Behaviors for Vertical Cavity Surface Emitting Laser

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ABSTRACT

VCSELs are a type of semiconductor laser with many advantages. In this article, we start a complete model that deals with the many dynamics. The Matlab program solves the model of the system. The results appeared to affect for the output power, carrier density, and gain with increasing the injection current.

The relaxation oscillation frequency increases with the laser bias current for modulation response.

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1. Introduction

Vertical-Cavity Surface-Emitting Lasers (VCSELs) are a new development of semiconductor lasers that be different significantly from the conventional edge emitting Lasers (EELs)[1]. In a typical VCSEL, an optical cavity is formed along the device's growth direction, with distributed Bragg reflectors (DBR's) regularly forming the cavity mirrors. Also results in other important advantages, including support for on-wafer probe testing, two-dimensional (2-D) integration of VCSEL arrays, and the ability to limit device area to a particular spot size[2-4]. Finally, because of their small volume, VCSELs should ultimately have relatively high modulation bandwidths[5].One such light source is the vertical-cavity surface-emitting laser (VCSEL) that could find applications within areas ranging from sterilization and medical treatment to car headlights and augmented reality displays[5,6]. These devices are not yet commercialized, because of challenging mirror formation and electrical injection. However, due to the recent substantial performance improvement of blue-emitting VCSELs, it might not be long before they are available[3-6]. The characteristics of VCSEL such as easy integration, low threshold current and high performance make it has many applications in data communication [7].

2- Rate equations

The common method for analyzing the dynamical behavior of semiconductor lasers begins with formulating a set of two coupled rate equations; one for the carrier density in the active region1, and one for the photon density of the lasing mode in the cavity[8].

The single mode rate equations analysis can be used to describe and understand the intrinsic dynamic modulation behavior of these VCSELs. The finite rate at which carriers are captured into the QWs from the SCH can cause a parasitic-like roll-off in the frequency response and should be accounted for in the general case[9-11].These effects can be included in the rate equation formalism by treating the carriers in the active region separately from the carriers in the SCH and formulate three equations rather than two [11,12]. However, the VCSEL design employed has a narrow, graded SCH and effects from carrier transport can be considered negligible.

We are consequently comfortable with using the two rate equations and following in reference [1], these can be written as:

$$\frac{dN}{dt}=\frac{\eta_i(I-I_{\text{off}}(T))}{q}-\frac{N}{\tau_n}-\frac{G_o(N-N_o)S}{1+\varepsilon S} \qquad (1)$$

$$\frac{dS}{dt}=-\frac{S}{\tau_p}+\frac{\beta N}{\tau_n}+\frac{G_o(N-N_o)S}{1+\varepsilon S} \qquad (2)$$

where Sis the photon number, N is carrier density, η_i is the injection efficiency, τ_n is the carrier recombination lifetime, G_o is the gain coefficient, N_o is the carrier transparency number, τ_p is the photon lifetime, β is the spontaneous emission coupling coefficient, and ε is the gain-compression factor. The optical output power can be described using $P_o=k\,S$ where k is a scaling factor accounting for the output coupling efficiency of the VCSEL[11].

For an active region at the high injection levels applicable for lasers, charge neutrality requires the density of electrons and holes to be equal. Consequently, it is sufficient to invent an equation for only one type of carrier.
All static thermal effects are now accounted for via the offset current, thereby circumventing the need for a more detailed approach. For simplicity, we choose to model this offset current using a polynomial function of temperature[1]:

$$I_{\text{off}}(T)=a_0+a_1T+a_2T^2+a_3T^3+a_4T^4+\cdots$$

where the coefficient (a1, a2 , a3,…) is given in reference [1].
In order to incorporate the phenomenological fact that gain is compressed at high photon densities, we write G as reference [2].

The intrinsic modulation response $H_i(f)$ is given by:

$$H_i(f)=\eta_d\,\frac{hc}{\lambda_0\,q}\cdot\frac{f_r^2}{f_r^2-f^2+j\,\frac{f}{2\pi}\gamma} \qquad (3)$$

The approximate expressions for f_r:

$$f_r\approx\frac{1}{2\pi}\sqrt{\frac{\upsilon_g\,g\,S}{\tau_p\,(1+\varepsilon\,S)}} \qquad (4)$$

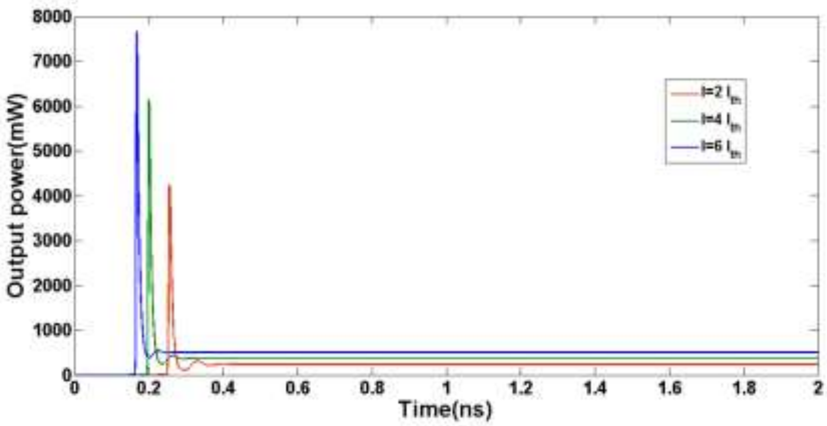
3.Results and discussion

VCSEL rate equations model is solved by matlab program (ode45 method). With the selected parameters as shown in table.1 with initial conditions. The threshold current is $I_{th}=4.5\,mA$. We note that the affect output power, carrier density and gain with increasing the injection current. For modulation response, the relaxation oscillation frequency increases with the laser bias current.

Table -1: selected parameters for system

Parameter	Value
η_i	1
β	10^{-6}
τ_n	5 ns
G_o	$1.6 \times 10^4\ \mathrm{s}^{-1}$
k	2.6×10^{-8} W
τ_p	2.064 ps
N_o	1.654×10^7

The effect of increasing the injection current leads to increasing the output power of photons and carrier density can be appeared as shown in figure (1) and figure (2), respectively.



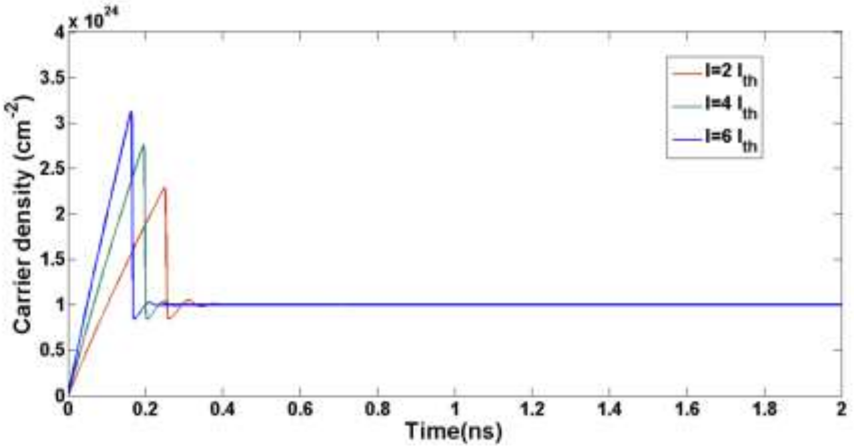


Fig -2: Time behavior of laser carrier density at various values of injection currents.

The effect of increasing the injection current leads to increasing the photons which causes increasing the gain as shown in figure (3).

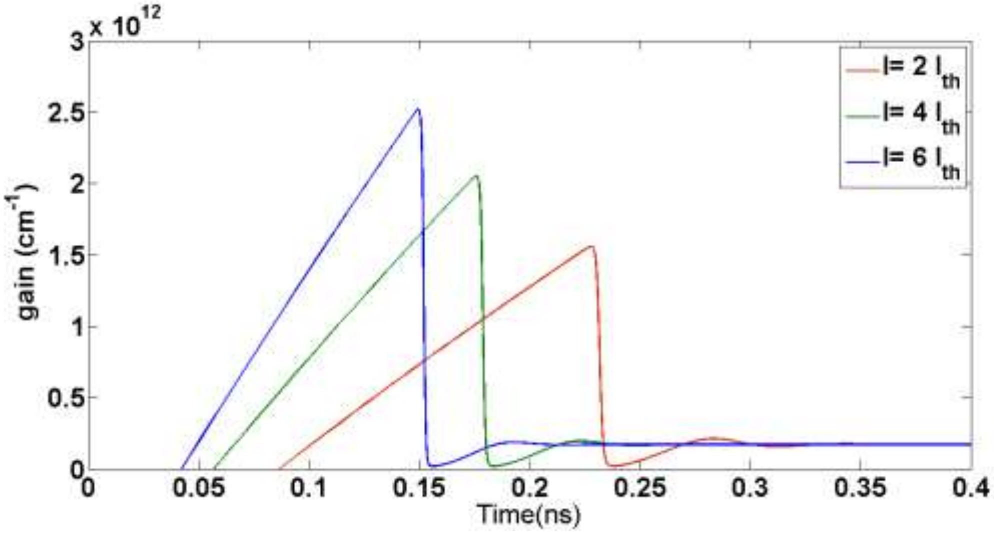


Fig -3 :Gain variation with time series.

The modulation responses at two bias currents and a temperature of 27 ^{o}C are reported, thereby providing us with an prospect to confirm small-signal capabilities as shown in figure. 4 (a,b).

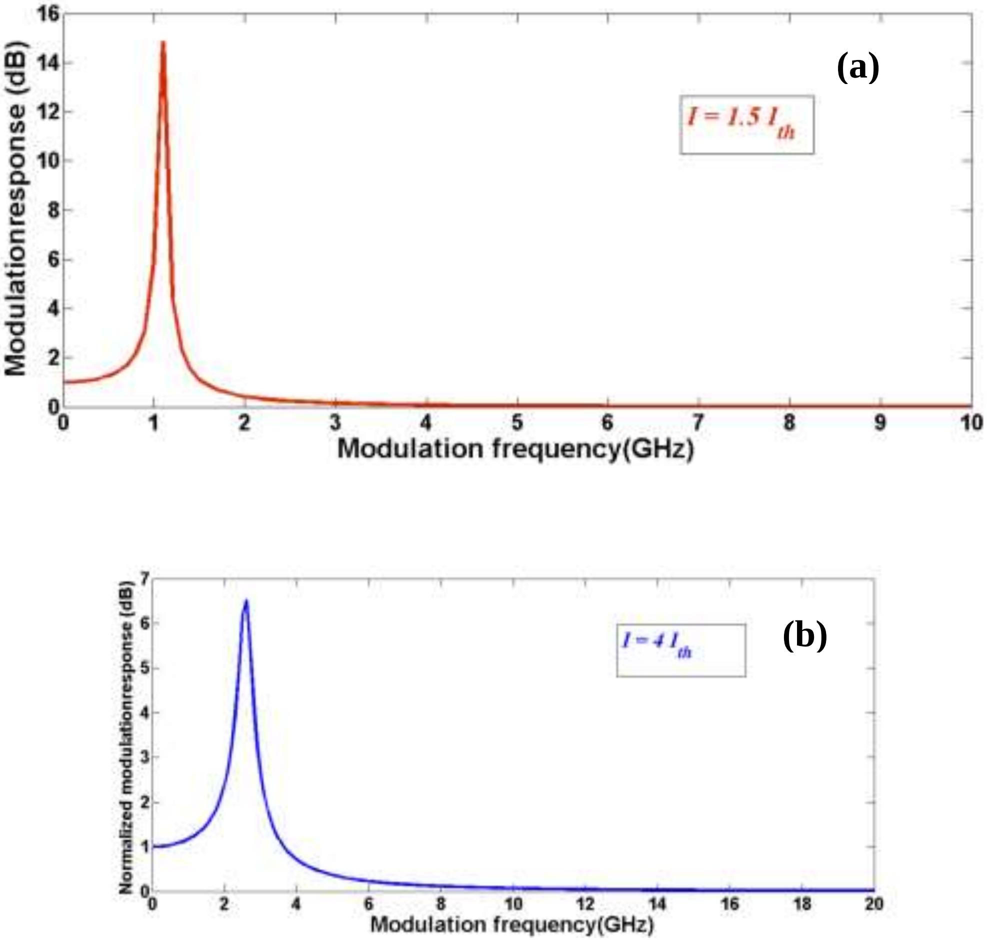


Fig.4. Modulation response at varying DC bias current
a: ($I = 1.5\ I_{th}$) and b: ($I = 4\ I_{th}$).

The peak values of output power with selected values of temperature is appeared in figure.5 .

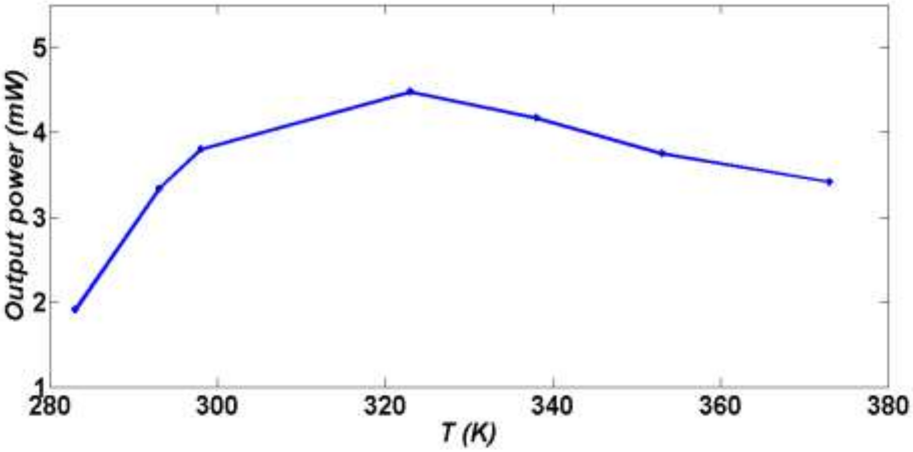


Fig 5: Peak values of output power with selected temperatures.

The current-voltage (IV) relationship, meanwhile, can be modeled in great detail based on the diode-like character of the VCSEL. However, for simplicity we have elected to represent the voltage across the device as an arbitrary empirical function of current and temperature using [13,14]:

$$V = f(I,T)$$

$$V = (0.829 - 1.007\times10^{-3}T + 6.594\times10^{-6}T^{2} - 2.18*10^{-8}T^{3})\cdot(2.298 + 366.2I - 6.097\times10^{4}I^{2} + 6.76\times10^{6}I^{3})$$

This behavior can be shown in figure (6).

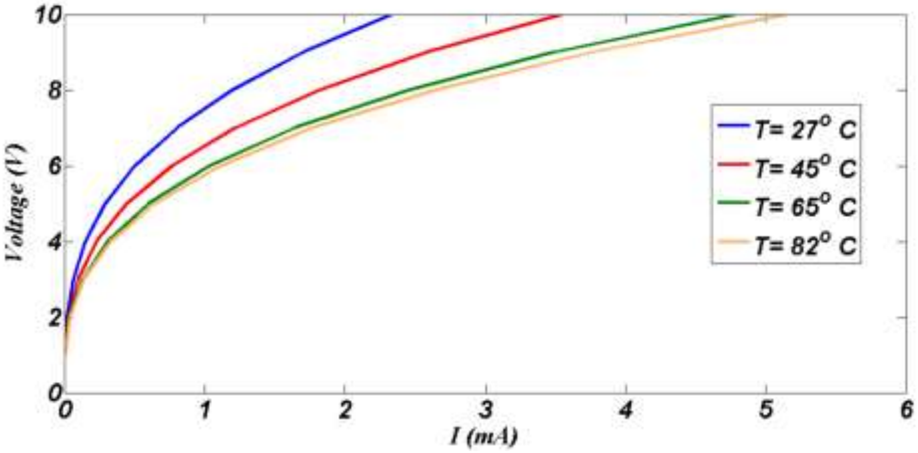


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Fig -6: Comparison of IV curves for temperatures from 27 to 82oC.

4. CONCLUSIONS

We have presented a simple rate-equation-based model of VCSEL thermal LI characteristics which utilizes an offset current to account for thermal effects. As we have seen, the model exhibits good agreement with experiment for numerous devices, suggesting its usefulness for describing a variety of VCSEL's. The relation between modulation response and modulation frequency with increasing current is noticed.

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