High Resonance Frequency in a Coupled Cavity DFB-LD with Two Phase-Shifts by Photon-Photon Resonance

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Abstract- **Enhancement of resonance frequency in a coupled cavity DFB-LD with two phase-shifts by photon-photon resonance is reported. The resonance frequency is 71.3 GHz and the 3-dB down band width is 95.9 GHz when the injected current is 3.075 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]-[8] have been studied. In this paper, to obtain a high resonance frequency and stable SLM operation simultaneously, a coupled cavity DFB-LD with two phase-shifts by photon-photon resonance is numerically studied. When the injected current is 3.075 times the threshold current, the resonance frequency is 71.3 GHz, much higher than 40.45 GHz [8]. The 3-dB down band width is 95.9 GHz.

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 optical confinement factor, G_i is amplification rate, β_i is self-saturation coefficient, θ_{ij} is 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 elementary charge, d is total thickness of active layers, τ_n is carrier lifetime. Stable condition for coexistence of two modes is given by

$$\frac{\theta_{12}\theta_{21}}{\beta_1\beta_2} \le 1.$$

From small-signal analysis for $S_1 \gg S_2$ the resonance frequency f_{r} is approximately written as

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

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=40 cm^{-1}, the region length L_2=300 μm, the corrugation pitch $\Lambda_2=\Lambda_1-\Delta\Lambda$, and the phase-shift $\Delta\Omega_2 = -0.9\pi$ 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.

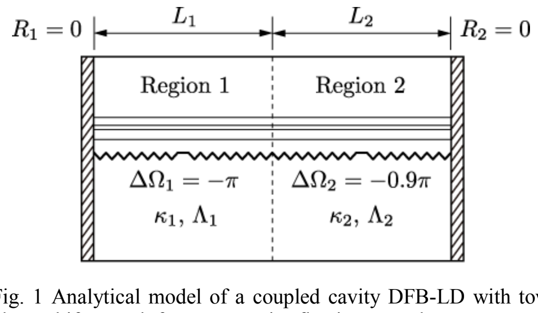

Fig. 1 Analytical model of a coupled cavity DFB-LD with tow phase-shifts. Both facets are anti-reflection coated.

Undoped active layers consist of five 7.5 nm-thick $In_{0.557}Ga_{0.443}As_{0.982}P_{0.018}$ strained quantum wells, which are sandwiched by 23 nm-thick $In_{0.738}Ga_{0.262}As_{0.568}P_{0.432}$ barriers. The substrate is n-InP with impurity concentration of 10^{18}cm^{-3}. The

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upper cladding layer is p-InP with impurity concentration of $5\times10^{17}\mathrm{cm}^{-3}$. The waveguide is 1.5 μm wide. Region 1 and Region 2 have a common anode; Region 1 and Region 2 have a common cathode. Even though common electrodes are used for the two regions, the push-pull modulations for the main-mode and the sub-mode are obtained when the following conditions are simultaneously satisfied.

$$\left[G_1(n) - \beta_1(n)S_1 - \theta_{12}(n)S_2\right] > 0$$
$$\left[G_2(n) - \beta_2(n)S_2 - \theta_{21}(n)S_1\right] < 0$$

III. SIMULATED RESULTS

Figure 2 shows the resonance frequency f_r as a function of the grating pitch difference ΔΛ for the injected current I = 20 mA. The resonance frequency f_r has a peak of 21.1 GHz at ΔΛ=1.6 nm. This f_r is 2.75 times of f_r =7.68 GHz at ΔΛ=0 nm.

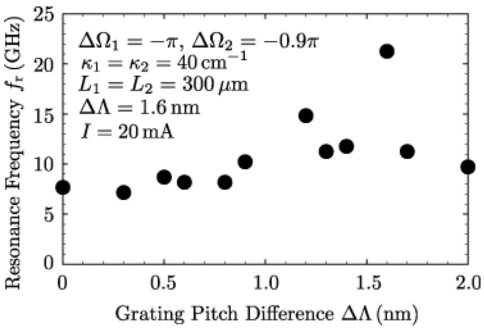

Fig. 2 Resonance frequency f_r as a function of the grating pitch difference ΔΛ.

Figure 3 shows the resonance frequency f_r as a function of $I/I_{th}-1$ at ΔΛ=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 71.3 GHz when $I/I_{th}-1$=2.075. When $I/I_{th}-1$ is larger than 2.075, the stable condition is not satisfied.

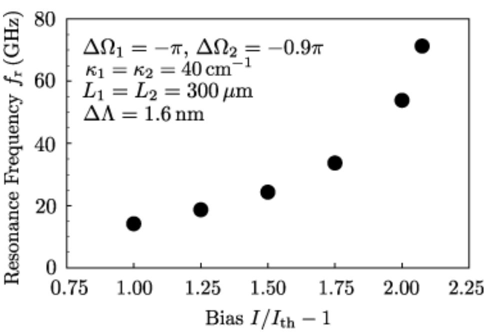

Fig.3 Resonance frequency f_r as a function of the relative bias current $I/I_{th}-1$.

Figure 4 shows frequency response for ΔΛ=1.6 nm and $I/I_{th}-1$=2.075. The resonance peak is clearly observed at the modulation frequency of 71.3GHz. The 3-dB down band width is 95.9 GHz.

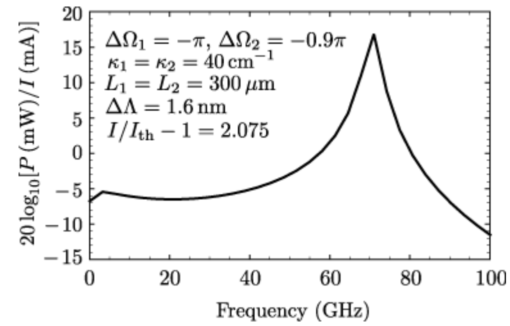

Fig.4 Frequency response.

Figure 5 shows oscillation spectrum for ΔΛ=1.6 nm and $I/I_{th}-1$=2.075. The main-mode oscillates at 1.52443 μm which is Bragg wavelength in Region 1. The wavelength of the largest sub-mode is 1.52294 μm. The resonance frequency was enhanced due to photon-photon resonance among the main-mode and the largest sub-mode.

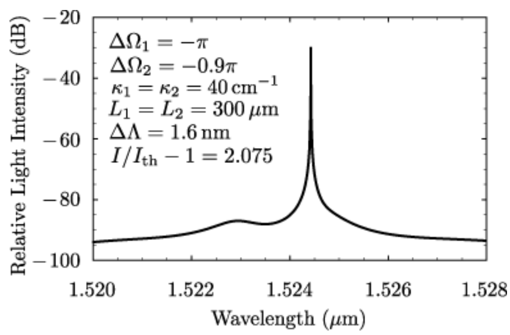

Fig.5 Oscillation spectrum.

IV. CONCLUSIONS

The coupled cavity DFB-LD with tow phase-shifts was proposed and simulated. When the grating pitch difference ΔΛ between Region 1 and Region 2 was 1.6 nm and $I/I_{th}-1$=2.075, the resonance frequency and the 3-dB down bandwidth were enhanced to 71.3 GHz and 95.9 GHz, respectively.

REFERENCES

[1] D. D. Marcenac, M. C. Nowell, and J. E. Carroll, IEEE Photon.Technol. Lett., vol.11, pp.1309-1311 (1994).
[2] M. C. Nowell, J. E. Carroll, R. G. **S.** Plumb, D. D. Marcenac, M. **J.** Robertson, H. Wickes, and L. M. Zhang, IEEE J. Selected Topics Quantum Electron. vol.1, pp.433-441 (1995).
[3] J. C. R. Maciejko, and T. Makino, IEEE J. Quantum Electron., vol.32, pp.2156-2165 (1996).
[4] Junqiu Qi, Yanping Xi, Xun Li, NUSOD 2015, pp.127-128, Taipei, Taiwan (2015).
[5] H. Ishihara, Y. Saito, W. Kobayashi, and H. Yasaka, IEICE Trans. Electron., vol.E95-C, pp.1549-1551 (2012).
[6] P. Bardella, W.W. Chow, I. Montrosset, NUSOD 2016, pp.11-12, Sydney, Australia (2016).
[7] T. Numai, Optik, vol.127, pp. 9578–9581 (2016).
[8] T. Numai, NUSOD 2017, pp.35-36, Copenhagen, Denmark (2017).