Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 994-995

E-8-3

Improvement of Kink-Free Light Output for Fiber Pump Semiconductor Lasers

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1. Introduction

High power 980-nm semiconductor lasers are pumping sources of erbium-doped optical fiber amplifiers (EDFAs) and contribute to wavelength division multiplexing optical fiber communication systems. Higher light output is desired to reduce the number of pumping semiconductor lasers and to improve performance of optical fiber communication systems. Generally, 980-nm semiconductor lasers employ a ridge laser structure so as not to expose their active region to air during their fabrication processes. When injected current increase to enhance light output, kinks appear in current versus light-output (*I-L*) curves [1]. Kinks in *I-L* curves are attributed to instability of transverse modes. Above kink levels in *I-L* curves, slope efficiency and fiber coupling efficiency of the semiconductor lasers are deteriorated. Therefore, to enhance light output with maintaining high slope efficiency and fiber coupling efficiency, higher kink-free light output is needed. Up to now, to increase kink-free light output, coupling of the optical field to the lossy metal layers outside the ridge [2], highly resistive regions in both sides of ridge stripe [3], and incorporation of a graded V-shape layer [4] have been proposed.

In this paper, a novel ridge structure which leads to stable single-transverse-mode oscillations is proposed, and its lasing characteristics are analyzed. It is found that the proposed ridge structure, where an anode is located in both sides of a mesa, enhances kink-free light output. Moreover, it is revealed that the proposed ridge structure improves current versus voltage (*I-V*) characteristics.

2. Laser Structure and Device Simulation

Figure 1 illustrates schematic cross-sectional views of (a) a conventional ridge structure where an anode is located on a mesa [5] and (b) a proposed ridge structure where an anode is placed in both sides of a mesa. A rectangular mesa is 2.5 μm wide. An active layer is 0.1 μm thick, and cladding layers in both sides of the mesa are 0.4 μm thick. The aluminum compositions of both p-AlGaAs cladding layer and n-AlGaAs cladding layer are 20%. The cavity length is 1200 μm. The reflectivity of the front facet and the reflectivity of the rear facet are 2% and 90%, respectively. In the proposed ridge structure shown in Fig.1 (b), both anodes are 1.25 μm wide, which means that the total width of the anode is common in Figs.1 (a) and (b). In Fig.1 (a), because an anode is located on a mesa, refractive index at the center of an optical emission region significantly decreases by free carrier plasma effect. Therefore, higher order transverse modes tend to oscillate with an increase in injected current. In Fig.1 (b), because an anode is placed in both sides of a mesa, significant reduction in refractive index at the center of light emission region can be avoided. Thus, it is expected that oscillations of higher order transverse modes are suppressed, and a fundamental mode in Fig.1 (b) becomes more stable than the fundamental mode in Fig.1 (a) when injected current increases.

Lasing characteristics are analyzed by using a device simulation software, ATLAS (Silvaco). To simulate the behavior of a semiconductor laser, ATLAS solves the Poisson's equation, the Schrodinger equation, current continuity equations for electrons and holes, and energy balance equation for electrons and holes.

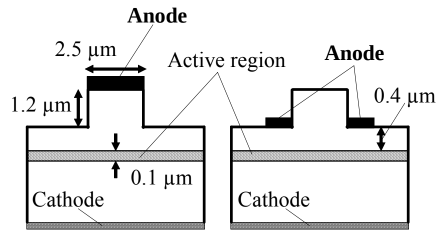


Fig.1 Schematic of (a) a conventional ridge structure and (b) a proposed ridge structures.

3. Simulated Results and Discussions

Figure 2 plots simulated current versus voltage (*I-V*) curves for the conventional ridge structure and the proposed ridge structures. As shown in Fig.2, *I-V* characteristic for the proposed ridge structure is better than *I-V* characteristic for the conventional structure. For example, at applied voltage of 1.4 V, injected current for the conventional ridge structure and injected current for the proposed ridge structure are 16 mA and 21 mA, respectively. In the conventional ridge structure where injected current flows though the mesa, a path for the injected current is longer than a path for the injected current of the present ridge structure. As a result, electrical resistance of the proposed ridge structure is lower than electrical resistance of the conventional ridge structure. Kinks in the *I-V* curves correspond to kinks in *I-L* curves. At the kink levels, a transverse mode changes from a fundamental mode to a higher order mode, and a carrier concentration distribution in an active layer abruptly changes. This phenomenon causes kinks in the *I-V* curves.

Figure 3 shows (a) electron concentration and (b) effective refractive index in an active region as a function of the distance from the center of the mesa in a horizontal direction at injected current of 330 mA. In the conventional ridge structure where an anode is located on the mesa, the electron concentration at the center of the mesa is the highest in the active region, as shown in Fig.3 (a). Therefore, effective refractive index at the center of light emission region significantly decreases by free carrier plasma effect, as illustrated in Fig.3 (b). In the proposed ridge structure where an anode is placed in both sides of the mesa, injected current flows from both sides of the mesa to a light emission region. Thus, a uniform electron concentration region in the proposed ridge structure is wider than the conventional ridge structure, as shown in Fig.3 (a).

Consequently, effective refractive index distribution is also uniform in the light emission region, as can be seen in Fig. 3 (b). In other words, anti-guiding effect by free carrier plasma effect in the proposed ridge structure is more suppressed than the conventional ridge structure. Simulated *I-L*

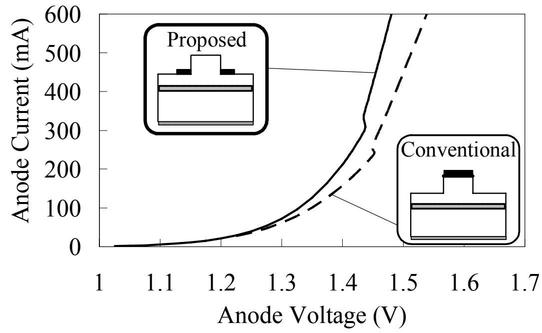
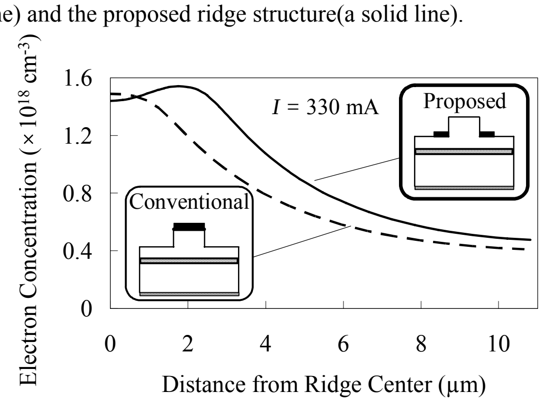
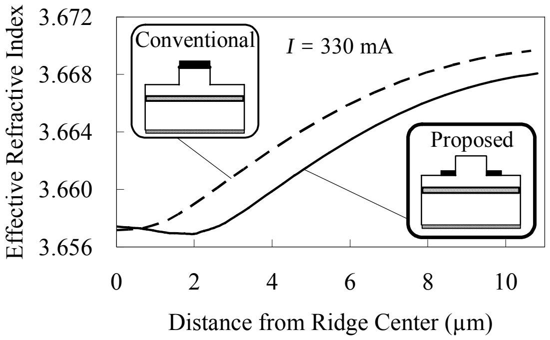


Fig.2 *I-V* curves for the conventional ridge structure (a broken line) and the proposed ridge structure(a solid line).



(a)



(b)

Fig.3 (a) Electron concentration and (b) effective refractive index as a function of the distance from the center of the mesa in a horizontal direction for the conventional ridge structure (a broken line) and the proposed ridge structure (a solid line) at injected current of 330 mA.

curves for the conventional ridge structure and the proposed ridge structure are shown in Fig.4. From Fig.4, kink-free light output for the conventional ridge structure and kink-free light output for the proposed ridge structure are about 30 mW and about 60 mW, respectively. It is revealed that a kink level in the proposed ridge structure is twice as high as that of the conventional ridge structure. However, threshold current of the proposed ridge structure is larger than that of the conventional ridge structure by 50 mA. It is possible to suppress an increase in the threshold current by optimizing a ridge structure or an anode. As can be seen in Fig.3 (a), in the proposed ridge structure, the electron concentration in light emission region is not always precisely uniform. By locating an anode not only in both sides of the mesa but also on lateral sides of the mesa, it is expected that the electron concentration in the active region becomes more uniform and local optical gain in the light emission region increases. Therefore, kink-free light output will be enhanced and increase in the threshold current will be suppressed. It is believed that the proposed ridge structure is a good candidate for a high performance fiber pump semiconductor laser.

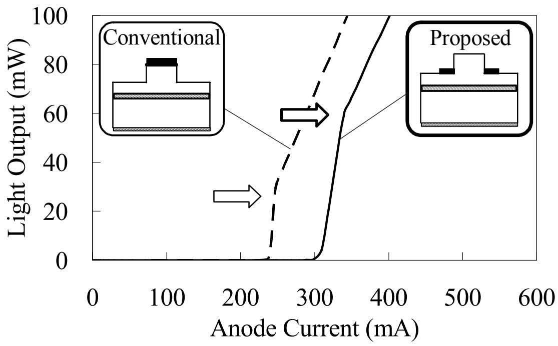


Fig.4 *I-L* curves for the conventional ridge structure (a broken line) and the proposed ridge structure (a solid line).

4. Conclusions

In summary, a novel ridge structure, where an anode is placed in both sides of a mesa, was proposed, and analyzed to improve kink-free light output. In the proposed ridge structure, kink-free light output of 60 mW, which is about twice as high as that of the conventional ridge structure, was obtained. Also, due to shorter path for injected current, electrical resistance became lower than the conventional ridge structure, and *I-V* characteristic was improved.

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