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Main Variables Competition in DFB Lasers under Dual Optical Injection

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Abstract**—**We theoretically investigate the effects of frequency detuning and injection power on the nonlinear dynamics of DFB lasers under dual external optical injection.

Keywords**—**Optical injection, DFB laser, frequency detuning, injection power.

I. Introduction

SEMICONDUCTOR lasers subject to optical injection have been a hot subject for investigation over the last few decades [1-6]. The driving force behind this investigation was to enhance the stability of the laser by the so-called injection locking [6]. Therefore, most of the studies were performed at very low injection level and under single optical injection signal. As nonlinear dynamical systems, semiconductor lasers have shown the possibility of exhibiting rich nonlinear and chaotic behaviors [7]. Since then, various levels of optical injection have been studied [8]. Moreover, the extension of the injected signals to include more than one laser has also been introduced [7,9,10]. The main goal for producing multiple signals was to enrich the nonlinear dynamics and chaotic behaviors. It was also believed to participate in revealing the underlying physics of the nonlinear and chaotic systems. In addition, it has shown to be very useful in modern telecommunication applications [11]. In this study we systematically investigate the competition between the two main variables in any injected laser, which are the frequency detuning (i.e. the difference in frequency between the injected signal and the free running laser) and the injection level (i.e. the ratio between the injected signal power and the free running laser power).

II. Theory

We used our theoretical model described in [7], which is based on Lang's approach [1]. We also used the characterized parameters stated in [12]. We numerically integrate the rate equations using the Runge–Kutta method. The theoretical power spectra were obtained by applying a fast Fourier transform (FFT) to a chosen time window of the injected laser electric field time series. A commercial software (Matlab) was used in obtaining the results.

III. Results and Discussion

In any optically injected semiconductor laser, the main variable that largely affects the nonlinear dynamics of the injected lasers are frequency detuning (Δf) and the injection power (K). Frequency detuning (Δf) is defined as the frequency difference between the injected laser (usually called slave laser, SL) and the injection laser (known as master laser, ML), i.e $\Delta f = f_{ML} - f_{SL}$. The injection power (K) or the so-called injection level is defined as the square of ratio between the electric fields of the ML and SL, respectively, i.e. K = $(E_{ML} / E_{SL})^2$.

In our case, we will be dealing with two master lasers ML_1 and ML_2. In order to study the effects of Δf and K of the two MLs and the completion between them in a systematic manner, we perform the following; the two MLs are injected in both side of the SL (one with shorter wavelength and the second with longer wavelength) but with equal Δf and constant K. The two MLs are then detuned towards the SL keeping the same conditions of equality. By doing so (varying Δf while keeping K constant), we study the behaviors of the SL as shown in the power spectra. Then we perform the opposite case (varying K while keeping Δf constant). This investigation is done in both low and high injection regions.

Fig. 1 shows the power spectra of the SL with the injection of the two MLs at K = -35 db (relatively low injection power). It can be seen from Fig. 1a and 1b that there is no observed dynamics when the two signals are injected far away from the locking region. As they get closer (Fig. 1c and 1d), the SL signal becomes slightly depleted with many FWM and sideband signals.

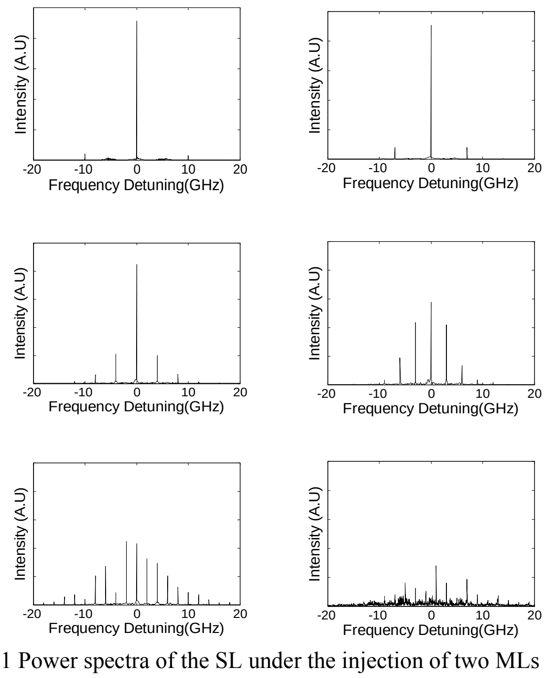

Fig. 1 Power spectra of the SL under the injection of two MLs at $K_{1,2}$ = -35 dB and $\Delta f_{1,2}$: (a) ±10 GHz, (b) ±7 GHz, (c) ±4 GHz, (d) ±3 GHz, (e) ±2 GHz, (f) ±1 GHz

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When the two MLs are injected very close to the SL (at ±2 GHz), the SL is still not locked to either signals and many peaks are presented with spacing equals to Δf as shown in Fig.1e. Finally, when the MLs are detuned to ±1 GHz, the SL is somehow locked to the signal in the positive detuning side but in a very chaotic manner and suppressed spectrum. This is shown clearly in Fig. 1f.

The situation is slightly different when raising the injection power to even higher level (-25 dB) as shown in Fig. 2. Again, when the two MLs are injected away from the locking bandwidth, the SL is not largely affected and the relaxation oscillation frequency (ROF) is enhanced as shown in Fig. 2a and b. However, when the two MLs injected at ±9 GHz, the SL is largely affected and suppressed with only MLs presented in the spectrum as shown in Fig. 2c. This indicates that the two MLs are competing each other with no preference for the SL to be locked to either of them.

Nevertheless, when the MLs detuned to the locking region, the SL prefers to be locked to the longer wavelength signal as shown in Fig. 2d. This clearly shows that the SL tends to be locked to the signal in the negative detuning side in spite of the fact that both signals have the same injection level and absolute detuning value. When detuning the two MLs even more inside the locking region, the SL is still locked to the longer wavelength signal with enhanced FWM signals as shown in Fig. 2e. Finally, when the MLs are detuned very close to the SL (at ±2 GHz), the latter seems not to be locked to either signals and is hugely suppressed as shown in Fig. 2f.

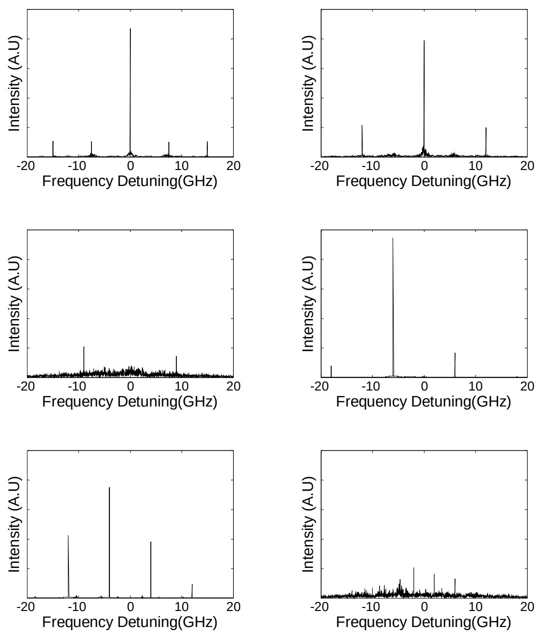

Fig. 2 Power spectra of the SL under the injection of two MLs at $K_{1,2}$ = -25 dB and $\Delta f_{1,2}$: (a) ±15 GHz, (b) ±12 GHz, (c) ±9 GHz, (d) ±6 GHz, (e) ±4 GHz, (f) ±2 GHz.

We will now investigate the effect of the injection power when keeping Δf constants at ±6 GHz. Fig. 3 shows different power spectra of the SL under these conditions. At low injection levels (Fig. 3a and 3b), the SL is not affected as previously observed.

However, when the power reaches -30 dB, the SL is clearly pulled towards the longer wavelength signal as shown in Fig. 3c. This pulling effect is reported elsewhere [13]. It normally takes place near the locking region and is found to be higher in the negative detuning side [13].

When increasing the injection power to higher level (-25 dB), the SL is then locked to the negative detuning side signal exhibiting the same feature observed before with the presence of the other signal but in a stable manner. This is shown clearly in Fig. 3d. Any further increase in the injection power does not affect the system and the SL remains locked to the same signal but with pronounced FWM as shown in Fig. 3e and 3f.

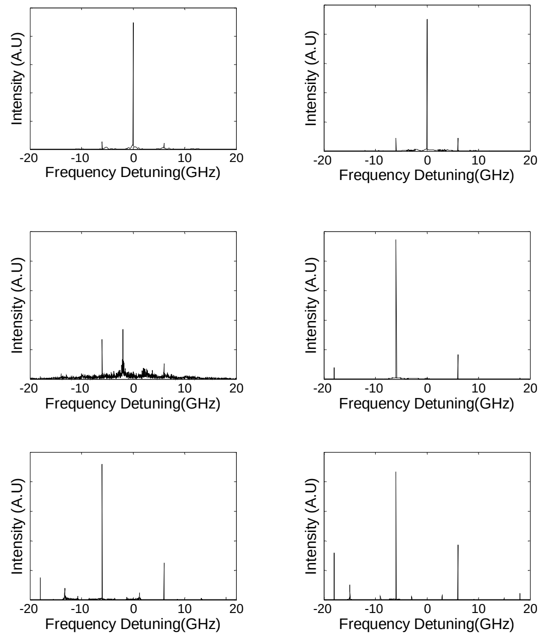

Fig. 3 Power spectra of the SL under the injection of two MLs at $\Delta f_{1,2}$ = ±6 GHz and $K_{1,2}$ = (a) -40 dB, (b) -35 dB, (c) -30 dB, (d) -25 dB, (e) -20 dB, (f) -15 dB

IV. Conclusion

The results have shown that when signals are injected far from the locking region, their effects on the SL dynamics can be ignored. For low injection level, when the two signals are injected close enough to the locking region they generate many FWM peaks. However, in the high injection level, the situation is different as the SL is largely suppressed with chaotic behaviors. Frequency pulling is also reported in the negative detuning side when the injected signals have higher power.

Further investigation is required for clear understanding and better interpretation of the nonlinear dynamics. In addition, experimental verification of the theoretical model is a subject for future investigations.

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