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Ridge-Type Semiconductor Lasers with Optical Antiguiding Layers for Horizontal Transverse Modes: Dependence on Step Positions

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1. Introduction

High power 980-nm semiconductor lasers are used as pumping sources of erbium doped optical fiber amplifiers and contribute to wavelength division multiplexing optical fiber communication systems [1]. To reduce the number of pumping sources and to improve performance of optical fiber communication systems, higher light output power is desired for 980-nm semiconductor lasers. Generally, 980-nm semiconductor lasers have ridge structures so as not to expose their active regions to air during their fabrication processes. With an increase in injected current, kinks appear in current versus light-output (*I-L*) curves [2]. These kinks are associated with lasing in higher order transverse modes, which is attributed to changes in local gain profile and refractive index due to spatial hole burning, free carrier plasma effect, and heating. Slope efficiency and fiber coupling efficiency above kink levels are lower than those below kink levels. Therefore, higher kink levels are needed to achieve lasing in the fundamental transverse mode with high light output power maintaining high slope efficiency and high fiber coupling efficiency. Up to now, to increase kink levels, coupling of the optical field to the lossy metal layers outside the ridge [3], forming highly resistive regions in both sides of ridge stripe [4], and incorporation of a graded V-shape layer [5] have been studied. Recently, a novel ridge structure with optical antiguiding layers has been proposed by the authors [6].

In this study, the dependence of the lasing characteristics of the novel ridge structure with steps in the optical guiding layers on step position is theoretically investigated. It is found that steps in both the upper guiding layer, which is adjacent to the p-cladding layer, and the lower guiding layer, which is adjacent to the n-cladding layer, increase kink level, and the contribution of the steps in the upper guiding layer is higher than that of the steps in the lower guiding layer. It is also revealed that steps in the upper guiding layer decrease threshold current and those in the lower guiding layer slightly increase threshold current.

2. Laser Structure and Device Simulation

Figure 1 shows schematic cross-sectional views of (a) a proposed ridge structure with steps in both the upper and lower guiding layers, (b) a proposed ridge structure with steps in only the upper guiding layer, (c) a proposed ridge structure with steps in only the lower guiding layer, and (d) a conventional ridge structure without steps in either guiding layer. In Fig. 1, Δt_p is the thickness of the steps in the upper guiding layer, Δt_n is the thickness of the steps in the lower guiding layer, t_0 is the thickness of the guiding layers without steps, and d is the distance from the bottom of the mesa to the bottom of the upper guiding layer. It should be noted that steps Δt_p and Δt_n lead to an antiguiding effect in horizontal transverse modes.

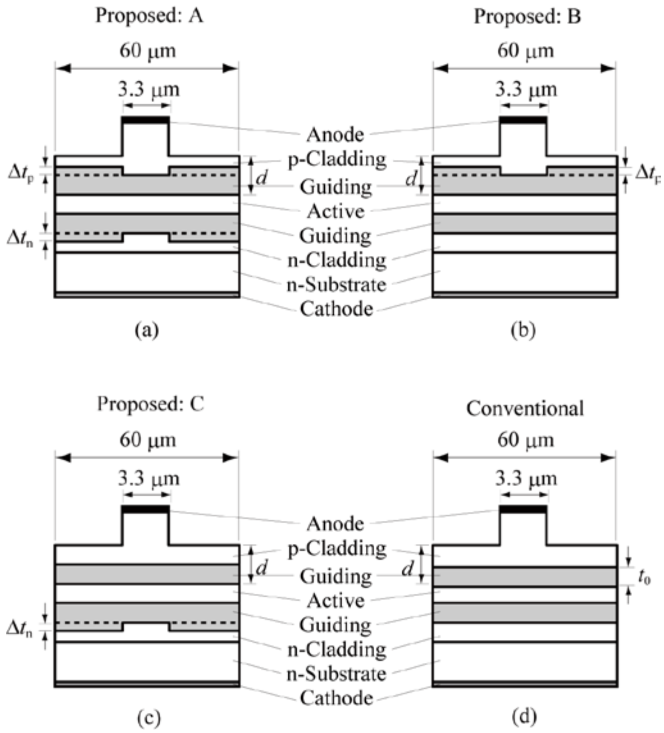

Fig. 1 Schematic cross-sectional views of (a) a proposed ridge structure with steps in both the upper and lower guiding layers, (b) a proposed ridge structure with steps in only the upper guiding layer, (c) a proposed ridge structure with steps in only the lower guiding layer, and (d) a conventional ridge structure without steps in either guiding layer.

Rectangular mesas are 3.3 μm wide, the bases are 60 μm wide, and the cavities are 1200 μm long. Reflectivity of the front and rear facets are 2 and 90%, respectively. Layer parameters such as band gap energy, refractive index, thickness, electron effective mass, hole effective mass, and doping concentration are the same as those described in Ref. 6.

Lasing characteristics are analyzed without including any thermal effects by solving Poisson's equations and Helmholtz equation with a finite element method. Physical parameters and their numerical values, which are used in the simulation, are the same as those described in Ref. 6.

3. Simulated Results and Discussions

Figure 2 shows kink level as a function of Δt_i (i=p or n) for d = (a) 250 and (b) 300 nm. The closed circles, open circles, and closed triangles represent $\Delta t_i = \Delta t_p = \Delta t_n$, $\Delta t_i = \Delta t_p$ with Δt_n=0, and $\Delta t_i = \Delta t_n$ with Δt_p = 0, respectively. For d =250 nm, the kink levels for (Δt_p, Δt_n) = (50 nm, 50 nm), (50 nm, 0 nm), (0 nm, 50 nm), and (0 nm, 0 nm) are 175, 142, 106, and 91 mW, respectively. For d = 300 nm, the kink levels for (Δt_p, Δt_n) = (50 nm, 50 nm), (50 nm, 0 nm), (0 nm, 50 nm), and (0 nm, 0 nm) are 216, 142, 122, and 90 mW, respectively. It is found that both Δt_p and Δt_n increase kink level and the contribution of Δt_p is higher than that of Δt_n. In addition, the kink level for d = 300 nm increased to a greater degree than that for d = 250 nm with increases in Δt_p and Δt_n, because spreading of the injected current for d = 300 nm is larger than that for d = 250 nm.

Figure 3 shows the threshold current I_{th} as a function of Δt_i (i=p or n) for d = (a) 250 and (b) 300 nm. The threshold current I_{th} decreases with an increase in Δt_p and slightly increases with an increase in Δt_n. As a result, the threshold current I_{th} decreases with an increase in $\Delta t_p = \Delta t_n$. For d = 250 nm, I_{th} values for (Δt_p, Δt_n) = (50 nm, 50 nm), (50 nm, 0 nm), (0 nm, 50 nm), and (0 nm, 0 nm) are 50.2, 49.9, 54.3, and 54.1 mA, respectively. For d = 300 nm, I_{th} values for (Δt_p, Δt_n) = (50 nm, 50 nm), (50 nm, 0 nm), (0 nm, 50 nm), and (0 nm, 0 nm) are 54.9, 54.4, 57.6, and 57.2 mA, respectively. The threshold current I_{th} for d = 250 nm is lower than that for d =300 nm due to concentration of carriers in the active region below the mesa.

4. Conclusions

In summary, the dependence of the lasing characteristics of a novel ridge structure with optical antiguiding layers for horizontal transverse modes on step position in the guiding layers was theoretically investigated. It was found that both Δt_p and Δt_n contribute to the increase in kink level, and the contribution of Δt_p is higher than that of Δt_n. It was also revealed that Δt_p decreases threshold current and Δt_n slightly increases threshold current.

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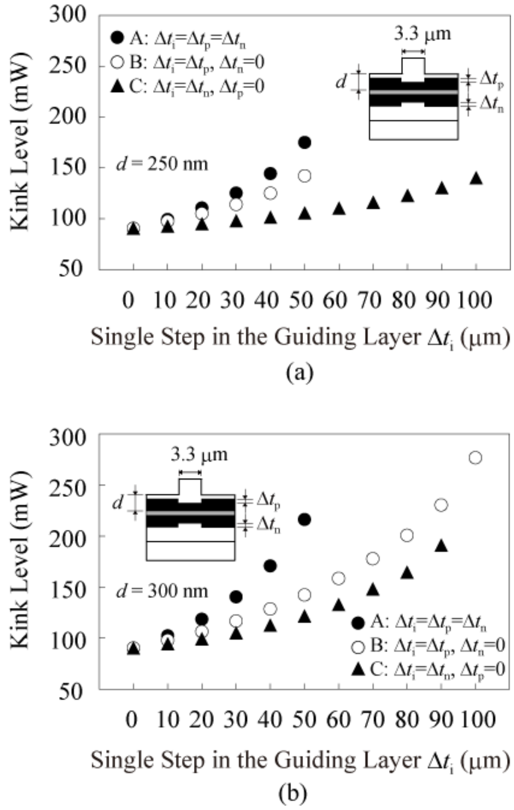

Fig. 2 Kink level as a function of t Δt_i (i=p or n) for d = (a) 250 and (b) 300 nm.

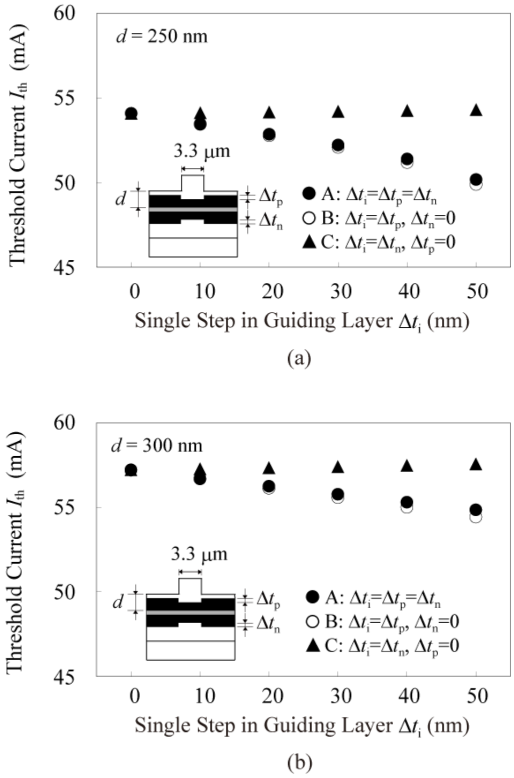

Fig. 3 Threshold current for the fundamental transverse mode I_{th} as a function of t Δt_i (i=p or n) for d = (a) 250 and (b) 300 nm.