Ultimate high power operation of 9xx-nm single emitter broad stripe laser diodes

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ABSTRACT

Design optimization of single emitter broad stripe 9xx-nm laser diodes was studied to achieve ultimate high power and high efficiency operation for a use in fiber laser pumping and other industrial applications. We tuned laser vertical layer design and stripe width in terms of optical confinement as well as electrical resistance. As a result, newly designed LDs with 4mm-long cavity and 220 µm-wide stripe successfully demonstrate maximum CW output power as high as 33 W and high efficiency operation of more than 60 % PCE even at 27 W output power. In pulse measurement, the maximum output of 68 W was obtained.

Keywords: semiconductor laser, high power laser, high efficiency, 915 nm

1. INTRODUCTION

High power and high efficiency 9xx-nm InGaAs / AlGaAs semiconductor lasers are widely used as light sources for fiber lasers and direct laser processing. In recent years, kW class fiber lasers have been commercialized [1], and LDs used as excitation light sources have strong demands for higher output and efficiency. Large amount of LD are used for fiber lasers, and their proportion to the cost is high. By reducing the number of LDs, the cost of fiber lasers can be greatly reduced. Therefore, improvement of the maximum output power of the LD is an essential task. For this reason, many manufacturers and research institutions are developing high power and high efficiency [2] [3]. In this paper, we report optimization of vertical structure and horizontal structure in our LD design and report on examination of high output power characteristics.

2. LASER DIODE STRUCTURE

Figure 1 shows the cross sectional schematic structure of our LD. The self-aligned structure (SAS) with embedded current blocking layer was adopted. The advantage of the SAS structure is that it is possible to simultaneously form the current blocking layer and the current non-injection structure of front and rear facets. Laser structure was grown by metal organic vapor phase epitaxy (MOVPE), and an injection stripe was formed by etching a current blocking layer. Front and rear facets are AR- and HR-coated, respectively.

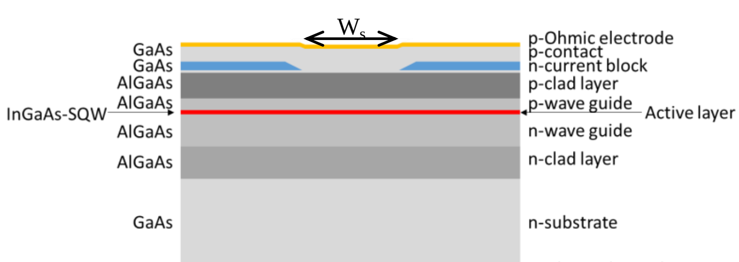

Fig.1. The cross sectional schematic structure of the LD

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3. DESIGN AND PERFORMANCE OF LASER DIODE

3.1 Vertical design

The Asymmetric Decoupled Confinement Heterostructure (ADCH) can achieve low waveguide loss and high reliability, and is a structure suitable for high power lasers [4]. We have adopted ultra-low confinement factor of 0.4% to realize highly reliable high power operation due to lowered optical density [5]. In this section, we adjusted the ADCH to accomplish even higher power operation. Vertical layer design was tuned in terms of optical confinement and carrier transportation through the multilayers. The confinement factor (Γ_{well}) was adjusted by shifting the position of the active layer. Since the ADCH has an asymmetric light density distribution spreading to n-side as shown Fig.2, shifting the active layer position to n-side leads optical confinement factor to increase. As a result, threshold current decreases and internal loss increases.

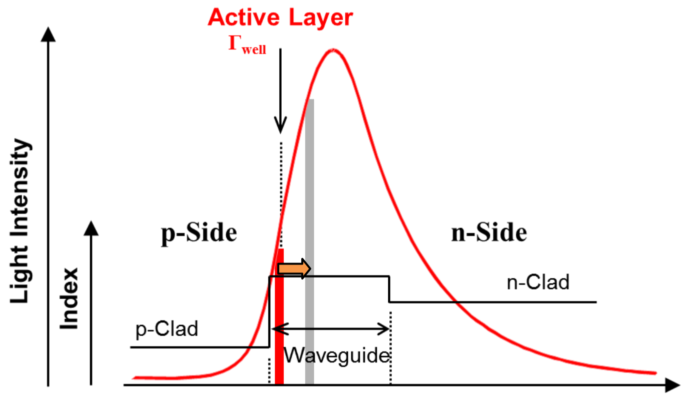


Fig.2. The mode profile, index guide structure and active layer position of ADCH

Figure 3 shows the inverse of differential quantum efficiency (1/ηd) and the threshold current density (Jth) calculated as a function of normalized active layer position defined by (distance from p-clad) / (waveguide thickness). Jth abruptly decreases as increasing the normalized position below 0.4, but thereafter tends to be saturated to 100 A/cm^2. On the other hand, 1/ηd increases monotonically. Based on this result, we considered that these parameters have optimal solutions maximizing power conversion efficiency (PCE). Calculated PCE operating at 15 W is shown Fig.4. In the conventional LD, the normalized position is designed to be 0.06 to realize high reliability due to lowered optical density, and the PCE is calculated to be 0.616. However the maximum PCE is obtained at even larger normalized position of 0.3 and, in that case, PCE improvement of 2 % is expected compared to the conventional LD.

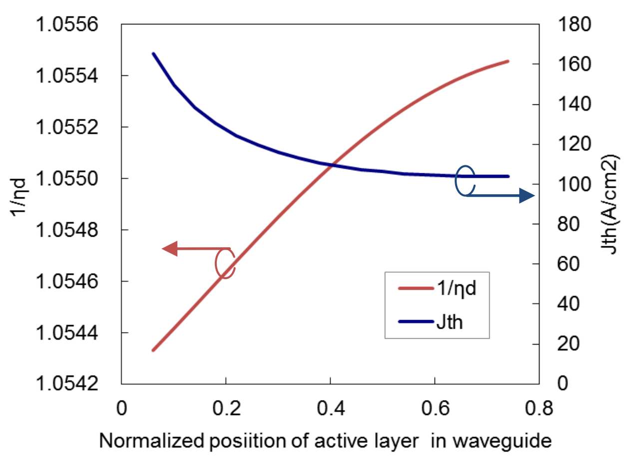


Fig.3. Calculated dependence of 1/ηd and Jth on the active layer position

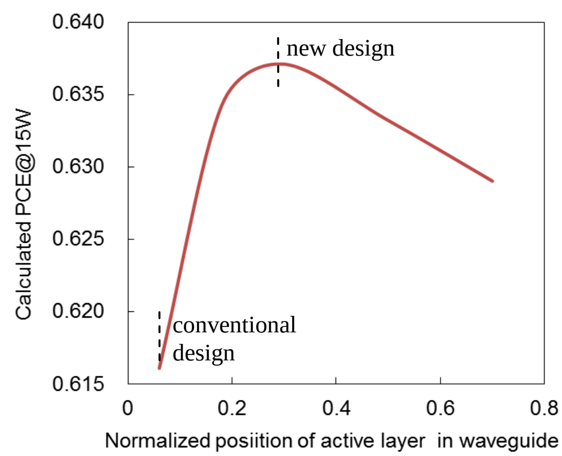
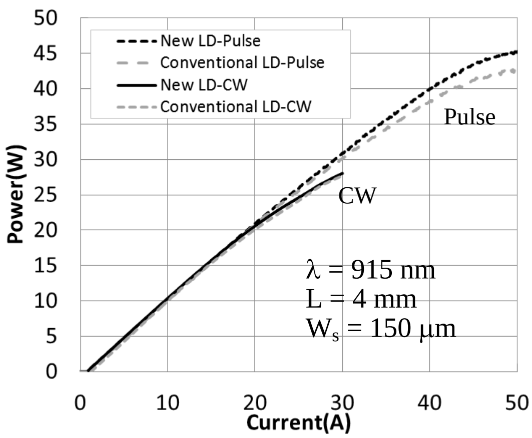
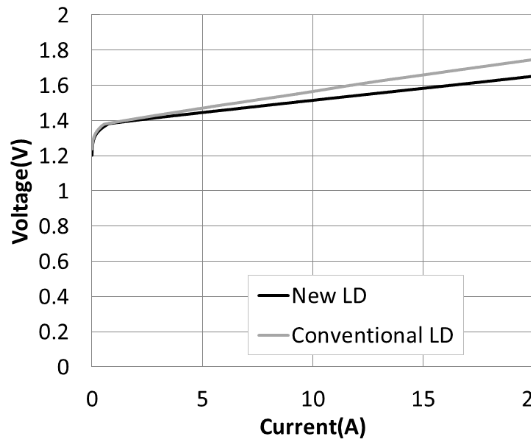


Fig.4. Calculated dependence of PCE on the active layer position at 15 W output power

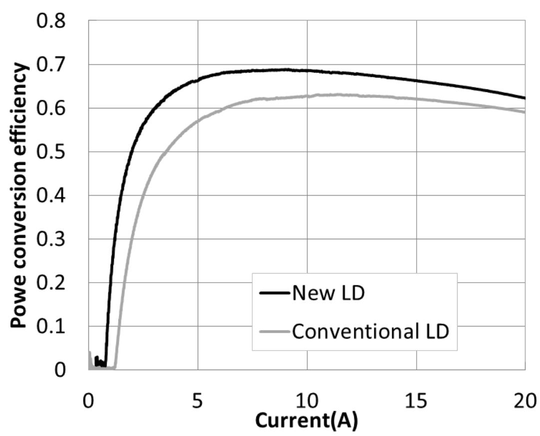
Newly designed LDs wih 4 mm-long cavity and 150 µm-wide stripe were fabricated based on the optimal normalized position of 0.3. The characteristics were experimentally evaluated and compared with conventional LD. Figure 5 shows (a) light output, (b) operating voltage, (c) PCE versus operating current characteristics of newly designed LDs and conventional ones. CW output power of over 25 W was obtained at room temperature. Moreover, the output power under pulsed condition reached 45 W at 50 A without Catastrophic Optical Damage (COD). The diode resistance decreased from 20 mΩ to 13 mΩ due to multilayer structure optimization from the carrier transportation points of view. PCE of new LD is improved by more than 4 % over the whole output power range. This improvement is bigger than expected in Fig.4, attributing reduced resistance. PCE reaches 68 % at the peak and, keeps more than 65 % up to 17 W output power level.



(a) L-I characteristics



(b) V-I characteristics



(c) PCE characteristics

Fig.5. Performance of newly designed LDs compared with conventional LDs measured at 25 deg-C

3.2 Horizontal design

We compared high power operation characteristics for newly designed LDs with different stripe width (W_s) in the range from 100 µm to 220 µm, where cavity length is fixed at 4mm. Widening W_s is the simplest way to increase the maximum light output power per one emitter through the effects of lowered resistance.

Measured L-I curves are shown in Fig.6. As widening Ws, the maximum output power increases monotonically because of lowered electrical resistance. For the widest W_s of 220 µm, the maximum output power reaches 33 W, which is 50 % improvement in comparison with W_s = 100 µm. Figure 7 shows PCE as a function of output power characteristics for different W_s. Although peak values of PCE do not change (keeping the same level of 68 %) for any W_s, those values in high power range exceeding 10 W are remarkably improved in wider W_s. High efficiency operation of more than 60 % PCE was achieved up to 27 W output power for W_s = 220 µm.

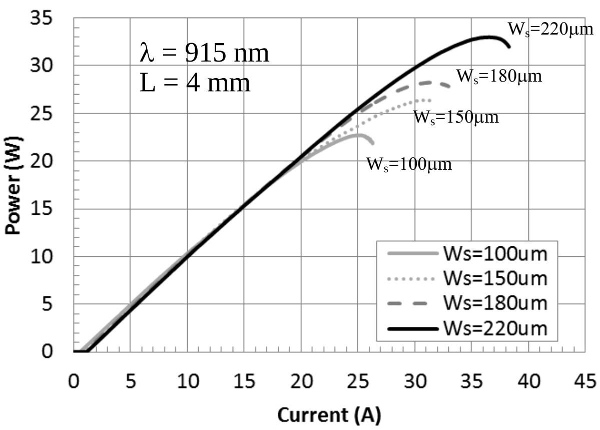


Fig.6. High power L-I characteristics of LDs with different W_s measured at 25 deg-C

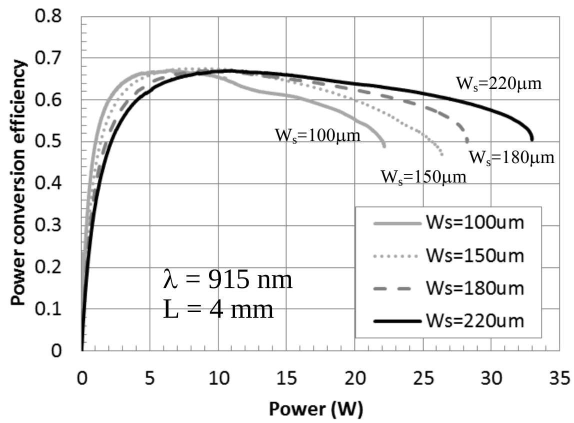


Fig.7. PCE versus output power characteristics of LDs with different W_s measured at 25 deg-C

Pulsed L-I characteristics with W_s = 220 µm is shown in Fig.8. In pulse measurement, the maximum output of 68 W was obtained, which was more than double of that of CW. The linearity of the pulsed L-I characteristic is still maintained even at such a high power level, and the maximum output can be expected to exceed 70 W by higher current injection. The difference of L-I characteristics between CW and pulse is caused by heat generation. Therefore, the maximum output improvement in CW can be possible by further improvement of the heat dissipation from the LD.

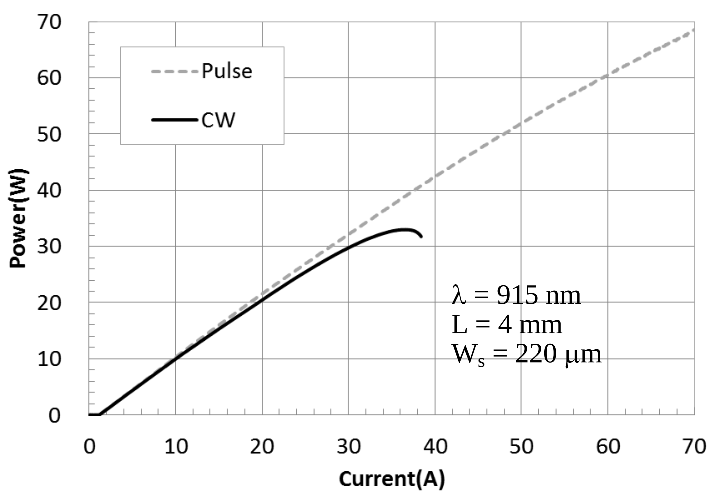


Fig.8. L-I characteristics of LD with W_s = 220 µm measured at 25 deg-C

Optical beam property is also investigated for different W_s. Figure 9 shows beam product parameter (BPP) versus output power for W_s = 100, 150 and 220 µm. BPP slightly increases as widening W_s. Even if W_s is doubled, the increment of BPP is small, 4.3 mm-mrad for W_s = 100 µm and 5.3 mm-mrad for W_s = 220 µm at 12 W operating.

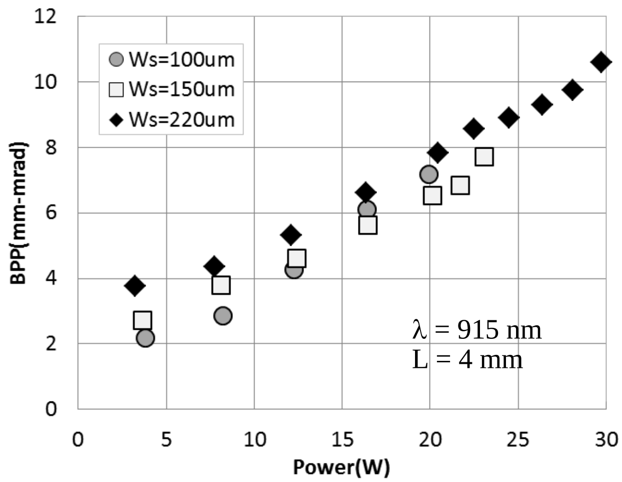


Fig.9. BPP versus output power characteristics of LDs with different W_s measured at 25 deg-C

4. SUMMARY

Ultimate high power and high efficiency operations of broad stripe InGaAs /AlGaAs 915-nm LDs are studied by tuning vertical and horizontal laser design. Optimization of active layer position and multi-layer structure realizes remarkable improvement in PCE by 4 % due to waveguide loss reduction and electrical resistance reduction. Dependence of laser performance on current injection stripe width is also investigated experimentally. The maximum light output power simply increases as widening stripe width and that reaches 33 W at CW operation and 68 W at pulsed operation for the widest stripe width of 220 µm. This is the highest level of output power per single emitter maintaining high PCE ever realized in the world.

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