Simulation of a Ridge-Type Semiconductor Laser for Separate Confinement of Horizontal Transverse Modes and Carriers

Hiroki Kato, Hazuki Yoshida, and Takahiro Numai
Graduate School of Science and Engineering, Ritsumeikan University
1-1-1 Noji-Higashi, Kusatsu, Shiga 525-8577, Japan
Phone: +81-77-561-5161 E-mail: numai@se.ritsumei.ac.jp

1. Introduction

High power 980-nm semiconductor lasers are indispensable for pumping sources of erbium doped optical fiber amplifiers [1]. Generally, 980-nm semiconductor lasers have ridge structures so as not to expose their active regions to air during their fabrication, because the active regions are easily oxidized and degraded in air. In the ridge structures, higher-order transverse modes as well as the fundamental transverse mode are confined. As a result, with an increase in injected current, higher-order transverse modes lase; kinks appear in their current versus light-output (*I-L*) curves [2]. These kinks are attributed to changes in the local gain profile and refractive index owing to spatial hole burning, the free-carrier plasma effect, and heating. To obtain high fiber-coupled optical power, semiconductor lasers with high kink levels operating in the fundamental transverse mode are required. To date, to increase kink levels, coupling of the optical field to the lossy metal layers outside the ridge [3], highly resistive regions in both sides of ridge stripe [4], and incorporation of a graded V-shape layer [5] have been demonstrated. To increase kink level and decrease the threshold current further, a ridge structure with optical antiguiding layers have been proposed [6] , [7], but the fabrication process is fairly complicated.

In this paper, a ridge-type semiconductor laser with selectively proton-implanted cladding layers is proposed to make the fabrication process more simple, increase kink level, and decrease threshold current. In this semiconductor laser, horizontal transverse modes are confined by the distribution of the effective refractive index; carrier distributions are controlled by selectively proton-implanted cladding layers. The proton-implanted cladding layers have higher refractive index than p-/n- cladding layers by appropriate annealing, because concentrations of the free carriers in the proton-implanted regions are low.

From simulations, it is found that the kink level is higher and the threshold current is lower than those of the ridge-type semiconductor lasers with optical antiguiding layers for horizontal transverse modes [6], [7]. In addition, it is revealed that they are optimal when the space between the proton-implanted regions in the p-cladding layer S_p is 1.3 µm.

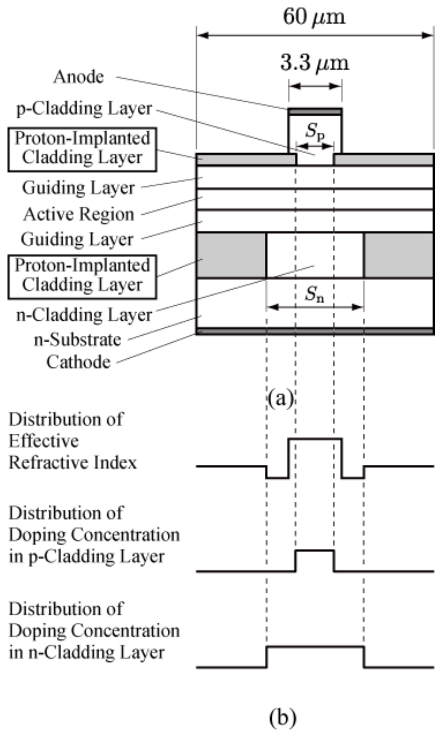

Fig. 1 (a) Schematic cross-sectional view of a proposed ridge structure with selectively proton-implanted cladding layers and (b) distributions of the effective refractive index of the semiconductor laser and doping concentration of the cladding layers. The shaded areas are undoped. Here, S_p is the space between the proton-implanted regions in the p-cladding layer; S_n is the space between the proton-implanted regions in the n-cladding layer.

2. Laser Structures and Simulations

Figure 1 (a) shows a schematic cross-sectional view of a proposed ridge structure with selectively proton-implanted cladding layers and (b) distributions of the effective refractive index of the semiconductor laser and doping concentration of the cladding layers. The shaded areas are undoped. Here, S_p is the space between the proton-implanted regions in the p-cladding layer; S_n is the space between the proton-implanted regions in the n-cladding layer. The p-cladding layer is 50 nm thick; the n-cladding layer is 1.5 µm thick. As a result, the distribution of the refractive index of the n-cladding layer contributes to the effective refractive

978-1-4673-1604-0/12/$31.00 ©2012 IEEE

index; the contribution of the p-cladding layer to the effective refractive index is negligible. Rectangular mesa is 1.55 μm high and 3.3 μm wide. The relatively wide mesa is selected in order to obtain high light-output power. The base is 60 μm wide, and the cavity is 1200 μm long. Reflectivities 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 Refs. 6 and 7. Lasing characteristics are simulated by using a device simulation software, ATLAS (Silvaco).

3. Simulation Results and Discussions

Figure 2 shows a kink level as a function of the space S_p between the proton-implanted regions in the p-cladding layer. The parameter is the space S_n between the proton-implanted regions in the n-cladding layer. The kink level has a maximum value of 603 mW at S_p=1.3 μm and S_n=2.3 μm. This kink level is 1.9 times as high as that in Ref. 7.

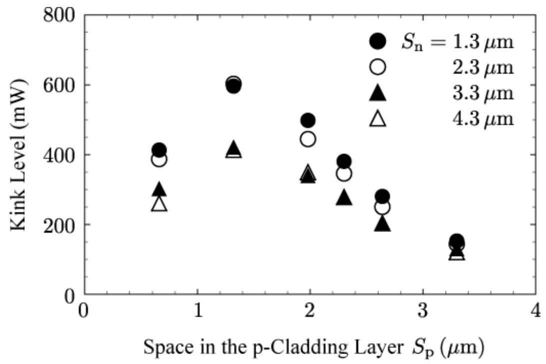

Fig.2 Kink level as a function of the space S_p between the proton-implanted regions in the p-cladding layer. The parameter is the space S_n between the proton-implanted regions in the n-cladding layer.

Figure 3 shows the threshold current for the fundamental transverse mode as a function of the space S_p between the proton-implanted regions in the p-cladding layer. The parameter is the space S_n between the proton-implanted regions in the n-cladding layer. The threshold current I_{th} has a minimum value of 46.3 mA at S_p =1.3 μm and S_n =4.3 μm. This value of the threshold current is 99 % of the previous result in Ref. 7.

There is the optimum value for S_p to obtain the lowest threshold current. The reason for this is that the lateral spreading of the carriers is suppressed most efficiently at S_p =1.3 μm. In this structure, it is considered that lateral spreading of the carriers is determined by the ambipolar lateral diffusion by the narrower space in the cladding layers S_p. The ambipolar lateral diffusion length L_a = 1.35 μm, which is quite similar to S_p=1.3 μm. Here, in $In_{0.2}Ga_{0.8}As$ QW active layers, it is assumed that the mobility of electrons is $\mu_e = 8.00\times10^3$ cm^2 V^{-1}s^{-1}; the mobility of holes is $\mu_h = 3.70\times10^2$ cm ^{2} V^{-1} s^{-1}. The lifetime τ_n of both electrons and holes is supposed to be 1.00×10^{-9} s.

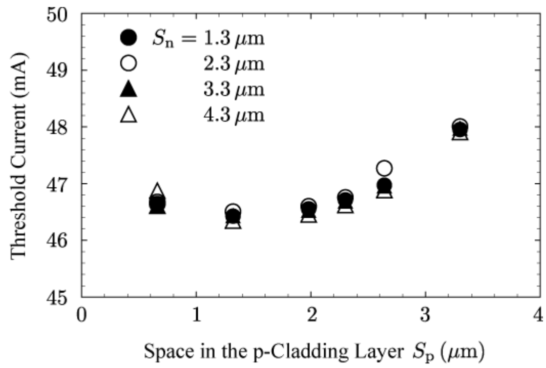

Fig.3 Threshold current I_{th} for the fundamental transverse mode as a function of the space S_p between the proton-implanted regions in the p-cladding layer. The parameter is the space S_n between the proton-implanted regions in the n-cladding layer.

4. Conclusions

To improve kink levels and decrease threshold current in ridge-type semiconductor lasers, a novel ridge structure with selectively proton-implanted cladding layers was proposed and simulated. It is found that kink level was 1.9 times as high as that in the previous result. The lowest threshold current was 99 % of the previous result.

References

[1] C. S. Harder, L. Brovelli, H. P. Meier, and A. Oosenbrug, *Proc. Optical Fiber Communication Conf.* '97, February, FC1, 1997, p.350.

[2] M. F. C. Schemmann, C. J. van der Poel, B. A. H. van Bakel, H. P. M. M. Ambrosius, A. Valster, J. A. M. van den Heijkant, and G. A. Acket, *Appl. Phys. Lett.*, vol.66, pp.920-922 (1995).

[3] M. Buda, H. H. Tan, L. Fu, L. Josyula, and C. Jagadish, *IEEE Photonics Technol. Lett.*, vol.15, **pp.**1686-1688 (2003).

[4] M. Yuda, T. Hirono, A. Kozen, and C. Amano, *IEEE J. Quantum Electron.*, vol.40, pp.1203-1207 (2004).

[5] B. Qiu, S. D. McDougall, X. Liu, G. Bacchin, and J. H. Marsh, *IEEE J. Quantum Electron.*, vol.41, pp.1124-1130 (2005).

[6] N. Shomura, M. Fujimoto, and T. Numai, *IEEE J. Quantum Electron.*, vol.44, pp.819-825 (2008).

[7] H. Yoshida and T. Numai: Jpn. J. Appl. Phys., vol.48, 082105, 2009.