First demonstration of novel active multi-mode interferometer (MMI) LDs integrated with 1st order-mode permitted waveguides

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Abstract: Here we propose novel active multi-mode-interferometer (MMI) laser diodes (LDs) for 14XX nm fiber amplifier pump applications. The waveguide of the LDs is consisted from 1x1-MMI couplers integrated with 1st order-mode permitted waveguides to enhance the total active area. Although there is no single-mode waveguide region inside the cavity, the novel active MMI-LDs emitted in stable single-transverse-mode output up to maximum output power. Moreover, they achieved high output power of 1.46 W, and low driving voltage of only 1.75 V at 1 W output power.

Keywords: active MMI-LD, single-transverse-mode, high power, low driving voltage, low power consumption

Classification: Photonics devices, circuits, and systems

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1 Introduction

Recent rapid growth of data traffic in optical transmission systems requires higher optical output power in 14XX nm pump LDs [1, 2, 3, 4] for fiber-amplifier applications. Using so many high power optical amplifiers will, however, also lead to a huge energy consumptions in the future. Since an optical amplifier is one of the major energy consumption devices, we have proposed the concept of active MMI-LDs [5, 6, 7] for fiber-amplifier pumping LDs. The active MMI-LD has a wide width waveguide of MMI section inside the cavity. The wide width results in an increase of optical output power as well as a reduction of driving voltage compared to regular single-stripe LDs. In the meantime the active MMI-LD emits in regular single-mode output which is useful for efficient fiber coupling.

One of the further performance improvement ways, especially for higher output power and lower driving voltage, is to enhance the active area also in the region of single-mode waveguide in the conventional active MMI-LD. However, it has been essential to consist of such a region to keep stable single-transverse-mode operation. In this work, we propose and demonstrate novel active MMI-LDs whose conventional regular single-mode waveguide regions are replaced with 1st order-mode permitted waveguides for the first time. Although there was no single-mode waveguide region inside the cavity, the implemented LDs emitted in stable single-mode output. They achieved high power of 1.46 W and low driving voltage of only 1.75 V at 1 W output.

2 Concept

Figure 1 shows a schematic structure of the novel active MMI-LD. It consists of a 1x1-MMI coupler [8] connected to non-MMI regions. The length and width of the MMI section were optimized so that the optical field at one end of the MMI was identically imaged at the other end of the MMI. Moreover, we integrated 1st order-mode permitted waveguides as shown in Fig. 1 in the region of non-MMI. We designed the MMI section so as to eliminate 1st order-mode lasing in the cavity even if the structure includes 1st order-mode permitted waveguides. In case of designing 1x1-MMI region with the length L_{MMI} as;

$$L_{MMI} = n \cdot \frac{3L_{\pi}}{4} \quad (1)$$

n : integer, excluding multiple of integer 4, L_{π} : beat length

Fig. 1. Schematic of Novel Active MMI-LD.

the phase of odd-mode at one end-port of the 1x1-MMI is not self-imaged at the other end-port of the 1x1-MMI. The MMI region works as odd-mode filter [9] under the condition of Eq. (1). In this work, we designed the novel active MMI laser diodes so that the above condition of Eq. (1) was satisfied with $n = 1$. Then, the proper MMI length for 1st order-mode became 4 times longer than the length of the designed MMI region, therefore, the 1st order-mode was no more steady-state in the laser cavity. The designed novel active MMI-LD was expected to contribute to higher output power and better electric resistance due to its wider width in the region of non-MMI.

3 Results and Discussions

Actual novel active MMI-LDs were fabricated on regular InGaAsP/InP multiple-quantum-wells at a wavelength of $1.48 \mu\text{m}$. They were implemented in a double-channel current-blockings [10]. The cavity was 3-mm long. The non-MMI waveguide region was designed with $4 \mu\text{m}$ width 1st order-mode permitted waveguide. For comparison, conventional active MMI-LDs, whose single-mode waveguide width was $2 \mu\text{m}$, and regular single-stripe LDs of $2 \mu\text{m}$ width were also fabricated simultaneously on a same wafer. The total active areas were $3.2 \times 10^{-4} \text{ cm}^2$, $3.0 \times 10^{-4} \text{ cm}^2$, and $6.0 \times 10^{-5} \text{ cm}^2$, for the novel

active MMI-LDs, the conventional active MMI-LDs, and the regular LDs, respectively.

Figure 2 shows the far-field-patterns of the fabricated novel active MMI-LDs (see Fig. 2(a)). For comparison, those of the regular single-stripe LDs were also shown (see Fig. 2(b)). As can be seen in the figures, stable single-transverse-mode operation was confirmed for the novel active MMI-LDs. The obtained coupling efficiency between single-mode fiber by using two-lens system was approximately 80%, which was slightly lower compared to that of conventional active MMI [7]. This was due to the foci difference between lateral and vertical direction, and the measured coupling efficiency corresponded to the calculated one with taking account of this foci difference. From this result, it is implied that the MMI region works as mode-stabilizing (odd-mode prohibiting) region. The foci difference can be optimized when the layer structure is modified for the novel active MMI-LD structure.

Fig. 2. Far Field Patterns (Lateral Direction). (a) Novel Active MMI-LDs, (b) Regular Single-Stripe LDs.

Figure 3 shows the light output power characteristics. As can be seen, the maximum output power was significantly improved in the novel active MMI-LDs, compared to the others. The obtained maximum output powers were 1.46 W, 1.11 W, and 0.62 W for the novel active MMI-LDs, the conventional active MMI-LDs, and the regular LDs, respectively. The obtained output power of the novel active MMI-LDs was 2.4 times higher than that of the regular LDs. In the novel active MMI-LDs, the larger active area improves heat dissipation, and the wider waveguide width at the LD output-end improves hole-burning. The driving voltage of the novel active MMI-LDs were also improved compared to the others. This was due to the resistance reduction of 56% compared to the regular LDs. The attained differential resistances were 0.35 Ω , 0.4 Ω , and 0.79 Ω for the novel active MMI-LDs, the conventional active MMI-LDs, and the regular LDs, respectively. The driving voltage of only 1.75 V was achieved at the output power of 1 W. Consequently, the wall-plug power consumption of 5.5 W at 1 W output power was obtained in

Fig. 3. Output Power Characteristics. (a) vs Current, (b) vs Voltage.

the novel active MMI-LDs. On the contrary, the regular LDs emitted 0.58 W at the same wall-plug power consumption of 5.5 W. From this result, the novel active MMI-LDs are superior also in energy conservation.

4 Conclusion

We demonstrated novel active MMI-LDs which were integrated with 1st order-mode permitted waveguides for the first time. We successfully confirmed stable single-transverse-mode output, high output power of 1.46 W, and low driving voltage of 1.75 V at 1 W output in a wavelength of 1.48 μm . We expect that this technology will contribute to energy conservation in the future.

Acknowledgements

A part of this work was supported by NEDO. The authors would like to thank to Mrs. Yoko Tarui for her technical assistance.