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Enhancement of asymmetry in light output from front/rear facets in resonance-shifted DFB-LDs

Kei-ichiro Ichikawa, Shogo Ito, Takahiro Numai*

Ritsumeikan University, College of Science and Engineering, 1-1-1 Noji-Higashi, Kusatsu, Shiga 525-8577, Japan

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ABSTRACT

To enhance asymmetry in light output from front/rear facets in a resonance-shifted DFB-LD maintaining single longitudinal mode (SLM) operation, lasing characteristics of resonance-shifted DFB-LDs with asymmetric regions are simulated. The laser cavity of the resonance-shifted DFB-LD is divided into two regions. Each region has uniform diffraction gratings; a corrugation pitch in Region 1 is different from a corrugation pitch in Region 2; length L_1 of Region 1 is different from length L_2 of Region 2. By adjusting the corrugation pitches of the two regions, a resonance mode in Region 1 and a resonance mode in Region 2 are overlapped. At the overlapped resonance mode, SLM operation is obtained. When a corrugation pitch difference is 0.2 nm with $\kappa L_1 = 2\kappa L_2 = 3$ where κ is a grating coupling coefficient, a normalized threshold gain difference is 0.413, which is large enough for SLM operation. Under this condition, the light output ratio from the front/rear facets is 67.6, which is larger than the reported highest value of 51 with SLM operations.

1. Introduction

Semiconductor lasers with stable single longitudinal mode (SLM) operations are indispensable for long-haul, high capacity optical fiber communication systems as signal light sources. Optical pulse broadening, which is caused by dispersions in optical fibers, is suppressed by semiconductor lasers with stable SLM operations. Phase-shifted DFB-LDs [1,2] show most stable SLM operations and have been used commercially [3], which contributes to infrastructures of Internet. In the phase-shifted DFB-LDs, light output power from a front facet and light output power from a rear facet are common. 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. Low light output such as −20 dBm is enough for the monitor. Therefore, it is expected that asymmetric light output from the front/rear facets with maintaining total light output leads to high wall-plug efficiency for the signal. To obtain asymmetric light output from the front/rear facets in semiconductor lasers, the following papers were reported. The $\lambda/4$-shift position was moved from the center of the DFB region toward the front side in the $\lambda/4$-shifted DFB-LDs [4]; the phase-shift was located at an interface of a chirped grating and a uniform grating [5]; two uniform corrugated regions with different corrugation pitches were integrated along a cavity axis [6]; a DFB region and a DBR region were integrated along a cavity axis [7,8]. In Ref. [4] a light output ratio from the front/rear facets was 2.3; SLM yield decreased with an increase in the distance between the $\lambda/4$-shift position and the center of the DFB region. With stable SLM operations, the light output ratios from the front/rear facets were 2.6 in Ref. [5] and 5.69 in Ref. [6]. In distributed reflector laser diodes (DR-LDs) [7,8], the light output ratios from

* Corresponding author.
E-mail address: numai@se.ritsumei.ac.jp (T. Numai).

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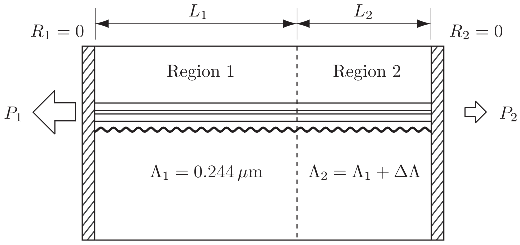

Fig. 1. Analytical model of a resonance-shifted DFB-LD.

the front/rear facets were 13 with cleaved facets [7] and 51 with an antireflection (AR) coated front facet and a cleaved rear facet [8].

In this paper, to enhance asymmetry in light output from the front/rear facets in a resonance-shifted DFB-LD [6], lasing characteristics are examined as a function of a ratio of length L_1 of Region 1 and length L_2 of Region 2 with maintaining the total number of corrugation periods as 4500. When length L_1 of Region 1 is $3000\Lambda_1$, length L_2 of Region 2 is $1500\Lambda_2$ where Λ_1 is a corrugation pitch in Region 1 and Λ_2 is a corrugation pitch in Region 2, and a corrugation pitch difference $\Delta\Lambda = \Lambda_2 - \Lambda_1$ is 0.2 nm, the light output ratio from the front/rear facets is 67.6, which is larger than the values obtained in the previous results. Under this condition, a normalized threshold gain difference is 0.413, which is large enough for SLM operation.

2. Laser structures and simulations

An analytical model of the resonance-shifted DFB-LD is illustrated in Fig. 1. The optical cavity has two uniform corrugated regions along the cavity axis. In Region 1, the corrugation pitch Λ_1 is 0.244 μm; length L_1 is $n_1\Lambda_1$ where n_1 is the number of the corrugation periods. In Region 2, the corrugation pitch Λ_2 is $\Lambda_1 + \Delta\Lambda$; length L_2 is $n_2\Lambda_2$ where n_2 is the number of the corrugation periods. The total number of the corrugation periods is $n = n_1 + n_2 = 4500$. For $\Delta\Lambda = 0$ nm, the total cavity length $L = L_1 + L_2$ is 1098 μm. In Fig. 1, P_1 is light output from the front facet, which is the left facet of Region 1; P_2 is light output from the rear facet, which is the right facet of Region 2. At the interface of Region 1 and Region 2, a phase-shift is not introduced. The corrugation depth is 30 nm. It is assumed that both facets are AR coated and the power reflectivities R_1 and R_2 are zero. The layer parameters are summarized in Table 1.

In Fig. 2 resonance modes in Region 1 and Region 2 are shown schematically. Here, λ_1 and λ_2 are wavelengths of the resonance modes in Region 1; λ_3 and λ_4 are wavelengths of the resonance modes in Region 2. The stopband width $(\lambda_2 - \lambda_1)$ is the same as the stopband width $(\lambda_4 - \lambda_3)$ for $L_1 = L_2$. The stopband width $(\lambda_2 - \lambda_1)$ is different from the stopband width $(\lambda_4 - \lambda_3)$ for $L_1 \neq L_2$. By selecting the corrugation pitch difference $\Delta\Lambda$ (>0) appropriately, $\lambda_2 = \lambda_3$ is satisfied as shown in Fig. 2. Under this condition, SLM operation with a propagation constant $\beta = 2\pi/\lambda_2 = 2\pi/\lambda_3$ is expected. When $\lambda_2 = \lambda_3$ and $L_1 = L_2$ are simultaneously satisfied, it is considered from optical spectrum that equivalent $\lambda/4$-shifted gratings are formed [9,10]. It should be noted that above explanations are qualitative ones. Strictly speaking, Region 1 and Region 2 form a coupled cavity because Region 1 and Region 2 are not isolated optically. Therefore, resonance modes have been calculated by using a transfer matrix [11] in Region 1 and a transfer matrix in Region 2. In addition, light intensity distribution along the cavity axis in the corrugated region depends on detuning. Since the detuning $(\beta - \pi/\Lambda_1)$ in Region 1 and the detuning $(\beta - \pi/\Lambda_2)$ in Region 2 have different values for $\Lambda_1 \neq \Lambda_2$ where β is the propagation constant, asymmetric light output from the front/rear facets is expected.

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

Table 1
Layer parameters.

Layer	Thickness (μm)	Impurity Conc. (cm^{-3})
p-InP cladding	1.0	5×10^{17}
p-$In_{0.71}Ga_{0.29}As_{0.61}P_{0.39}$ guiding	0.15	5×10^{17}
$In_{0.71}Ga_{0.29}As_{0.61}P_{0.39}$ barrier	0.046	
$In_{0.76}Ga_{0.24}As_{0.79}P_{0.21}$ QW	0.008	
$In_{0.71}Ga_{0.29}As_{0.61}P_{0.39}$ barrier	0.046	
n-$In_{0.71}Ga_{0.29}As_{0.61}P_{0.39}$ guiding	0.15	5×10^{17}
n-InP cladding	1.0	5×10^{17}