Opto-Electro-Thermal Model for MQW Laser Including Self-Heating and Chirping effects

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Abstract- **A new method of analyzing the chirp characteristics and self-heating effect for MQW laser is presented in this paper. With rate equations of MQW laser and thermal equation, this model allows the calculation of the electrical, optical and thermal interactions.**
With considering the threshold current as a function of temperature, we are able to analyze separately the effects of diode thermal resistance, series resistance, turn on voltage, characteristic temperature and well number on the chirp and self-heating parameter. We have shown when self-heating occurs in the laser, the chirp effect is increased.

Keywords: **Self heating, frequency chirp, MQW laser**

1. Introduction

InGaAsP based lasers as the key elements in WDM optical communication, are very sensitive to temperature variations. Temperature affects the main parameters of the laser structure such as, the threshold current, the optical gain, the carrier lifetime and external quantum efficiency [1]. In this paper a model involving the self-heating effect on the frequency chirping of MQW laser is presented. The seriousness of the chirping induced performance degradation increases with the transmission bit rate and can ultimately limit the performance of the system [2].
Our results are in good agreement with the experimental and numerical results obtained considering chirp feature for MQW laser. In section 2, we obtain rate equations considering self-heating effect and output phase shifting (chirping) for MQW lasers. Simulation results and discussion are included in section 3. Finally, in section 4, a conclusion is presented.

2. Theory of Model

The rate equations in quantum well laser including the optical phase can be expressed as

$$\frac{dN(t)}{dt} = \frac{I(t)}{qV_a} - g_0 \frac{[N(t)-N_0]S(t)}{1+\varepsilon S(t)} - \frac{N(t)}{\tau_n} \quad (1)$$

$$\frac{dS(t)}{dt} = \Gamma g_0 \frac{[N(t)-N_0]}{1+\varepsilon S(t)} S(t) - \frac{S(t)}{\tau_p} + \frac{\Gamma\beta}{\tau_n} N(t) \quad (2)$$

$$\frac{d\varphi(t)}{dt} = \frac{1}{2}\alpha\left[\Gamma g_0 [N(t)-N_0] - \frac{1}{\tau_p}\right] \quad (3)$$

were q is the electron charge, V_a is the volume of active region, g_0 is the gain slope, ε is the gain saturation parameter, τ_n is the carrier lifetime, Γ is the optical confinement factor, N_0 is the carrier density at transparency, τ_p is the photon lifetime, α is the line-width enhancement factor. The optical power is defined as [3, 4]:

$$p(t) = \frac{S(t)V_a \eta_0 h\nu}{2\Gamma \tau_p} \quad (4)$$

The relationship between frequency chirp and output optical phase is given by [2, 5]

$$\Delta\nu = \frac{1}{2\pi}\frac{d\varphi}{dt} \quad (5)$$

Substituting (4) into (5) gives

$$\Delta\nu = \frac{1}{4\pi}\alpha\left[\Gamma g_0 [N(t)-N_0] - \frac{1}{\tau_p}\right] \quad (6)$$

The thermal rate equation is written as

$$C_{th}\frac{dT}{dt} = -\frac{\Delta T}{R_{th}} + P_J + P_{nR} \quad (9)$$

where R_{th} is the equivalent thermal resistor defined as

$$R_{th} = \frac{1}{\kappa}\left(\frac{L_{active}}{WL} + \frac{L_{sub}}{W_{sub}L}\right) \quad (10)$$

$$C_{th} = LWN_W L_W \rho_m c_p \quad (11)$$

where L_{sub} and W_{sub} are the substrate thickness and width, respectively and L_{active} is the total active region thickness. The temperature rise in the active region of the laser due to current injection of magnitude I was calculated according to (12)

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$$\Delta T = R_{th}U_0 I_{app} + R_{th}R_0 I_{app}^2 - R_{th}L \tag{12}$$

where I_{app} is the applied input current intensity, U_0 is the positive turn-on voltage of the corresponding ideal diode and R_s is the series resistance [6, 7]. The optical output power L can be written as

$$L = K(I - I_{th}) \tag{13}$$

where K is the proportional coefficient. The threshold current density J_{th} increases when the temperature increases and it may be written as

$$J_{th} = J_0 e^{\frac{T}{T_0}} \tag{14}$$

where J_0 is the constant and T_0 is the laser characteristic temperature.

3. Results and Discussion

Based on the model, we analyze L-I and chirp characteristics of MQW laser, the L-I characteristics of a four- well quantum laser for the cases of with and without considering the self-heating effect at $T=300\ K$ are depicted in Fig. 1.

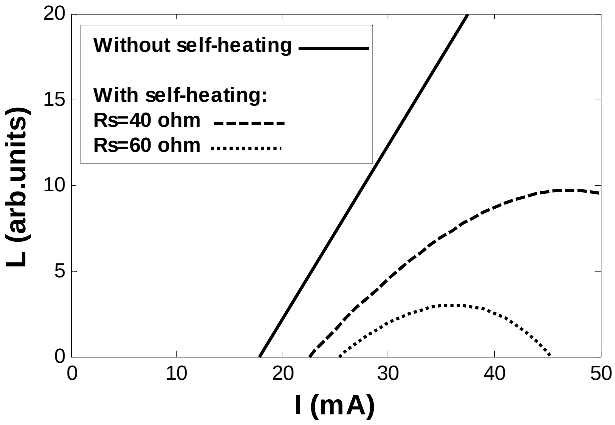

Figure 1. L-I characteristic of a laser with four wells at T=350 K without self-heating effect and with self-heating effect and assuming U_0=1 V, R_{th}=500 KW^{-1}.

In Fig. 1 optical output power is saturated with increase of input current when self-heating effect is considered, but without considering the self-heating effect, the saturation of output power does not happen. Fig. 2 shows the L-I characteristics of MQW laser for different number of wells with self-heating effect and R_{th}=*500* KW^{-1}, R_s=*40* Ω, *U0=1 V*, *T=25 C*. A smaller well number is suitable for lower threshold current and higher differential quantum efficiency at *T=25 C*. I_{th} increases monotonically from *19* to *23 mA* at *T=25 C* when N_W increases from *8* to *10*.

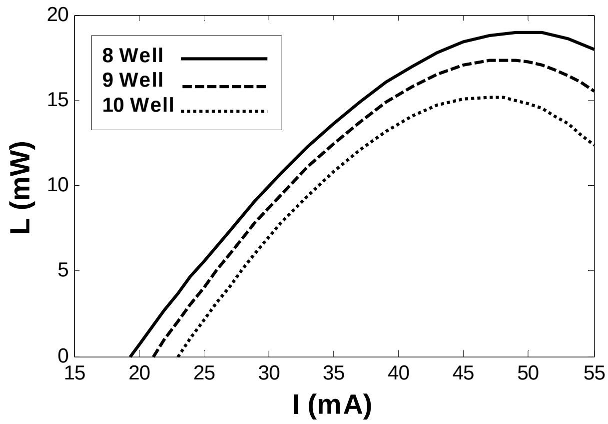

Figure 2. L-I characteristic of laser with self-heating effect.

In Fig. 3 shows the chirp variation of six well quantum lasers for different value of applied currents in the form of the pulse train. Self-heating effect happens with the increase of current. For *I=50* to *52 mA* the optical output power and chirping value increased while for *I=53* to *55 mA* where the self-heating effect occurs, the optical output power and chirping value decreases.

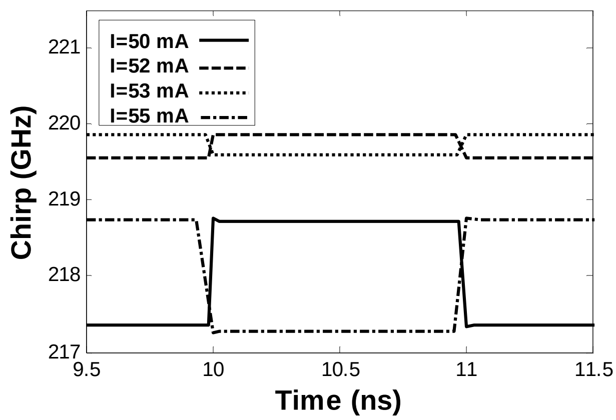

Figure 3. Chirp characteristics of six well quantum laser for T=25 C, Rth=500 KW^{-1}, U_0=1 V.

Fig. 4 shows the effect of well number on chirp characteristics without self-heating effect at *T=25 C* , *I=40 mA* for *6*, *8* and *10* wells and Fig. 5 shows this curve with self-heating effect for Rth=*500* KW^{-1} , Rs=*40* Ω , U_0=*1 V* . Having different threshold current densities the self-heating effects are more important for those laser with higher threshold current. In these curves with increase of well number the value of chirp is decreased. The laser characteristic temperature T_0 is also responsible for the laser sensitivity to self-heating. If there is a similar increase in the active region temperature self-heating effect are less pronounced when T_0 is high. Fig. *6* shows the effect of T_0 on chirp characteristics without self-heating effect for several T_0 at $T=25$ C, six - well, $I=40$ mA and Fig. 7 shows this curve with self-heating effect and assuming $R_{th}=500$ KW^{-1}, $U_0=1$ V, $R_s=40$ Ω.

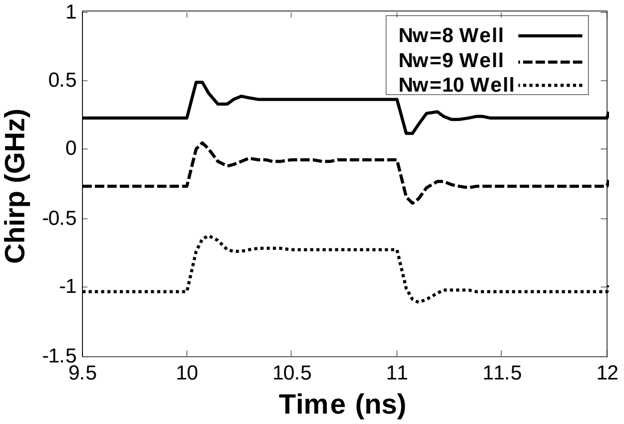

Figure 4. Chirp characteristics without self-heating effect for 8, 9 and 10 wells with T=25 C, I=26 mA.

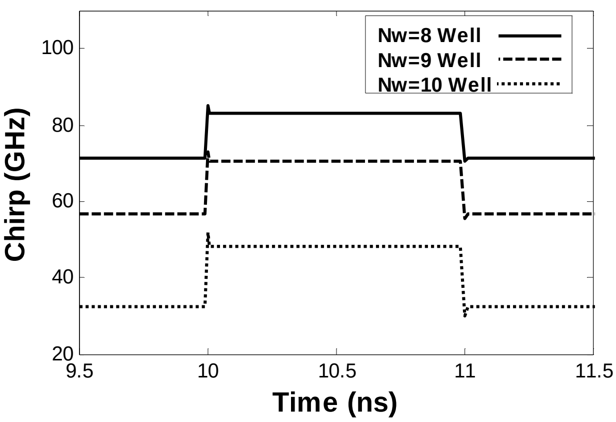

Figure 5. Chirp characteristics with self-heating effect for 8, 9 and 10 wells with T=25 C, I=25 mA, R_{th}=500 KW^{-1}, R_s=40 Ω, U_0=1 V.

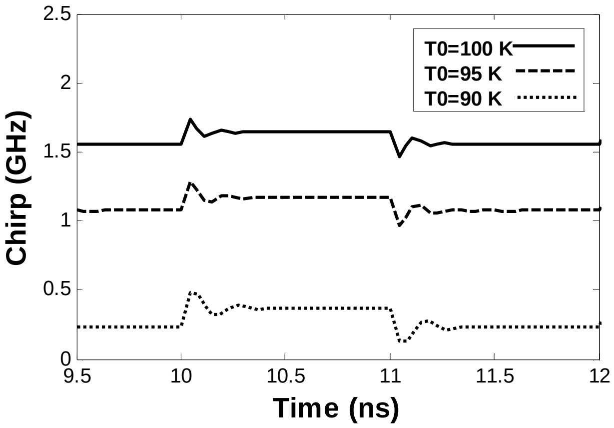

Figure 6. Chirp characteristics without self-heating effect for several T_0.

Effect of thermal resistance and series resistance on self-heating and chirping characteristic is shown in Fig. 8. The curves are calculated at, $T_0=25$ C for $I=25$ mA, $U_0=1$ V and 6 wells. According to these curves, series resistance variation has larger effect for high values of thermal resistance.

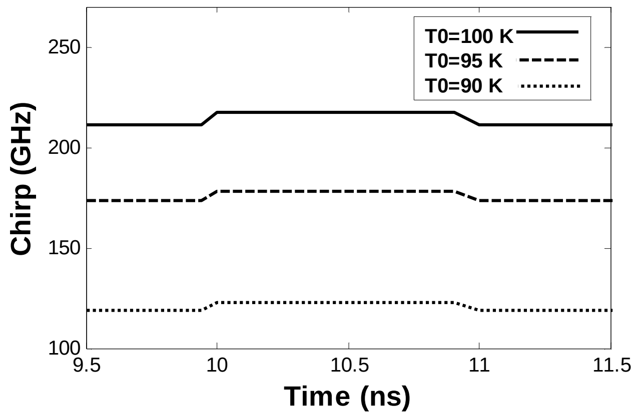

Figure 7. Chirp characteristics with self-heating effect for several T_0.

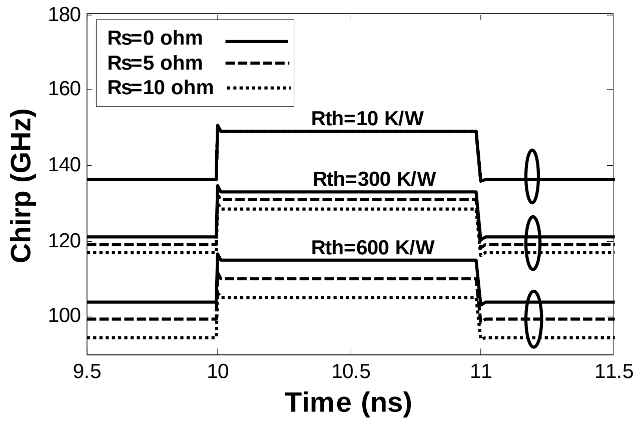

Figure 8. Effect of R_{th} and R_s in chirp characteristic.

The increase of the thermal and series resistances tend to decrease the chirp value. The effect of R_{th} and R_s is also more pronounced at higher temperatures.

4. Conclusion

A model has been used to explain the self-heating and chirping effect in MQW lasers. This model identifies several laser diode parameters responsible for the laser self-heating, the diode thermal resistance, series resistance, turn-on voltage and characteristic temperature. When the thermal resistance and series resistance increased, the active region temperature and consequently the threshold current increased. This effect on chirping characteristics is especially important at high temperatures and high currents and a decrease in emitted optical power with increasing current may even be observed. Also, the effect of well number on self-heating and chirping effect have been investigated. A smaller well number is helpful to decrease the thermal resistance and series resistance and the effects on chirp characteristics of laser. With increases of these parameters, the chirping value is decreased.

Refference

[1] M Torres Pereira: Temperature effects on the large signal transient response of long-wavelength MQW lasers, *in Proc. MELECON '98, 1998, pp. 1432-1435.*

[2] J.C. Cartledge, J.S. Burley: The effect of laser chirping on lightwave system performance, *j. Lightwave Technol., vol. 7. No.3, 1989.*

[3] L.Bjerkan, A.Royest, L.hafskjear, and D.Myhre: Measurement of laser parameters for simulation of high-speed fibre optic systems, *J. Lightwave Technol., vol. 14, No.5, pp. 839-850, May. 1990.*

[4] R.S. Tucker & D.J.Pope: Large Signal Circuit Model for Simulation of Injection-Laser Modulation Dynamics, *IEEE J. Quantum Electron., vol. QE-19, pp. 1179-1183, July 1983.*

[5] K.Czotscher, S.Weisser, A.Leven: Intensity modulation and chirp of 1.55µm multiple quantum well laser diodes, modelling and experimental verification, *IEEE J.Select. Topic. Quantum Electron. Vol.5, No.3, pp. 606-612, 1999.*

[6] J.M.Torres Pereira: The effect of temperature on the light-current characteristics of InGaAsP quantum well lasers, *in Proc. Conftele '99, Sesimbra, Portugal, 1999, pp. 565-568.*

[7] J.M. Torres Pereira: self–heating effects at CW operation of MQW long-wavelength lasers, *Mater Science and Eng B*., vol. 74, pp. 84–88. 2000.