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CHIRP REDUCTION IN A SINGLE MODE DM-SQW-DFB LASER OPERATED AT SECOND QUANTIZATION STATE

Abida Yousuf and Hakim Najeeb-ud-din
Department of Electronics and Communication Engineering, National Institute of Technology, Srinagar, India

Abstract

We have observed the reduction in the chirp parameters (gain compression and above threshold α-factor) by operating the single quantum well laser at second quantization state. In this study, the carrier density at threshold is clamped by increasing the total cavity loss, so that the second energy level is populated leading to operation at second quantization state. We have identified wavelength shift towards the shorter wavelength side of the spectrum. Implies higher differential gain of the lasing mode, consequently decreases the effect of chirping in a directly modulated single QW laser.

Keywords:

Directly Modulated (DM), Quantum Well (QW), Gain Compression, α-Factor, Chirping, Differential Gain

1. INTRODUCTION

Carrier density in semiconductor lasers is not vigorously clamped above threshold due to gain compression effects. The important reason behind this non clamping is the red shift of the operating wavelength, through the carrier density dependent optical gain change in directly modulated semiconductor laser [1]-[4]. The gain compression parameter is important in describing the relation between the AM and FM modulation behavior of laser diodes and is the dominant effect that introduces damping in the intensity modulation, which reduces the transient chirp and introduces the adiabatic chirp in the FM modulation [5]-[6]. This phenomenon limits the modulation dynamics of directly modulated lasers through the adiabatic chirp and is responsible for the bending of the light-current characteristics. The *α*-factor is another most important parameter in describing the coupling between the intensity and frequency modulation of the laser diode. Above threshold, gain compression leads to enhancement of the *α*-factor through differential gain reduction [6]. Therefore, we focus on reducing the gain compression effects. Which can be achieved by increasing the carrier density at threshold inside the cavity. This increased carrier density compensates the reduction of gain due to saturation effects.

Gain saturation is a function of photon density and is introduced into the rate equation formalism via a phenomenological gain compression factor (ε). Optical gain or the differential gain in the laser cavity is then written as $g = g_0(N-N_0)/(l + \varepsilon S)$. The gain compression term of the form $(1+\varepsilon S)^{-1}$ originally suggested by Channin et al. and is valid for $S \geq 0$ to describe damping in the IM response of the diode laser [7]. In [8], Aggarwal et al. suggested another expression of the form $(1+\varepsilon S)^{-0.5}$ which is also valid for $S \geq 0$. In [9], Su et al. suggested that the origin of the gain compression is the standing waves induced by the feedback of the dielectric grating in an active layer volume. In [10], Ogasawara et al. shows that the origin of the gain compression is attributed to refractive index modulation due to carrier density pulsation, induced by the beat frequency between cavity modes. In [11], Wang et al. shows that the positive temperature gradient of the gain reduces the gain compression to even negative values.

In this study, we simulate the single mode dynamics of directly modulated SQW-DFB laser. We focus on reducing the chirp parameters (gain compression, and above threshold α-factor). Therefore, the total cavity loss is increased so much that the second energy level is populated, leading to operation at second quantization state. The gain compression effect has been modeled by assuming that gain is reduced at high photon densities by a factor of $1/(1+\varepsilon S_0)^p$ where p varies from 0 to 1, however p = 1 is best suited [11]. This analysis is restricted to single frequency lasers, which can be described by single mode rate equations [12]. In this work, the laser chirp above threshold is reduced by decreasing the effect of chirp parameters (gain compression, and above threshold α-factor) through increased carrier density at threshold.

2. SIMULATIONS AND RESULTS

Carrier density is an important parameter for studying the laser chirp, wavelength shift, and spectral line width. The modulation of the carrier density modulates the gain, it also modulates the index of the active region. As a result, the optical length of the cavity is modulated by the current, causing the resonant mode to shift back and forth in frequency. A large signal solution of the laser rate equation gives the frequency response or the time variation of frequency depending on the driving conditions. The response of the laser to the carrier density is determined from phase rate equation as [12],

$$\frac{d\phi}{dt} = \frac{\alpha}{2}\left[\Gamma_{g_0}\left(N-N_t\right)-\frac{1}{\tau_p}\right] \quad (1)$$

or

$$\frac{d\phi}{dt} = \frac{\alpha\Gamma_{g_0}}{2}\left[N-\left(N_t-\frac{1}{\Gamma_{g_0}\tau_p}\right)\right] \quad (2)$$

If we assume that all the carrier and photon densities within the cavity are uniform, then

$$\Gamma_{g_0}\left(N_{th}-N_t\right) \approx \frac{1}{\tau_p} \quad (3)$$

or

$$N_{th} \approx N_t - \frac{1}{\Gamma_{g_0}\tau_p} \quad (4)$$

From Eq.(2) and Eq.(4), we have,

$$\frac{d\phi}{dt} = \frac{\alpha\Gamma_{g_0}}{2}\left[N-N_{th}\right] \quad (5)$$

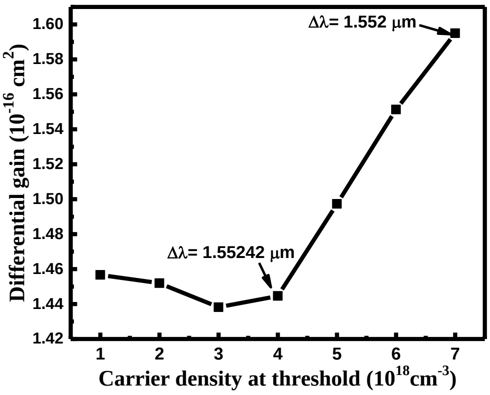
Therefore, for large signal modulation, the frequency shift can be obtained from phase rate equation as,

$$\Delta v(t) = \frac{1}{2\pi}\left[\frac{d\phi}{dt}\right] \tag{6}$$

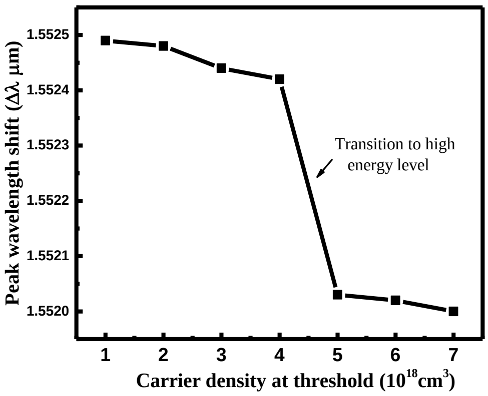
Using Eq.(5), we have,

$$\Delta v(t) = \frac{\alpha}{4\pi}\Gamma g_0\left(N - N_{th}\right) \tag{7}$$

On inspecting Eq.(7), higher the carrier density at threshold (N^{th}), lower will be the optical frequency shift or chirping. Carrier density at threshold is clamped by increasing the total cavity loss, which can be accomplished by decreasing the active layer volume and subjected to strong optical injection [13]. So that the carriers are populated, leading to operation at the second quantization state. An increase in differential gain for lasing at second quantized state is observed in Fig.1(a). This increase in differential gain is attributed to the band filling effect, results in stronger excited state transitions [13]. The band filling effect leads to blue shift of the lasing wavelength towards the shorter wavelength side of the optical spectrum plotted in Fig.1(b). As seen in Fig.1(b), when the carrier density at threshold is small, the lasing wavelength shifts towards longer wavelength side (red shift) and when the threshold carrier density is larger, lasing wavelength is shorter (blue shift) corresponding to the transition of second quantization state of single quantum well laser. Therefore, high carrier density at threshold induced lasing wavelength shift towards shorter wavelength side i.e. differential gain of the lasing mode increases and consequently decreases the effect of chirping phenomenon.

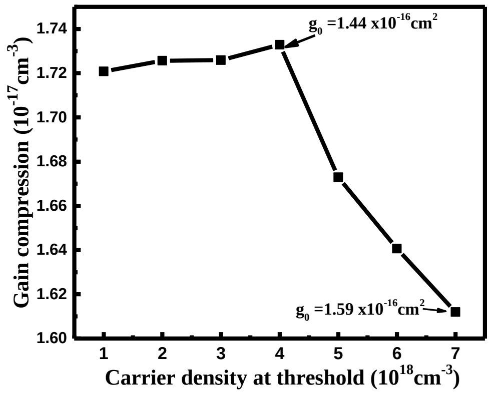


(a)

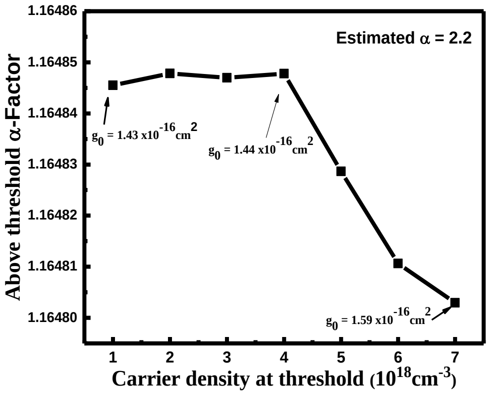


(b)

Fig.1. (a). Differential gain (b). Carrier induced peak wavelength shift as a function of carrier density at threshold



(a)



(b)

Fig.2. (a). Gain compression (b). Above threshold α-factor as a function of carrier density at threshold

Further, the effect of operating the laser at second quantized state of single quantum well laser on the chirp parameters (gain compression and above threshold α-factor) is observed. The Fig.2(a) and Fig.2(b) shows dependence of gain compression and the above threshold α-factor on the carrier density at threshold. As seen in Fig.2(a)-Fig.2(b), it is observed that gain compression and α-factor are larger at small threshold carrier density. But an abrupt downward transition occurs when the carrier density inside the cavity is populated to higher energy level. Therefore, both gain compression and above threshold α-factor is smaller at higher energy state than that for first quantized state.

3. CONCLUSION

We investigate the chirping phenomenon of directly modulated SQW-DFB laser. We have observed the reduction in the chirp parameters: gain compression and above threshold α-factor, by operating the laser at second quantization state. The carrier density at threshold is clamped by increasing the total cavity loss, so that the second energy level is populated leading to operation at second quantization state. Also, we identified higher carrier density at threshold induced wavelength shift towards the shorter wavelength side of the spectrum. This implies higher differential gain of the lasing mode and consequently decreases the effect of chirping in directly modulated SQW laser.

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