High Polarization Purity High Power Laser Diodes

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High power laser diode (LD) modules are demanded for sources of fiber laser systems. It is important to use high polarization purity LDs in polarization multiplexing techniques for improving the power of LD modules. We have achieved transverse electric (TE) polarization purity of over 99% in our original self-aligned stripe (SAS)-LDs. The maximum output power of 394 W has been achieved in the LD module by using SAS-LDs for light sources, applied with polarization multiplexing.

1. Introduction

High power LD modules are strongly demanded for pump sources of fiber laser systems, which recently exceeded 10 kW of commercial output power. Polarization multiplexing is one of the promising technologies for doubling the output power of LD modules [1]. To realize highly efficient LD module with polarization multiplexing, it is essential to use high polarization purity LDs. Polarization purity of LDs deteriorate by TM polarized component, which is known to possibly arise from the external strain [2]. Especially when the LD is mounted onto the sub-mount, mechanical strain tends to localize at patterned edges of the non-flat surface. In this work, higher polarization purity compared to the conventional Ridge-LDs has been achieved in LDs based on the original SAS structure with small patterned edge. The development of LD modules using high polarization purity SAS-LDs is also presented.

2. Development of high power high reliability LDs

In addition to high power and high efficiency, high reliability is required for LDs for sources of high power fiber laser systems. To fulfill these requirements, we have developed high power, high efficiency LDs of 9xx-nm range by applying ADCH laser structure and wide injection stripe [3]. As shown in Fig. 1, maximum output power of 33 W has been achieved in the LD with 220 μm stripe width under CW operation. The maximum power conversion efficiency is 68%. In addition, over 69 W has been achieved without COD failure under pulse operation (pulse width = 20 μs, duty cycle = 1%) [4]. Long-term reliability has been evaluated in the aging test of LDs with 180 μm stripe width. As shown in Fig. 2, stable operation of over

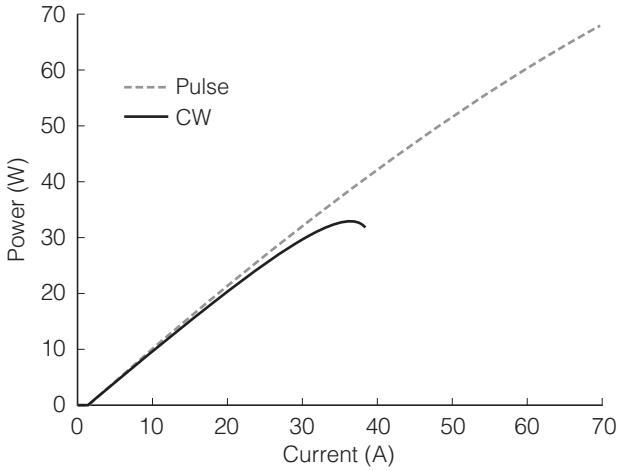

Fig. 1. Light-output versus current characteristics of the developed high power LD(emission width = 220 μm).

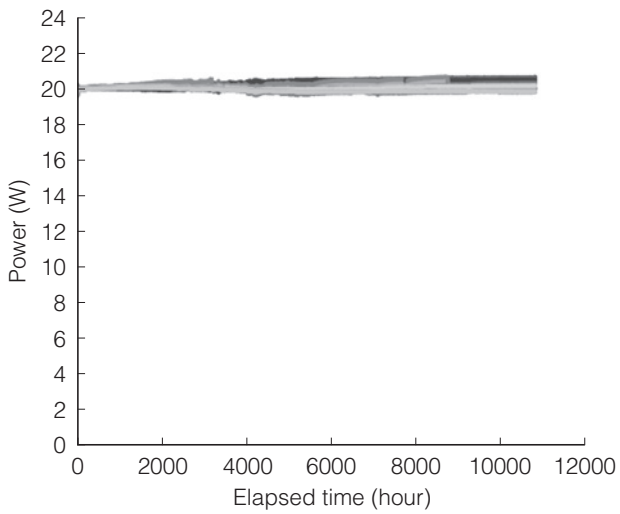

Fig. 2. Reliability test of high power LDs (emission width = 180 μm).

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10000 h without any failure has been demonstrated with 20 W output power [5]. In the following sections, fabrication of SAS-LDs and Ridge-LDs based on ADCH structure and evaluation of polarization purity is presented.

3. LD structure

Figure 3 shows cross-sectional view of SAS-LD and Ridge-LD. In Ridge-LDs, current injection area is formed by the convex area called mesa. In SAS-LDs, the injection stripe is formed by etching the current blocking layer, which leads to the smaller surface mechanical edges than Ridge-LDs. Vertical layers of these two types of lasers are based on the ADCH structure, and are designed identically for high-power, high-efficiency operation. The laser structures with InGaAs/AlGaAs material system are grown by MOCVD on n-type GaAs substrates to have emission wavelength of 915 nm. Both types of LDs are fabricated to have 180 μm-wide stripe and 4 mm-long cavity. Front and rear facets are anti-reflection and high-reflection coated, respectively. In order to improve heat dissipation, p-side (nearer side from the active layer than n-side) surface of LDs is mounted on ceramic base high thermal conductive sub-mounts with AuSn solder (p-side mounting).

Numerical simulation of strain in the p-side mounted Ridge-LD is carried out as shown in Fig. 4. The result indicates that the strong strain is applied at both sides of the ridge by mounting the LD to the sub-mount. It is known that the strain tends to accumulate at mechanical edges [6], such as edges of the ridge structure in Ridge-LDs. The height of the ridge stripe is approximately 2 μm, which is larger than the step height of the surface of SAS-LD (0.6 μm). Larger mechanical edge may result in larger strain. In addition, the strain field induced in the Ridge-LD overlaps with the waveguide region as seen in Fig. 4. The mechanical edge of the surface of Ridge-LDs is closer to the waveguide region than that of SAS-LDs. The emission light of LDs is mainly TE polarized. However, TE polarized light is possibly rotated to be TM polarized when an external strain is induced. The polarization purity of Ridge-LDs might deteriorate by influences of the strain as indicated above.

4. Polarization properties of LDs

4. 1 Laser output characteristics and NFP measurements

Light-output versus current characteristics of the SAS-LD and the Ridge-LD are shown in Fig. 5. The output power of both types of LDs reaches over 20 W at 20 A. Maximum power conversion efficiency is 64%. From these results, it is confirmed that SAS-LDs and Ridge-LDs have no apparent difference in laser output

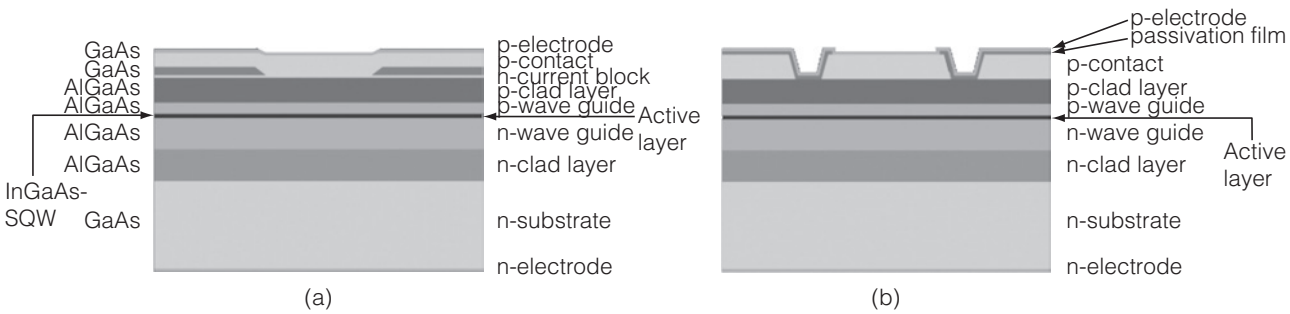

Fig. 3. Cross-sectional view of (a) SAS-LD, and (b) Ridge-LD.

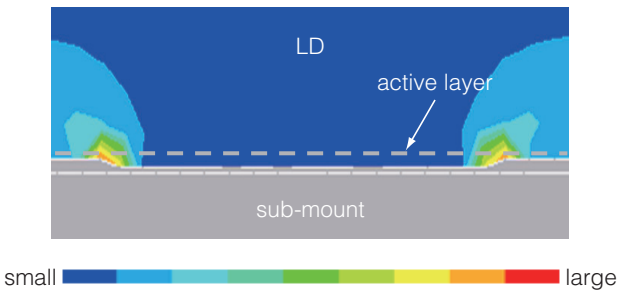

Fig. 4. Strain simulation of Ridge-LD mounted on sub-mount.

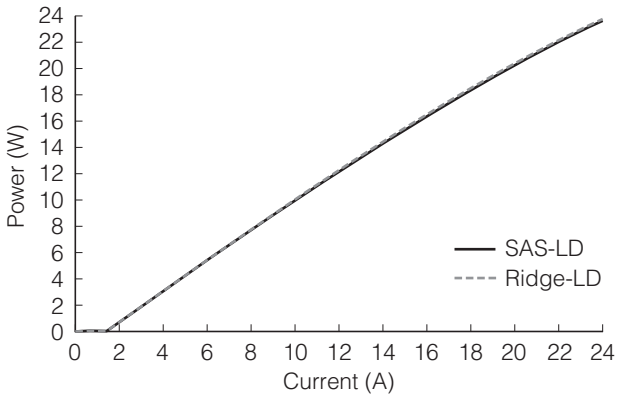

Fig. 5. Light-output versus current characteristics of SAS-LD and Ridge-LD.

characteristics, both of which show excellent high-power operation.

In order to evaluate the polarization characteristics of LDs, NFP of TE and TM polarizations are measured separately. These measurements are done by inserting a polarizer in the optical path of the NFP measurement system. Figure 6 shows NFP profiles of TE and TM polarizations in SAS-LD and Ridge-LD at injection current of 18A. Peaks of TM polarization are observed at the side edges in the Ridge-LD. It is thought that TM polarization arise by the strain, as expected by the result of strain simulation in Fig. 4. On the other hand, SAS-LD shows a relatively flat and weak TM polarization profile compared to the Ridge-LD.

4. 2 Polarization purity

To evaluate the polarization purity of LDs quantitatively, the TE polarization purity is defined as below.

TE polarization purity = $I_{TE}/(I_{TE} + I_{TM})$

I_{TE} and I_{TM} denote the total intensity of TE and TM polarization. When the laser emission is completely TE polarized, the value is 1. Figure 7 shows the dependence of TE polarization purity on injection current in the SAS-LD and the Ridge-LD. The SAS-LD shows TE polarization purity exceeding 99%, and those values stay almost constant up to 18 A. On the contrary, those of the Ridge-LD deteriorate to 96% as the injection current increases. TE polarization purity data for SAS-LDs and Ridge-LDs measured at injection current of 12 A are plotted in Fig. 8. The average TE polarization purity of SAS-LDs and Ridge LDs are 98.4% and 96.8%, respectively. From the result shown in Fig. 7 and Fig. 8, it is confirmed that SAS-LDs have higher TE polarization purity and they are suitable sources for polarization multiplexing.

4.3 Improvement of polarization purity with strain-free mounting

The result of the strain simulation (Fig. 4) and the NFP measurement (Fig. 6) indicates the strong influence of strain on the polarization purity in LDs when they are mounted on sub-mounts. To clarify the effect of the strain induced by mounting, LDs are

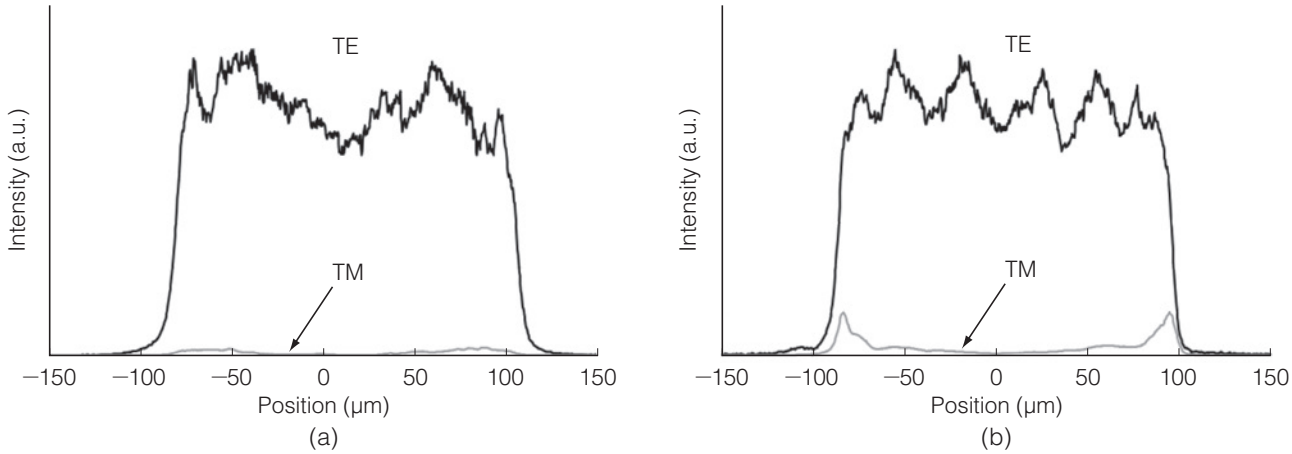

Fig. 6. NFP profiles of TE and TM polarization for (a) SAS-LD, and (b) Ridge-LD at 18 A.

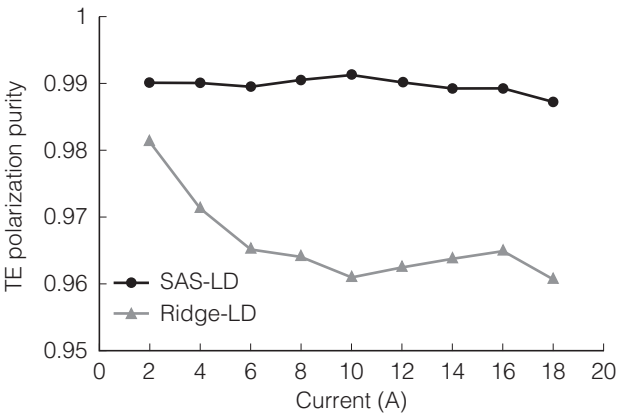

Fig. 7. Injection current dependence of polarization purity.

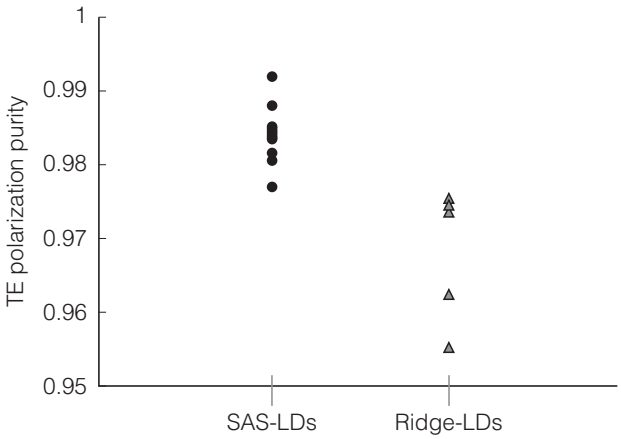

Fig. 8. Polarization purity of SAS-LDs and Ridge-LDs at 12 A.

n-side mounted, that is, in the inverse direction of the normal p-side mounting. Vertical distance of the active layer from the mounted surface in p-side mounted lasers is approximately 4 μm, while that in the n-side mounted LDs increases to 120 μm. Therefore, it is expected that the strain induced to the active layer by mounting is drastically reduced by n-side mounting. However, n-side mounting is not usually applied in high power LDs since the heat dissipation is worse than p-side mounting. Figure 9 shows the dependence of polarization purity on injection current in p-side mounted and n-side mounted SAS-LD and Ridge-LD. These measurements are carried out with pulse operation (pulse width 40 μs, duty 1%).

Polarization purity of both types of LDs improves by n-side mounting. In n-side mounted SAS-LDs, polarization purity reaches 99.9% at maximum, which is essentially a complete TE polarized laser emission. In Ridge-LDs, polarization purity improved about 2 percentage points by n-side mounting, but the value is still lower than SAS-LDs. These results of Ridge-LDs indicate that there may be an additional strain induced in Ridge-LDs compared to SAS-LDs. In Ridge LDs, the passivation film is grown on the top surface to form the current injection area. There is a large difference of coefficient of thermal expansion (CTE) between semiconductor layer (GaAs) and the passivation film (silicon nitride). It is thought that thermal stress by the CTE mismatch between GaAs and the passivation film is induced during the deposition of the passivation film.

Results shown in Fig. 9 suggest the possibility of further improvement of polarization purity in p-side mounted LDs as well by reducing the strain arises with mounting. Various mounting conditions are applied to SAS-LDs to reduce the strain including the heating profile of AuSn soldering, load applied to LDs during mounting, AuSn solder composition, etc. Figure 10 shows the dependence of TE polarization purity on injection current of the p-side mounted SAS-LDs under previous bonding condition and the optimized condition. The values improved approximately 0.5 to 0.7 percentage points by optimizing the bonding condition.

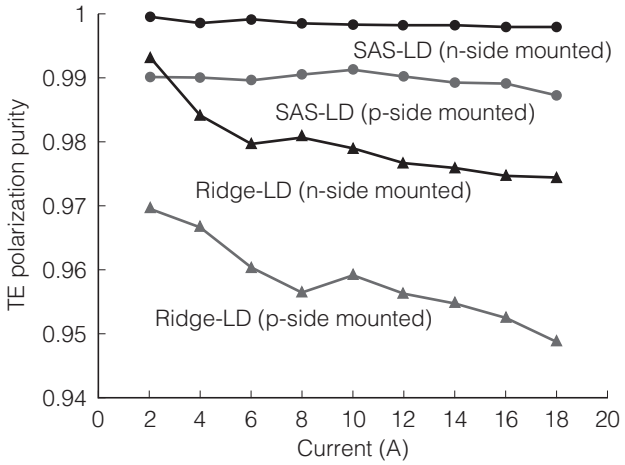

Fig. 9. Polarization purity of SAS-LD and Ridge-LD by different mounting.

5. LD modules using SAS-LDs

High power LD modules for fiber laser systems have been developed by using high polarization purity SAS-LDs. To improve the output power of LD modules, polarization multiplexing is applied in addition to spatial beam multiplexing. Figure 11 shows the schematic view of the polarization multiplexing system in the LD module. At the dielectric multilayer film of the polarization beam combiner, horizontal polarized light is reflected, while vertically polarized light is transmitted. TM polarization of the laser emission becomes loss at the polarization beam combiner. Therefore, high polarization purity is advantageous for improving the output power of LD modules.

The photograph and the light-output versus current characteristics of the newly developed high power LD

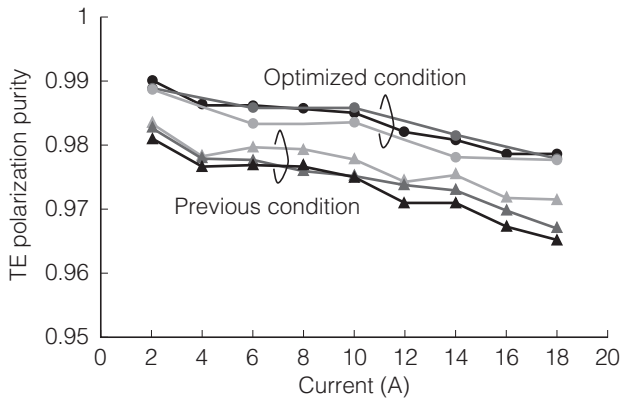

Fig. 10. Polarization purity of p-side mounted SAS-LDwith previous bonding condition and optimized condition.

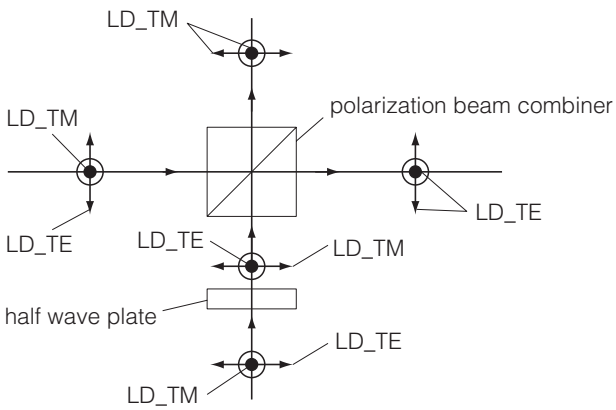

Fig. 11. Schematic view of polarization multiplexing system.

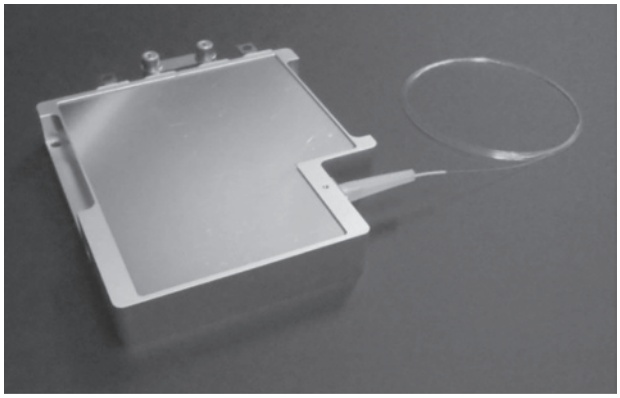

Fig. 12. Photograph of developed high-power LD module.

module are shown in Fig. 12 and Fig. 13, respectively. The emission wavelength of LDs are 976 nm, fiber core diameter is 118 μm. The output power measurement is done under 25 °C of case temperature. The maximum output power of 394 W has been achieved at the operation current of 23 A. Our company has accomplished 5 kW single-mode fiber laser systems by utilizing the developed LD modules [7) 8)].

6. Conclusion

Polarization purity of SAS-LDs and Ridge-LDs are investigated to realize highly efficient LD modules with polarization multiplexing. Polarization purity of LDs is evaluated by separating TE and TM polarization in NFP measurements. In SAS-LDs, TE polarization purity exceeds 99%, which indicates that they are advantageous compared to the conventional Ridge-LDs for high polarization purity operation. In order to clarify the influence of strain induced by mounting, n-side mounting is applied to increase the distance from the sub-mount surface to the active layer. Polarization purity improves by n-side mounting, suggesting further improvement in p-side mounted LDs as well by reducing the strain that arises with mounting. By optimizing the mounting conditions, polarization purity improved approximately 0.5 to 0.7 percentage points. High power LD modules with polarization multiplexing have been newly developed by using SAS-LDs. The maximum output power of 394 W has been achieved at 23 A.

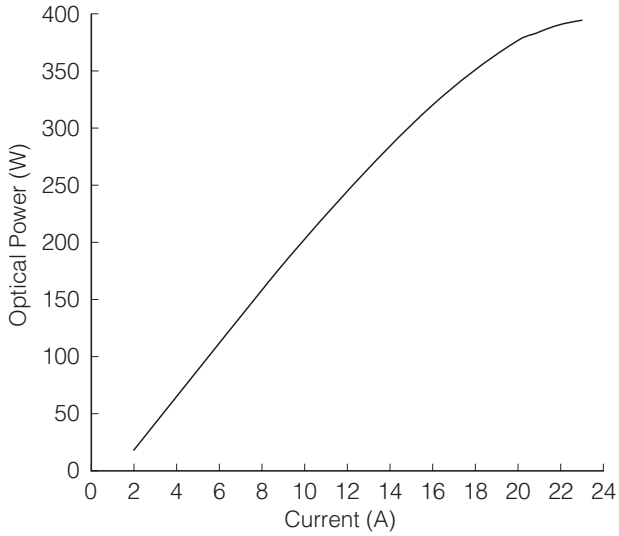

Fig. 13. Light-output versus current characteristics of the LD module.

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