High Resonance Frequency in a Coupled Cavity DFB-LD with Asymmetric Grating Coupling Coefficients by Photon-Photon Resonance

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Abstract- **Enhancement of resonance frequency in a coupled cavity DFB-LD with asymmetric grating coupling coefficients by photon-photon resonance is reported. The resonance frequency is 61.3 GHz and the 3-dB down band width is 82.7 GHz when the injected current is only 2.5 times the threshold current.**

I. INTRODUCTION

To achieve high resonance frequencies for high speed direct modulations of semiconductor lasers, push-pull modulations [1]-[4], external injection of intensity modulated light [5], photon-photon resonance [6]-[9] have been studied. In this paper, to obtain a high resonance frequency and stable single longitudinal mode operation simultaneously, a coupled cavity DFB-LD with asymmetric gating coupling coefficients by photon-photon resonance is numerically studied. When the injected current is 2.5 times the threshold current, the resonance frequency f_r is 61.3 GHz and the 3-dB down bandwidth f_{3dB} is 82.7 GHz, which are much higher than f_r =37.2 GHz and f_{3dB} =53.4 GHz [8] , respectively.

II. OPERATING PRINCIPLE AND STRUCTURE

Rate equations are written as

$$\frac{\mathrm{d}}{\mathrm{d}t}S_1 = \Gamma_1\left[G_1 - \beta_1 S_1 - \theta_{12}S_2\right]S_1 - \frac{1}{\tau_{\mathrm{ph1}}}S_1,$$

$$\frac{\mathrm{d}}{\mathrm{d}t}S_2 = \Gamma_2\left[G_2 - \beta_2 S_2 - \theta_{21}S_1\right]S_2 - \frac{1}{\tau_{\mathrm{ph2}}}S_2,$$

$$\frac{\mathrm{d}}{\mathrm{d}t}n = \frac{J}{ed} - \left[G_1 - \beta_1 S_1 - \theta_{12}S_2\right]S_1 - \left[G_2 - \beta_2 S_2 - \theta_{21}S_1\right]S_2 - \frac{1}{\tau_n}n,$$

where S_i is photon density, Γ_i is an optical confinement factor, G_i is an amplification rate, β_i is a self-saturation coefficient, θ_{ij} is a cross-saturation coefficient, $\tau_{\mathrm{ph}i}$ is photon lifetime where subscripts i and j are 1 or 2, n is carrier concentration, J is injected current density, e is the elementary charge, d is total thickness of active layers, τ_n is carrier lifetime.

From small-signal analysis for $S_1 \gg S_2$ the resonance frequency f_r is obtained

$$f_{\mathrm{r}} \simeq \frac{1}{2\pi}\left[\frac{\partial G_1}{\partial n}\frac{S_{10}}{\tau_{\mathrm{ph1}}} + \Gamma_1 S_{10}\Gamma_2 S_{20}(2\beta_1\beta_2 - \theta_{12}\theta_{21})\right]^{1/2},$$

where S_{10} and S_{20} are steady state values of S_1 and S_2, respectively. The second term in the bracket contributes to enhancement or diminution of resonance frequency. To obtain high resonance frequency, it is important to achieve

$$2\beta_1\beta_2 - \theta_{12}\theta_{21} > 0.$$

To satisfy this condition, a coupled cavity DFB-LD shown in Fig.1 is proposed. Region 1 has phase-shifted gratings with the grating coupling coefficient κ_1=40 cm^{-1}, the region length L_1=300 μm, the corrugation pitch Λ_1=238.45 nm, and the phase-shift $\Delta\Omega_1 = -\pi$ at the center of Region 1. Region 2 has phase-shifted gratings with the grating coupling coefficient κ_2=33 cm^{-1}, the region length L_2=300 μm, the corrugation pitch $\Lambda_2=\Lambda_1-\Delta\Lambda$, and the phase-shift $\Delta\Omega_2 = -\pi$ at the center of Region 2. Both facets are anti-reflection coated; the power reflectivities R_1 and R_2 are assumed to be zero.

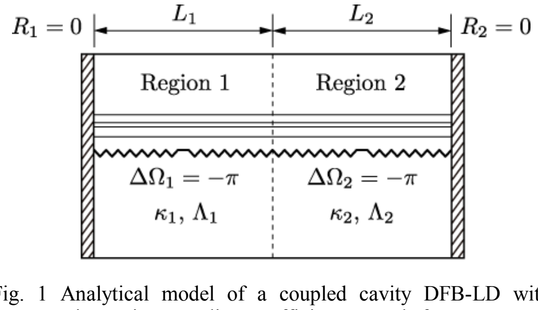

Fig. 1 Analytical model of a coupled cavity DFB-LD with asymmetric grating coupling coefficients. Both facets are anti-reflection coated.

Undoped active layers consist of five 7.5 nm-thick $In_{0.557}Ga_{0.443}As_{.82}P_{0.018}$ strained quantum wells (QWs). These QWs are sandwiched by 23 nm-thick $In_{0.738}Ga_{0.262}As_{0.568}P_{0.432}$ barriers. The substrate is n-

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InP with impurity concentration of $10^{18}cm^{-3}$. The upper cladding layer is p-InP with impurity concentration of $5\times10^{17}cm^{-3}$. The waveguide is 1.5 μm wide. Region 1 and Region 2 have a common anode and a common cathode.

III. SIMULATED RESULTS

Figure 2 shows the resonance frequency f_r as a function of the grating pitch difference $\Delta\Lambda$ for the injected current I = 20 mA. The resonance frequency f_r has a peak of 53.0 GHz at $\Delta\Lambda$=1.6 nm. This f_r is 6.9 times as high as f_r =7.68 GHz at $\Delta\Lambda$=0 nm.

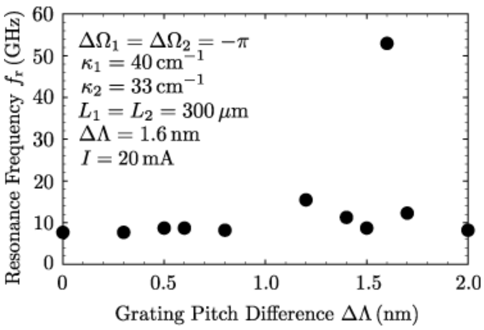

Fig. 2 Resonance frequency f_r as a function of the grating pitch difference $\Delta\Lambda$.

Figure 3 shows the resonance frequency f_r as a function of $I/I_{th}-1$ at $\Delta\Lambda$=1.6 nm where I is the injected current and I_{th} is the threshold current. The resonance frequency f_r increases with $I/I_{th}-1$, and the resonance frequency f_r is 61.3 GHz when $I/I_{th}-1$=1.5. When $I/I_{th}-1$ is larger than 1.5, the stable condition is not satisfied.

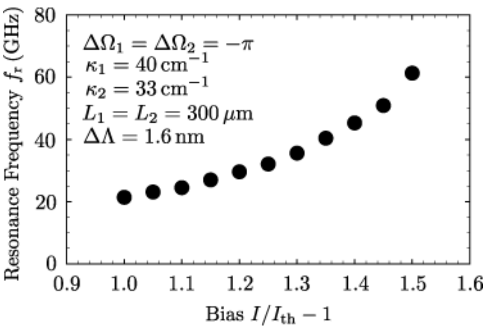

Fig.3 Resonance frequency f_r as a function of the relative bias current $I/I_{th}-1$.

Figure 4 shows frequency response for $\Delta\Lambda$=1.6 nm and $I/I_{th}-1$=1.5. The resonance peak is clearly observed at the modulation frequency of 61.3GHz. The 3-dB down band width is 82.7 GHz.

Figure 5 shows oscillation spectrum for $\Delta\Lambda$=1.6 nm and $I/I_{th}-1$=1.5. The main-mode oscillates at 1.5244 μm which is Bragg wavelength in Region 1. Slight sub-mode exists at 1.5223μm.

Table 1 summarizes f_r and f_{3dB} with conditions in the references and the present work.

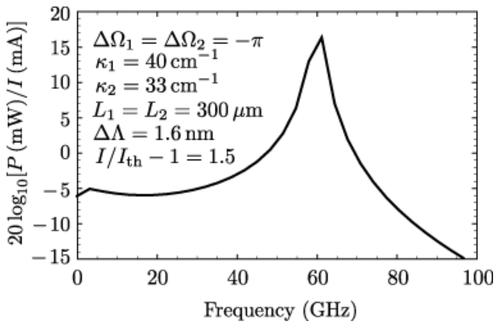

Fig.4 Frequency response.

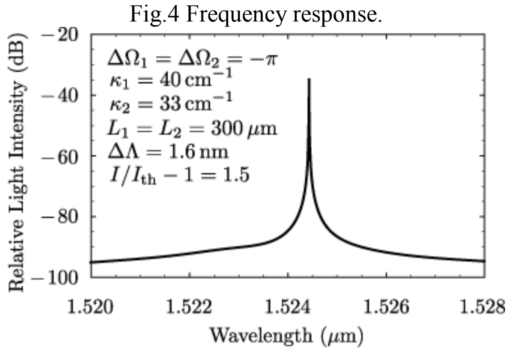

Fig.5 Oscillation spectrum.

Table 1 f_r and f_{3dB} when $I/I_{th}-1$=1.5.

κ_2 (cm^{-1})	L_2 (μm)	$\Delta\Omega_2$	f_r (GHz)	f_{3dB} (GHz)	Ref.
40	300	$-\pi$	21.4	31.6	[7]
40	310	0	37.2	53.4	[8]
40	300	-0.9π	24.3	35.7	[9]
33	300	$-\pi$	61.3	82.7	Pres.

IV. CONCLUSIONS

The coupled cavity DFB-LD with asymmetric grating coupling coefficients was proposed and simulated. For $\Delta\Lambda$=1.6 nm and $I/I_{th}-1$=1.5, the resonance frequency and the 3-dB down bandwidth were enhanced from 37.2 GHz to 61.3 GHz and from 53.4 GHz to 82.7 GHz, respectively.

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