi.com/en/NEWS/products/HL63283HD_HL63290HD.html

[4] News release from Ushio Opto Semiconductors, Inc. http://www.ushio-optosemi.com/en/NEWS/products/HL63520HD.html

[5] M. Hagimoto, S. Miyamoto, Y. Kimura, H. Fukai, M. Hashizume, and S. Kawanaka, "USHIO 3.5W red laser diode for projector light source" Proc. SPIE 10939, 109391I (2019).

[6] D. P. Bour, R. S. Geels, D. W. Treat, T.L. Paoli, F. Ponce, R. L. Thornton, B. S. Krusor, R. D. Bringans, and, D. F. Welch, “Strained $Ga_xIn_{1-x}P/(AlGa)_{0.5}In_{0.5}P$ heterostructures and quantum-well laser diodes” IEEE Journal of Quantum Electronics 30 (2), 593-607 (1994).

[7] D.P. Bour, D.W. Treat, R.L. Thornton, R.S. Geels, and D.F. Welch, "Drift leakage current in AlGaInP quantum-well lasers" IEEE Journal of Quantum Electronics 29 (5), 1337-1343 (1993).

[8] A. Valster, C.J. van der Poel, M.N. Finke, and M.J.B. Boermans, "Effect of strain on the threshold current of GaInP/AlGaInP quantum well lasers emitting at 633 nm" 13th IEEE International Semiconductor Laser Conference, 152-153 (1992).

[9] T. Tanaka, H. Yanagisawa, S. Yano, and S. Minagawa, "Tensile strained QW structure for low-threshold operation of short-wavelength AlGaInP LDs emitting in the 630nm band" Electronics Letters 29 (7), 606-607 (1993).

[10] T. Tanaka, H. Yanagisawa, S. Kawanaka, M. Takimoto, and S. Minagawa "Low-Threshold Operation of Short-Wavelength Tensile-Strained QW AlGaInP Laser Diodes in 630-nm Band" 1993 International Conference on Solid State Devices and Materials, LC-10 (1993).