Modeling of Current Dependent Microwave Behavior of a Two-Section DFB Laser

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Abstract- **A current dependent model of RF generation is developed for the dual wavelength lasers. Because of the nature of current based operation, it is more convenient to have current as the main variable. From the numerical analysis, certain parameters such as wavelength change rate and linewidth enhancement factor (LEF) can affect the generated RF power more substantially than other parameters.**

I. INTRODUCTION

Wireless transmission is one of the most important technologies for communication these days due to its high market share, but the cost for complicated networks is a big concern for the future. Radio over fiber (ROF) is a promising way to extend the wireless network by transmitting microwave signal via optical fiber. In order to reduce the cost for building such a network, a monolithic and efficient device for light-microwave conversion is needed. In the past we have demonstrated our two-section DFB laser for tunable RF generation with narrow linewidth microwave signals (< 2MHz) [1, 2]. Their central frequencies are tunable up to 45 GHz when the laser driving current is varied. However most models in the past [3] used detuned frequency (Δf) as the main variable which is not suitable for our current-driven devices. In this work a current dependent model will be developed to describe the generated microwave signals, and we believe this feature can be beneficial for the application of ROF systems.

II. THEORY

Fig.1 shows the schematic diagram of our two-section DFB laser. The front section is called the slave laser while the back section is the master laser. The chip integrates two DFB lasers together to have a dual-wavelength signal simultaneously. This dual-wavelength optical signal can then optically heterodyne (or mix) to generate a differential-frequency signal which can be detected by a high speed photodetector [4]. Since the wavelength of each section can be tuned by the driving current, the differential frequency is also affected by the driving current. In the normal operating condition, one of the two section will be at constant bias, while the other one (usually the master laser) can have various current inputs. If we use ΔI as the amount of current deviation from the initial bias condition, we found that wavelengths of both lasers (or sections) can be affected by this ΔI, therefore we can use two equations to describe the two output wavelengths:

$$\lambda_M = \lambda_{M0} + \alpha\Delta I \qquad (1)$$

$$\lambda_S = \lambda_{S0} + \beta\Delta I \qquad (2)$$

Where α, β is the wavelength change rate (nm/mA) of the Master and Slave laser caused by tuning the master laser current respectively, ΔI is the current difference compare to the starting current (mA). Assuming that $\lambda_S > \lambda_M$ and c is the speed of light, the output frequency can be written as

$$\Delta f = \frac{c}{\lambda_M} - \frac{c}{\lambda_S} = \frac{c[(\lambda_{S0} - \lambda_{M0}) + (\beta - \alpha)\Delta I\,]}{(\lambda_{M0} + \alpha\Delta I\,)(\lambda_{S0} + \beta\Delta I)} \qquad (3)$$

Due to αΔI and βΔI are too small compare to the two starting wavelengths, the equation can be simplified into

$$\Delta f = \frac{c[(\lambda_{S0} - \lambda_{M0}) + (\beta - \alpha)\Delta I\,]}{\lambda_{M0}\,\lambda_{S0}} \qquad (4)$$

For a more straightforward understanding we can split the equation into two parts

$$\Delta f = \Delta f_0 + P\Delta I \qquad (5)$$

$$\Delta f_0 = \frac{c(\lambda_{S0} - \lambda_{M0})}{\lambda_{M0}\,\lambda_{S0}} \qquad P = \frac{c(\beta - \alpha)}{\lambda_{M0}\,\lambda_{S0}} \qquad (6)$$

Δf_0 is the starting frequency difference (Hz), P is the frequency change rate (Hz/mA). This linear approximation will have an error rate more than 5% when the laser is operating at high current difference and the laser wavelength change rate is more than 0.25nm/mA. Because the lasers are usually biased at moderate current and wavelength change rate due to current is small, therefore we can conclude that the simplified equation is suitable for most DFB laser situations.

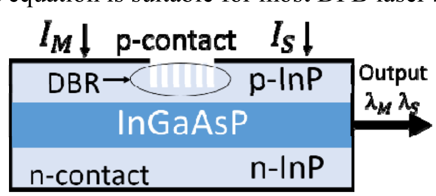

Fig.1 The structure of the two section DFB laser

III. SIMULATION RESULTS

In the past experiments individual components were independently controlled for RF generation [5]. In these cases the detuned frequency is the major variable, and the positive and the negative values are symmetric according to formula

[6]. However, in our case, due to the laser power and frequency is dependent to the driving current, the RF power becomes asymmetric, as shown in Fig.2. By implementing the current-based model, the RF formula becomes

$$\sigma^2 = \left|\frac{\eta * A_i}{A_0}\right|^2 \frac{[2\pi(\Delta f_0 + P\Delta I)]^2 + (\gamma_r - \gamma_p)^2}{\left([2\pi(\Delta f_0 + P\Delta I)]^2 - \Omega_r{}^2\right)^2 + [2\pi(\Delta f_0 + P\Delta I)]^2 \gamma_r{}^2} \quad (7)$$

And together with the ratio of side mode peaks at four-wave-mixing regime, the relaxation frequency and linewidth enhancement factor can be found by fitting the measured data to the model [2]. Fig.3 shows the relation between ratio of the four wave mixing and regenerate peak amplitude with the tuning current difference, and the change rate causes the curve to vary sharply or slowly. Fig.4 shows how the ratio of the two peak changes while we vary the linewidth enhancement factor and the photon decay rate(PDR), we can see that the photon decay rate doesn't' have significant effect on the curve, only at the high current difference area when its effect can be more clearly observed. Fig.5 shows the effect of different coupling rate, we can see with larger coupling rate, the curve is slightly higher than the other one. Based on these calculation, we saw the current dependent wavelength change rate is more sensitive than other parameters. Meanwhile the LEF can really affect the shape of the outcome. The coupling rate of the two section, on the other hand, is not an important factor to determine the shape of the RF power function. These understanding can be an important guideline when we design the dual-wavelength DFB laser for RF generation.

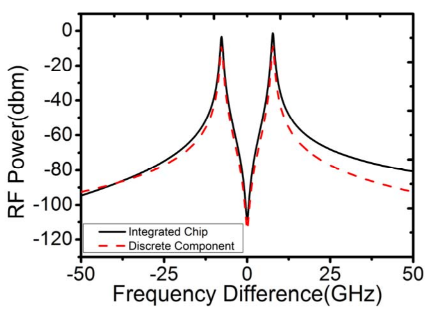

Fig.2 Output RF Power curve of two section DFB laser (asymmetric) and two discrete lasers (symmetric)

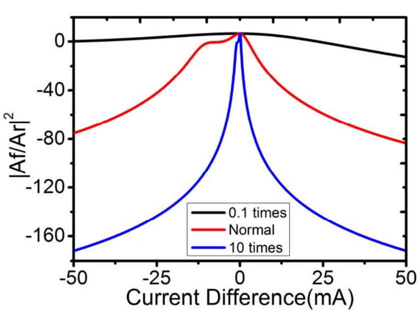

Fig.3 The difference of amplitude ratio $|A_f/A_r|^2$ caused by the wavelength change rate (nm/mA)

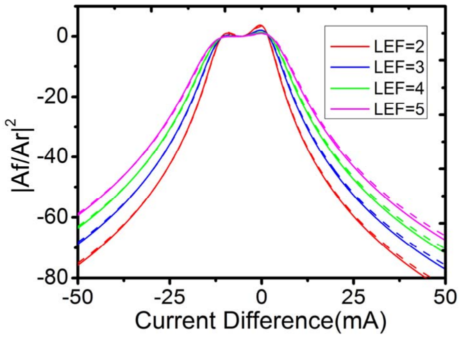

Fig.4 The difference of amplitude ratio $|A_f/A_r|^2$ caused by different LEF, the same color indicates the same LEF, the dash curve of each color is PDR $=2\times 10^9 s^{-1}$, when the solid curve PDR =0

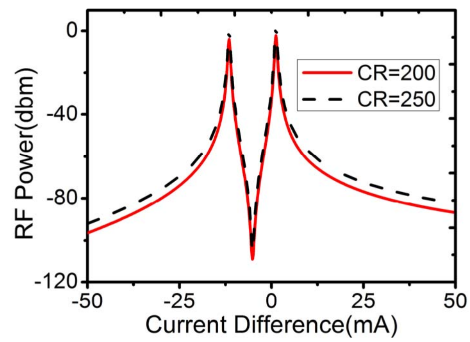

Fig.5 The output RF power curve with different coupling rate (CR), and PDR $=2\times10^9 s^{-1}$.

IV. Conclusions

We proposed a model of RF generation in dual wavelength lasers based on biased current. By using the biased current, the formula was re-written and reveal the asymmetric nature due to our device operating condition. From the simulation, important and sensitive parameters can be found and use for future device design.

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