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Resonance-shifted DFB-LD for asymmetric light output from front/rear facets

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ABSTRACT

To obtain asymmetric light output from front/rear facets in a semiconductor laser maintaining single longitudinal mode (SLM) operation, a resonance-shifted DFB-LD is proposed and its lasing characteristics are simulated. The laser cavity of the resonance-shifted DFB-LD is divided into two regions. Each region has uniform diffraction gratings, and the corrugation pitch of region 1 is different from that of region 2. By adjusting the corrugation pitches of the two regions, a resonance mode in region 1 and that in region 2 are overlapped. At the overlapped resonance mode, SLM operation is obtained. When the corrugation pitch difference is 0.3 nm with $\kappa L_1 = \kappa L_2 = 3$ where κ is the grating coupling coefficient; length L_1 of region 1 and length L_2 of region 2 are about 560 μm, the normalized threshold gain difference was 0.509, which is large enough for SLM operation. Under this condition, the light output ratio from the front/rear facets is 5.69. This light output ratio is larger than the highest value of 2.6, which was achieved in a phase-shifted DFB-LD with asymmetrically-pitch-modulated gratings.

1. Introduction

For semiconductor lasers, which are light sources of long-haul, high capacity optical fiber communication systems, stable single longitudinal mode (SLM) operation is required to suppress optical pulse broadening, which is caused by dispersions in optical fibers. A semiconductor laser, which shows the most stable SLM operation, is a phase-shifted distributed feedback laser diode (DFB-LD), which was proposed by Prof. Haus in 1976 [1]. Eleven years later, commercially available phase-shifted DFB-LDs were developed [2] and have been 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 is introduced at the center of the cavity axis and both facets are anti-reflection coated to achieve the most stable SLM operation. As a result, light output power from a front facet and light output power from a rear facet are common in the phase-shifted DFB-LDs. Light output from the front facet is used as a signal while light output from the rear facet is used as a monitor to avoid tracking errors. As the monitor, we need light output power, which is much lower than light output power for the signal. Therefore, if light output for the signal from the front facet is larger than light output for the monitor from the rear facet maintaining the total light output, it is expected that wall-plug efficiency for the signal is improved. To obtain asymmetric light output from the front/rear facets in the phase-shifted DFB-LDs, the phase-shift was introduced at a position other than the center of the cavity axis [3] or a position of the phase-shift

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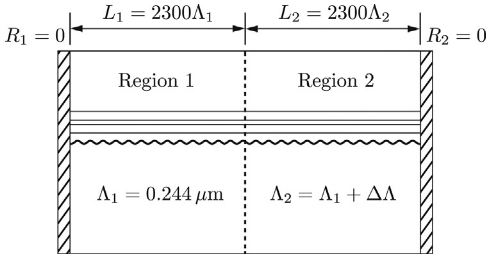

Fig. 1. Analytical model of a resonance-shifted DFB-LD.

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}

was located at an interface of a chirped grating and a uniform grating [4]. In Ref. [3] a light output ratio from the front/rear facets was 2.3; SLM yield decreased with an increase in the distance between the position of the phase-shift and the center of the cavity axis. In Ref. [4], the light output ratio of 2.6 from the front/rear facets was obtained.

In this paper, to achieve asymmetric light output from the front/rear facets and stable SLM operation simultaneously in DFB-LDs, a resonance-shifted DFB-LD is proposed. The laser cavity of the resonance-shifted DFB-LD has two regions, and the corrugation pitch Λ_1 in region 1 is different from the corrugation pitch Λ_2 in region 2. When the length L_1 in region 1 is $2300\Lambda_1$, the length L_2 in region 2 is $2300\Lambda_2$, and the grating pitch difference $\Delta\Lambda = \Lambda_2 - \Lambda_1$ is 0.3 nm, the light output ratio from the front/rear facets is 5.69, which is larger than the values obtained in Refs. [3,4]. Under this condition, the normalized threshold gain difference is 0.509, which is large enough to obtain stable 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 regions along the cavity axis. In region 1, the corrugation pitch Λ_1 is 0.244 μm; the region length L_1 is $2300\Lambda_1 = 561.2$ μm. In region 2, the corrugation pitch Λ_2 is $\Lambda_1 + \Delta\Lambda$; the region length L_2 is $2300\Lambda_2$, which is almost the same as L_1. At the interface of region 1 and region 2, phase-shift is not introduced. The corrugation depth is 30 nm. It is assumed that both facets are anti-reflection coated and the power reflectivities R_1 and R_2 are zero. The layer parameters are shown in Table 1.

In Fig. 2 resonance modes in region 1 and region 2 are shown. 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 almost the

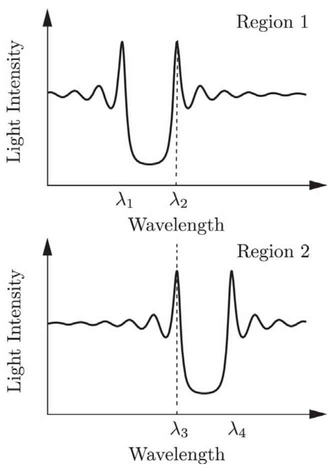

Fig. 2. Resonance modes in region 1 and region 2.