DFB-LD connected in series to DBR with optical gain

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***Abstract*—This paper reports on a DFB-LD connected in series to a DBR with optical gain. This DFB-LD shows highly stable single longitudinal mode (SLM) operation with high external quantum efficiency more than 64% due to asymmetric facet light output. It is found that the main mode is determined by one of the resonance modes in the DFB-LD within high reflective wavelength region in the DBR. It is expected that the present DFB-LD shows SLM operation up to 600 mA.**

Keywords—laser diode, grating, single longitudinal mode

I. Introduction

Because of dispersion in the optical fibers, single longitudinal mode (SLM) LDs have been utilized in long-haul, large capacity optical fiber communication systems. The most stable SLM LD is a phase-shifted DFB-LD which has been used in the trunk lines more than 30 years [1]. In the phase-shifted DFB-LD, front facet light output is almost the same as the rear facet light output. The front facet light output of 0 dBm is used as a signal and the rear facet light output is used as monitor light to suppress tracking errors. The rear facet light output of -20 dBm is enough as the monitor light. As a result, if we can obtain asymmetric light output between the front facet light output and the rear facet light output, we can expect improvement of external quantum efficiency and wall-plug efficiency of the DFB-LD. To achieve asymmetric light output between the front facet light output and the rear facet light output, slight transfer of the phase-shift position toward the front facet [2], introducing phase-shift at the boundary of uniform corrugations and chirped ones [3], DR-LDs [4], [5], and resonance-shifted DFB-LDs [6], [7] have been reported.

In this paper, a DFB-LD connected in series to a DBR with optical gain is studied. The external quantum efficiency more than 64% due to asymmetric facet light output is obtained. The oscillation mode is determined by one of the resonance modes in the DFB-LD within high reflective wavelength region in the DBR with SLM operation up to 600 mA.

II. Structure

Figure 1 shows a schematic cross-sectional view of the DFB-LD connected in series to a DBR with optical gain.

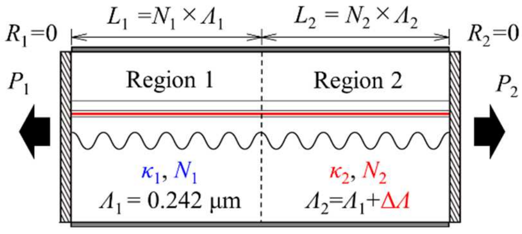


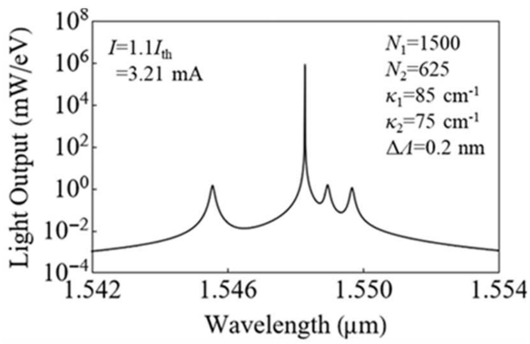
Fig. 1 Cross-sectional view cut along the longitudinal axis.

Region 1 with grating coupling constant κ_1 is connected to Region 2 with grating coupling constant κ_2 in series. The grating pitch Λ_1 in Region 1 is 0.242 μm; the grating pitch Λ_2 in Region 2 is $\Lambda_1+\Delta\Lambda$. The number of grating periods in Region 1 is N_1; the number of grating periods in Region 2 is N_2. As a result, length of Region 1 is $L_1=N_1\Lambda_1$; length of Region 2 is $L_2=N_2\Lambda_2$.

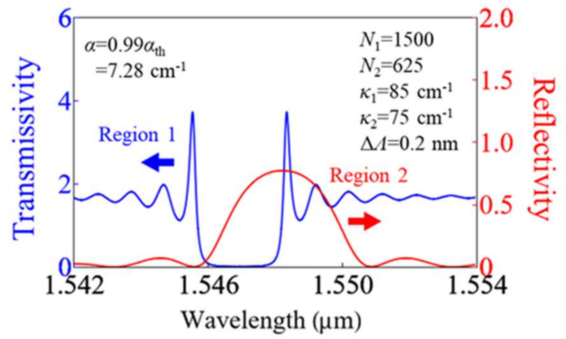
III. Simulated Results and Discussion

Figure 2 (a) illustrates oscillation spectrum for $N_1 = 1500$, $N_2 = 625$, $\kappa_1 = 85$ cm^{-1}, $\kappa_2 = 75$ cm^{-1}, $\kappa_1 L_1 = 3.09$, $\kappa_2 L_2 = 1.14$, $\Delta\Lambda = 0.2$ nm, injection current $I = 1.1 I_{th} = 3.21$ mA where I_{th} is threshold current.

Figure 2 (b) depicts transmission spectrum of Region 1 and reflection spectrum of Region 2 for amplitude optical gain $\alpha = 0.99\alpha_{th} = 7.28$ cm^{-1} where α_{th} is threshold amplitude optical gain. The main mode is a resonance mode of Region 1, which is located in the wavelength region with high reflectance of Region 2. It should be noted that the main mode is not determined by resonance modes of the coupled cavity consisting of Region 1 and Region 2.



(a) Oscillation spectrum



(b) Transmission spectrum of Region 1 and reflection spectrum of Region2

Fig. 2 Optical spectra.

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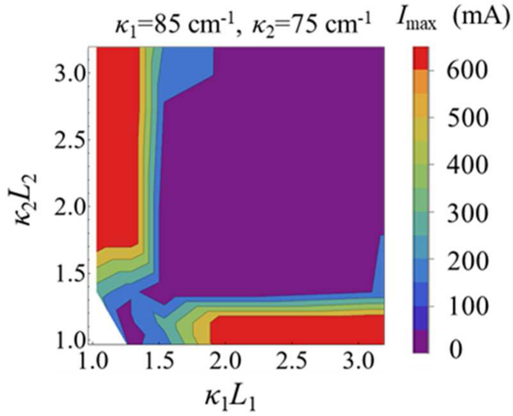
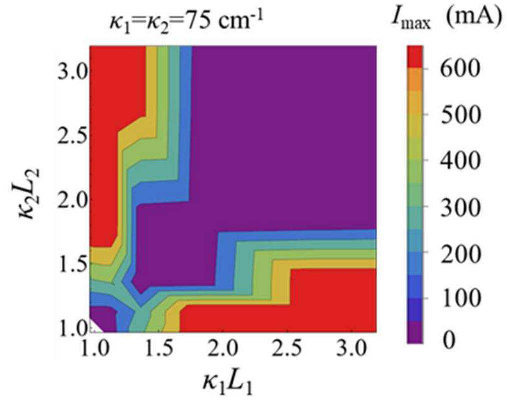
Figure 3 shows maximum injection current I_{max} for SLM operation as a function of relative grating coupling coefficient $\kappa_1 L_1$ of Region 1 and relative grating coupling coefficient $\kappa_2 L_2$ of Region 2. In Fig. 3 (a) κ_1 is 85 cm^{-1}; in Fig. 3 (b) κ_1 is 75 cm^{-1}. In Fig. 3 (a) and (b) κ_2 is 75 cm^{-1}. We can expect highly stable SLM operation because I_{max} exceeds 600 mA. The condition to obtain $I_{max} \geq 600$ mA is to satisfy $\kappa_i L_i \leq 1.36$ and $\kappa_j L_j \geq 1.59$ simultaneously (i, j = 1, 2). It should be noted that a region with $\kappa_i L_i \leq 1.36$ functions as a DBR with optical gain; a region with $\kappa_j L_j \geq 1.59$ acts as a DFB-LD.



(a) κ_1=85 cm^{-1}, κ_2=75cm^{-1}

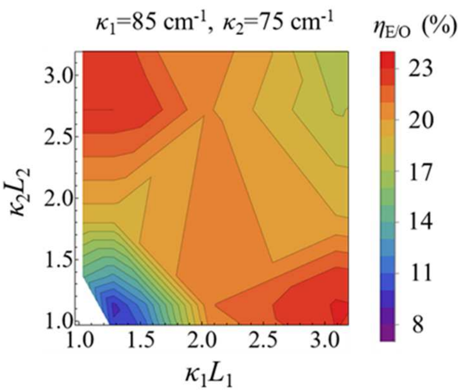


(b) κ_1=κ_2=75 cm^{-1}

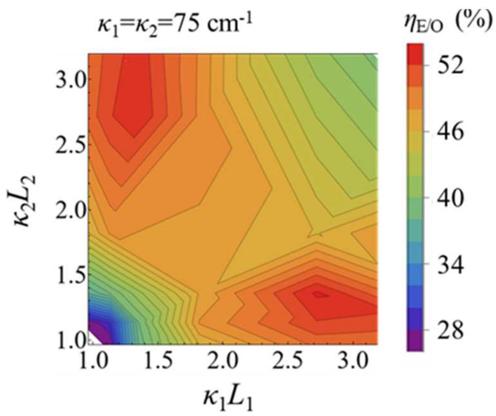
Fig. 3 Maximum injection current for SLM operation as a function of relative grating coupling coefficients of Region 1 and Region 2.

Figure 4 reveals wall-plug efficiency for the front facet light output as a function of relative grating coupling coefficient $\kappa_1 L_1$ of Region 1 and relative grating coupling coefficient $\kappa_2 L_2$ of Region 2. In Fig. 4 (a) κ_1 is 85 cm^{-1} and the front facet light output P_f=1 mW; in Fig. 4 (b) κ_1 is 75 cm^{-1} and the front facet light output P_f=10 mW. In Fig. 4 (a) and (b) κ_2 is 75 cm^{-1}.

The highest wall-plug efficiency for P_f=1 mW is 23.1% when N_1=1500, N_2=625, κ_1=85 cm^{-1}, κ_2=75 cm^{-1}, $\kappa_1 L_1$=3.09, $\kappa_2 L_2$=1.14, and $\Delta\Lambda$=0.2 nm. In this condition the external quantum efficiency is 64% while the average external quantum efficiency for DR-LDs is 20% [5]. The highest wall-plug efficiency for P_f=10 mW is 53.2% when N_1=1500, N_2=750, κ_1=κ_2=75 cm^{-1}, $\kappa_1 L_1$=2.72, $\kappa_2 L_2$=1.36, and $\Delta\Lambda$=0.3 nm. In this condition the external quantum efficiency is 74%. These external quantum efficiencies are the highest among SLM LDs with asymmetric light output from the front/rear facet to the authors' knowledge.



(a) P_f =1 mW, κ_1=85 cm^{-1}, κ_2=75cm^{-1}



(b) P_f =10 mW, κ_1= κ_2=75 cm^{-1}

Fig.4 Wall-Plug efficiency for the front facet light output as a function of relative grating coupling coefficients of Region 1 and Region 2.

IV. CONCLUSIONS

A DFB-LD connected in series to a DBR with optical gain was studied. This DFB-LD showed highly stable single longitudinal mode operation with high external quantum efficiency more than 64% which exceeds 20% in DR-LDs [5] due to asymmetric facet light output. The main mode was determined by one of the resonance modes in the DFB-LD within high reflective wavelength region in the DBR with optical gain. We can expect that the present DFB-LD shows SLM operation up to 600 mA.

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