Simulation of a Resonance-shifted DFB-LD for High Efficiency Operation

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1. Introduction

Because of dispersions in optical fibers, stable single longitudinal mode (SLM) operation is required for semiconductor lasers, which are light sources of long-haul, high capacity optical fiber communication systems. To date, phase-shifted distributed feedback laser diodes (DFB-LDs) [1] have shown the most stable SLM operation. Due to the highest stability in SLM operation, the phase-shifted DFB-LDs [1] are used in the trunk line optical fiber communication system in Japan and the fourth transpacific ocean cable system (TPC-4) between Japan and US.

In the phase-shifted DFB-LDs, the phase-shift position is located at the center of the cavity axis and both facets are anti-reflection coated to achieve the most stable SLM operation. Therefore, light output from a front facet and light output from a rear facet have a common value in the phase-shifted DFB-LDs. Light output from the front facet is used as a signal; light output from the rear facet is used as a monitor to avoid tracking errors. Light output for the monitor can be much lower than that for the signal. If we obtain asymmetric light output from the front/rear facets, wall-plug efficiency for the signal light will be improved.

To obtain asymmetric light output from the front/rear facets in the phase-shifted DFB-LDs, the phase-shift position was shifted from the center of the cavity axis [2] or a phase-shift was introduced at an interface of a chirped grating and a uniform grating [3]. In Ref. 2, a light output ratio from the front/rear facets was 2.3; SLM yield decreased with an increase in the shift of the phase-shift position. In Ref. 3, the light output ratio from the front/rear facets was 2.6. In a DR-LD [4] where a DFB-LD and a distributed Bragg reflector (DBR) are integrated along a cavity axis, the light output ratio from the front/rear facets was 13.

In this paper, to obtain asymmetric light output from the front/rear facets and stable SLM operation simultaneously, a resonance-shifted DFB-LD is proposed and simulated. In the proposed resonance-shifted DFB-LD, the light output ratio from the front/rear facets is 68, which is much larger than the values obtained in Refs. 2-4.

2. Laser Structures and Simulations

Figure 1 shows an analytical model of the resonance-shifted DFB-LD where an optical cavity is divided into two regions along the cavity axis. In region 1, the corrugation pitch Λ_1 is 0.244 μm, and the region length L_1 is 3000 Λ_1 = 732 μm. In region 2, the corrugation pitch Λ_2 is $\Lambda_1 + \Delta\Lambda$, and the region length L_2 is 1500 Λ_2, which is almost half of L_1. At the interface of region 1 and region 2, phase-shift is not introduced. The corrugation depth is 30 nm. Both facets are anti-reflection coated and the power reflectivities R_1 and R_2 are zero.

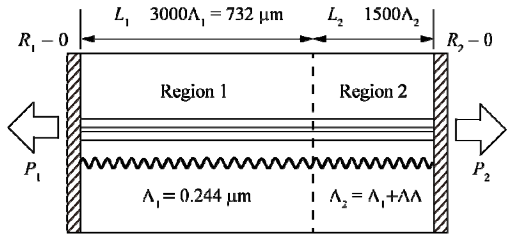

Fig. 1 Analytical model of a resonance-shifted DFB-LD. Both facets are anti-reflection coated.

Due to the pitch difference $\Delta\Lambda$, stable SLM operation and asymmetric light output from the front/rear facets are expected. To obtain large asymmetry in the light output from the front/rear facets, L_1 is almost twice of L_2.

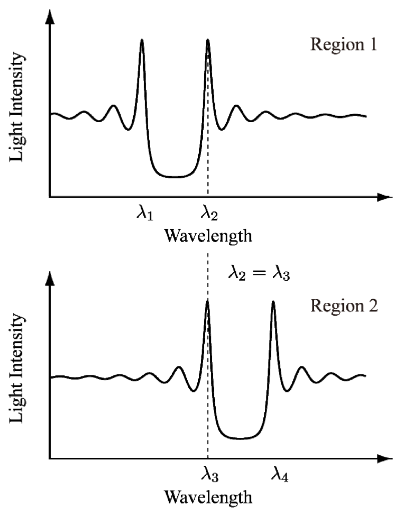

Fig. 2 Resonance modes in region 1 and region 2.

Figure 2 shows resonance modes in region 1 and region 2. Here, λ_1 and λ_2 are resonance wavelengths in region 1; λ_3 and λ_4 are resonance wavelengths in region 2. By appropriately selecting the pitch difference $\Delta\Lambda$, λ_2 and λ_3 have a common value as shown in Fig.2. In this case, the oscillation wavelength of laser light is $\lambda_2 = \lambda_3$.

Lasing characteristics are simulated by commercial simulators, PICS3D (Crosslight) and LaserMod (RSoft), which solve Poisson's equation and two-dimensional Helmholtz equation self consistently with a finite element method.

3. Simulated Results and Discussions

Figure 3 shows the sub-mode suppression ratio (SMSR) and 10 $\log_{10}(P_2/P_1)$ as a function of the pitch difference $\Delta\Lambda$. Here, P_1 is light output from the front facet; P_2 is light output from the rear facet. Closed circles show the SMSR and the closed circles are joined with solid lines. Open circles show 10 $\log_{10}(P_2/P_1)$ and the open circles are joined with broken lines. At $\Delta\Lambda$ = 0.20 nm, light output from the front/rear facets is most asymmetric where $10\log_{10}(P_2/P_1)$ is −18.30 dB and the light output ratio from the front/rear facets P_1/P_2 is 68; the SMSR is 85 dB. The light output ratio from the front/rear facets P_1/P_2 = 68 is much higher than the results of 2.3[2], 2.6 [3], and 13 [4]. Because the SMSR is 85 dB, it is expected that stable SLM operation is obtained.

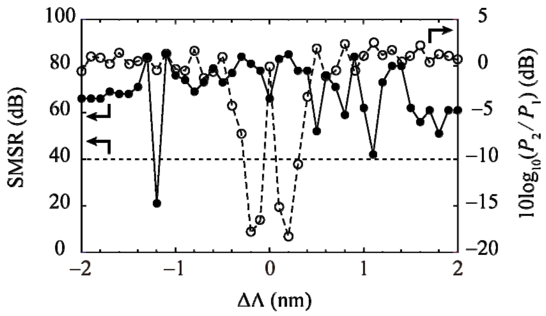

Fig.3 SMSR and 10 $\log_{10}(P_2/P_1)$ as a function of the pitch difference $\Delta\Lambda$.

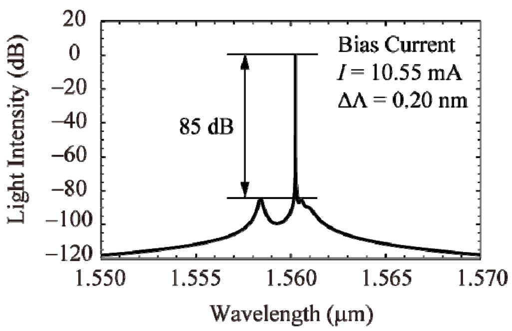

Fig.4 Light output spectrum.

Figure 4 shows light output spectrum for the injected current I =10.55 mA and the pitch difference $\Delta\Lambda$ = 0.20 nm. Note that the threshold current is 4.25 mA. The oscillating wavelength is 1.5602 µm; the gain-peak wavelength is 1.5596 µm, which is slightly shorter than the oscillating wavelength.

Figure 5 shows light intensity distribution along the cavity axis for the injected current I =10.55 mA and the pitch difference $\Delta\Lambda$ = 0.20 nm. Here, the interface of region 1 and region 2 is located at the origin of the horizontal axis. Light output ratio from the front/rear facets P_1/P_2 is 68.

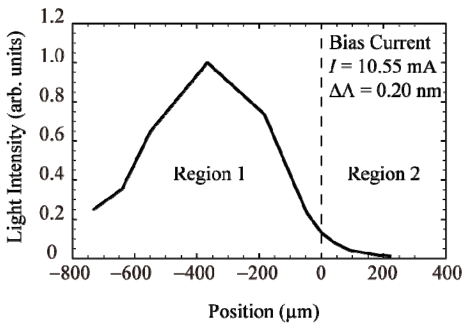

Fig.5 Light intensity distribution along the cavity axis.

4. Conclusions

To obtain asymmetric light output from the front/rear facets and stable SLM operation simultaneously, the resonance-shifted DFB-LD with anti-reflection coated facets was proposed and simulated. The resonance-shifted DFB-LD has two regions along the cavity axis. The corrugation pitch Λ_1 and the region length L_1 in region 1 are different from the corrugation pitch $\Lambda_2 = \Lambda_1 + \Delta\Lambda$ and the region length L_2, respectively. When the grating depth is 30 nm and L_1 is almost twice of L_2, the light output ratio from the front/rear facets P_1/P_2 was 68; the SMSR was 85 dB. This light output ratio was more asymmetric than those in Refs 2-4, and the SMSR of 85 dB is considered to be high enough to achieve stable SLM operation.

References

[1] T. Numai, M. Yamaguchi, I. Mito, and K. Kobayashi, "A New Grating Fabrication Method for Phase-Shifted DFB LDs," Jpn. J. Appl. Phys., Part 2, vol.26, pp.L1910-L1911 (1987).

[2] M. Usami, S. Akiba, and K. Utaka, "Asymmetric l/4-Shifted InGaAsP/InP DFB Lasers," IEEE J. Quantum Electron. vol.QE-23, pp.815-821 (1987).

[3] K. Sato, Y. Muroya, and T. Okuda, "Design of High Slope-Efficiency Phase-Shifted DFB Laser Diodes with Asymmetrically-Pitch-Modulated (APM) Gratings," IEICE Transl. Electron., vol.E83-C, pp.855-859 (2000).

[4] J. I. Shim, K. Komori, S. Arai, I. Arima, Y. Suematsu, and R. Somchai, "Lasing Characteristics of 1.5 µm GaInAsP-InP SCH-BIG-DR Lasers," IEEE J. Quantum Electron., vol.27, pp.1736-1745 (1991).