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Effect of Scattering Parameter on Small Signal analysis in Direct Modulated Dynamic Semiconductor Lasers

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الخلاصة

تأثير عنصر التشتت هو ذلك التأثير الذي يؤثر على عمل وخواص ليزرات أشباه الموصلات ذات التضمين المباشر بواسطة تحليل أشارة صغيرة لكثافة تيار الحقن ، حيث يؤثر هذا التأثير على كمية كثافة حاملات الشحنة المكممة المحصورة حيث جزء من هذه الحاملات تفقد في المنطقة الفعالة . عنصر التشتت يقودنا إلى ظهور تأثيرات الربح اللاخطية حيث تقوم بتقليل تردد الاستجابة لعملية التضمين المباشر.
نحن سنستخدم معادلات المعدل الخاصة بليزرات أشباه الموصلات ذات النمط المنفرد والتي تمتلك خواص تستخدم لتضمين إشارة صغيرة ذات موجة مستمرة . نحن نستطيع تمثيل هذا التأثير ومناقشته بواسطة جهاز بسيط متكون من جزئيين.

Abstract

Effect of scattering parameter is that the effect which it is effected on the operating characteristics of direct modulated semiconductor lasers by small signal analysis for injection current density , where this parameter is effected on amount of quantum confinement carriers density where the part of this carriers density is lost in the active region. The scattering parameter leads to appear the nonlinear gain effects which they are reduced the response frequency of the direct modulation process.

We use the rate equations of the single-mode semiconductor lasers and that they have characteristics are used to continuous-wave small-signal modulation. We can presented this effect and discussion it by the simple two-port device.

I. Introduction

The main application of semiconductor lasers is as a source for optical communication systems, where the output of the semiconductor lasers is modulated by applying the electrical signal either directly to the optical source or to the external modulator [1]. In direct modulation , the typical approach to enhance modulation band width is to fabricate the high speed semiconductor laser using new materials and structures[1,2]. For example, 33GHz GaAs-based penudomorphic multiple-quantum-well (MQW) ridge-wave guide laser have been reported[2]. However, When the electrical signal applied to semiconductor laser is small signal ,this leads to the distortions that they are appeared in the output of laser will be decreased. But calculation of this signal is depended on the scattering parameters[1,2].

II. Theory and analysis

For a semiconductor laser which is operating above threshold, the output power depends linearly on the input injection current. It is then expected that for an ac current input with a dc offset above threshold, the optical output power will have a corresponding ac and dc component as depicted in Fig.1[3]

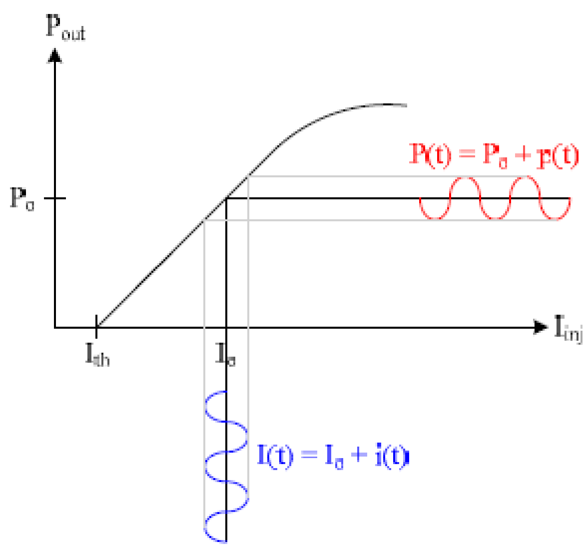

Fig.1 Graphical representation of output power modulation by input current modulation in a semiconductor laser

To examine the dynamics of the output power dependence on input current under ac modulation, rate equations for carrier and photon densities are used [3]:

$$\frac{dN}{dt}=\frac{\eta_i J}{qd}-\frac{n}{\tau}-vg(N)S \quad (1)$$

$$\frac{dS}{dt}=\Gamma vg(N)S-\frac{S}{\tau_P}+\beta R_{SP} \quad (2)$$

Where N is the carrier density (cm^{-3}). η_i is the injection efficiency , J is the current density (A/cm^2).q is the elementary charge (C), d is the gain region thickness (cm), τ is the carrier lifetime (s) , υ is the group velocity of light in the material (cm/s). g(N) is the gain coefficient (1/cm), S is the photon density (cm^{-3}) , Γ is the optical confinement factor. τ_P is the photon lifetime (s). β is the spontaneous emission factor , and R_{SP} is the spontaneous emission rate per unit volume ($cm^{-3}\ S^{-1}$).

Each term of the rate equations corresponds to a physical process which occurs to change the total number of photons or carries .In eq. (1) , the carrier density is increased by the first term , the injected number of carriers

per unit volume per second ($\eta_i J/qd$). The carrier density is decreased due to radiative and nonradiative recombination events which are lumped together in the second term(N/τ), and also due to stimulated emission (υ g(N)S).In eq.(2), the photon density is increased by stimulated emission ($\Gamma\upsilon$ g(N)S)) and a fraction of the spontaneous emission which couples into the lasing mode (βR_{SP}). The photon density is decreased due to absorption and cavity losses (S/τ_P)[3,4].

For this analysis , the gain term will be approximated using a nonlinear model as shown in eq. (3), where g_0 and $g^/$ are the gain and differential gain , respectively. At the bias point N_0 and the $1+\varepsilon S$ term accounts for gain saturation which occurs at high photon densities where ε is the gain suppression factor[4].

$$g(N)=\frac{g_0+g^/(N-N_0)}{1+\varepsilon S} \quad (3)$$

The equations for the total injection current density . carrier density , and photon density are given in Equation (4a) , (4b) , and (4c) , respectively[4] :

$$J(t)=J_0+j(t) \quad (4a)$$

$$N(t)=N_0+n(t) \quad (4b)$$

$$S(t)=S_0+s(t) \quad (4c)$$

For small-signal analysis , the ac variations j(t). n(t) .and s(t) are assumed to be very small compared to their dc counterparts J_0 , N_0, and S_0 . The dc steady state solutions to the rate eqs. (1) and (2) can be obtained by setting the derivatives as well as the ac components of the current , carrier , and photon densities all equal to zero ,and solving for S_0 and N_0 in terms of J_0 [5].

Assuming an ac sinusoidally varying current , carrier , and photon density, the rate equations can be analytically solved through the use of the phasor expressions j(ω),n(ω),and s(ω), where ω is the angular frequency of modulation . Substituting in the steady state solutions of S_0 and N_0 into the solution for s(ω) and dividing by j(ω) yields the small-signal modulation response[5] :

$$\left|M(\omega)\right|^2 = \left|\frac{s(\omega)}{j(\omega)}\right|^2 = \left(\frac{\Gamma\tau_P}{qd}\right)^2 \frac{\omega_r^4}{(\omega^2-\omega_r^2)^2+\omega^2\gamma^2} \qquad (5)$$

Where (assuming negligible spontaneous emission) the relaxation oscillation frequency $f_r=\omega/2\pi$ and the damping coefficient γ are given by Equations (6) and (7), respectively.

$$f_r = \frac{\omega_r}{2\pi} = \frac{1}{2\pi}\sqrt{vg^{/}\frac{S_0}{\tau_P}} \qquad (6)$$

$$\gamma \approx vg^{/}S_0\left(1+\frac{\varepsilon}{vg^{/}\tau_P}\right)+\frac{1}{\tau} \qquad (7a)$$

$$= Kf_r^2+\frac{1}{\tau} \qquad (7b)$$

In eq. (7b) , the K factor (with units of seconds) has been defined for convenience .

The small signal bandwidth of the device is defined as the frequency at which the modulation bandwidth is equal to one-half the value at dc . this corresponds a 3-dB drop on a logarithmic scale . and as such , the bandwidth is often termed the 3-db frequency . it can be shown that the maximum 3-dB bandwidth possible occurs when the following condition is met[4] :

$$2\omega_r^2 = \gamma^2 = K^2 f_r^4 \qquad (8)$$

From eq. (8) , the theoretical maximum relaxation oscillation freque found to be

$$f_{r\max} = \frac{2\pi\sqrt{2}}{K} \qquad (9)$$

Unfortunately, this model is somewhat poor for a real semiconductor laser. Parasitic effects such as series resistance, capacitance between the contact pads, and capacitance due to the oxide region create the need for a more accurate model oxide-confined devices are primarily limited due to the capacitance of the oxide region. Adding another term to the modulation transfer function yields the three pole model[5,6]:

$$\left|M(\omega)\right|^2 = \frac{1}{1+(\omega/\omega_{par})^2}\left|\frac{s(\omega)}{j(\omega)}\right|^2 = \left(\frac{\Gamma\tau_P}{qd}\right)^2 \frac{1}{1+(\omega/\omega_{par})^2}\frac{\omega_r^4}{(\omega^2-\omega_r^2)^2+\omega^2\gamma^2} \qquad (10)$$

Where ω_{par} is the frequency of the pole due to the parasitics.

To accurately calculate the small-signal modulation characteristics of the photonic crystal semiconductor, scattering parameters were employed. Fig.2 illustrates a simple two-port device (due to high frequency operation, transmission lines must be considered) [6].

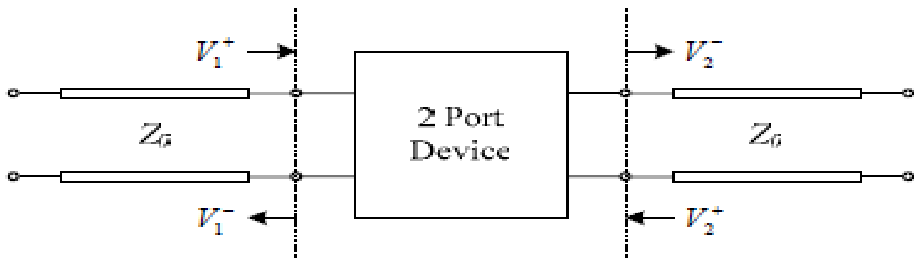

Fig.(2) Linear two – port device model

The voltage and current at port one and port two are defined as

$$V_1^{total} = V_1^+ + V_1^- \, and \, V_2^{total} = V_2^+ + V_2^- \tag{11}$$

$$I_1^{total} = \frac{V_1^+ - V_1^-}{Z_0} \, and \, I_2^{total} = \frac{V_2^+ - V_2^-}{Z_0}$$

The normalized forward and backward traveling waves are defined as

$$a_1 = \frac{V_1^+}{\sqrt{Z_0}} \, and \, b_1 = \frac{V_1^-}{\sqrt{Z_0}} \tag{12}$$

$$a_2 = \frac{V_2^+}{\sqrt{Z_0}} \, and \, b_2 = \frac{V_2^-}{\sqrt{Z_0}}$$

The system scattering parameters (or S- parameters) are defined as

$$\begin{aligned} b_1 &= S_{11}a_1 + S_{12}a_2 \\ b_2 &= S_{21}a_1 + S_{22}a_2 \end{aligned} \tag{13}$$

By matching the end of transmission line connected to port 2 (in Fig. (2)), the reflected wave b_2 becomes zero . it is straightforward to show that S_{21} (often called the system transmission) is given by[6]

$$S_{21} = \frac{V_2}{V_1}(1 + S_{11}) \tag{14}$$

And for small or constant S_{11} , which is valid when the two port device is either matched to Z_0 or has a very small reactance associated with it , the transmission S_{21} is proportional to the voltage gain of the system[7]

$$S_{21} \propto \frac{V_2}{V_1} \tag{15}$$

Under bias , all semiconductor lasers show a small- signal linear relationship between injection current and input voltage . therefore , by using a high-speed photodetector which gives a small-signal linear voltage response which is proportional to the input light power, the transmission S_{21} is proportional to the small signal modulation response[6,7]

$$\left|S_{21}(\omega)\right| \propto \left|M(\omega)\right| = \left|\frac{s(\omega)}{j(\omega)}\right| \qquad (16)$$

i.e. The transmission S_{21} is calculate as a function of frequency. Therefore S_{21} is given as

$$S_{21}(\omega) = (1-\Gamma^{(\text{port one})})\sqrt{\frac{\epsilon_0}{\mu_0}}\left|M(\omega)\right| \qquad (17)$$

Where ϵ_0 and μ_0 are dielectric and permeability in the vacuum.

Table(1) is parameters values of the 1.3µm Buried hetero structure lasers[2].

Table(1)[2]

The parameters values of 1.3µm Buried hetero-structure laser

Parameter	Symbol	Value
Active-layer thickness	D	0.2 µm
Cavity length	L	250 µm
Active-region width	W	2 µm
Group velocity	c/μ_g	m/s
Effective refractive index	$\bar{\mu}$	3.4
Group refractive index	μ_g	5
Carriers recombination lifetime	τ_{SP}	2.2ns
Photon lifetime	τ_P	1.6ps
Confinement factor	Γ	0.3
Threshold current	I_{th}	15.8mA
Fraction of spontaneous emission entering the lasing mode	β	$10^7\ s^{-1}$
Gain compression factor	ε	$3\times10^{-12}\ m^2/s$
Confinement factor of port one	$\Gamma^{(\text{port one})}$	0.023

III. Results and Discussions

From the table (1) and the eqs.(10) and (17),Fig.3 shows the relaxation resonant frequency (f_r) as a function of the square root of the photon density ($\sqrt{P}$) , we can observed from this figure the relaxation resonant frequency without scattering parameter effect is higher than these frequency with scattering parameter effect due to the scattering parameter on the small signal will decrease the injection carriers density. In addition, this different between two frequencies will lead to nonlinear gain effects where this effect will reduce the response frequency due to the K- factor will decrease{ where we can calculated the K- factor from Fig.3 which it is represented the slope of the curve } ,this leads to the damping rate and the response frequency will reduce .

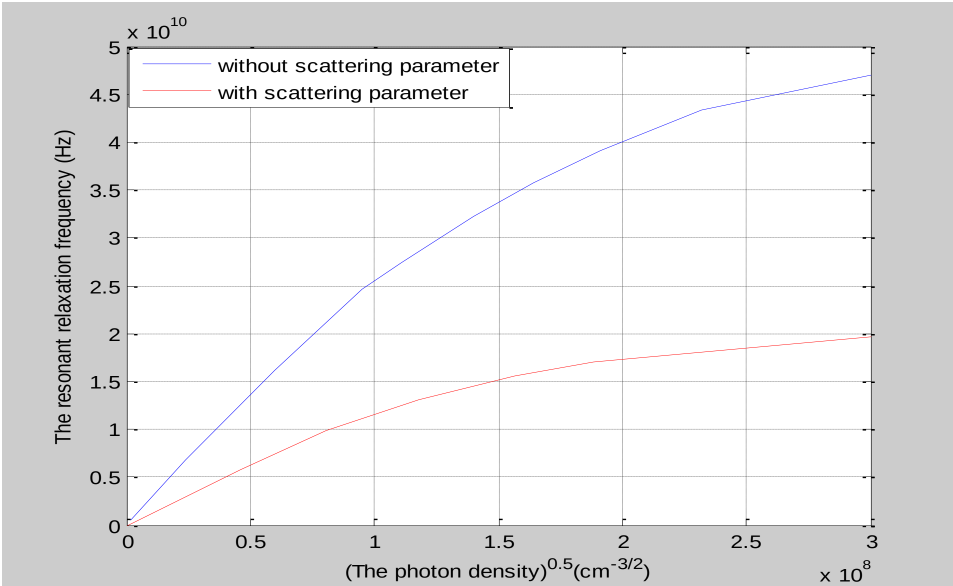

Fig.3 The resonant relaxation frequency with respect to (the photon density)$^{0.5}$

Fig.4 shows frequency response as a function of the modulation frequency where we are observed the different between two cases of frequencies response s due to the effect of the scattering parameter on the small signal

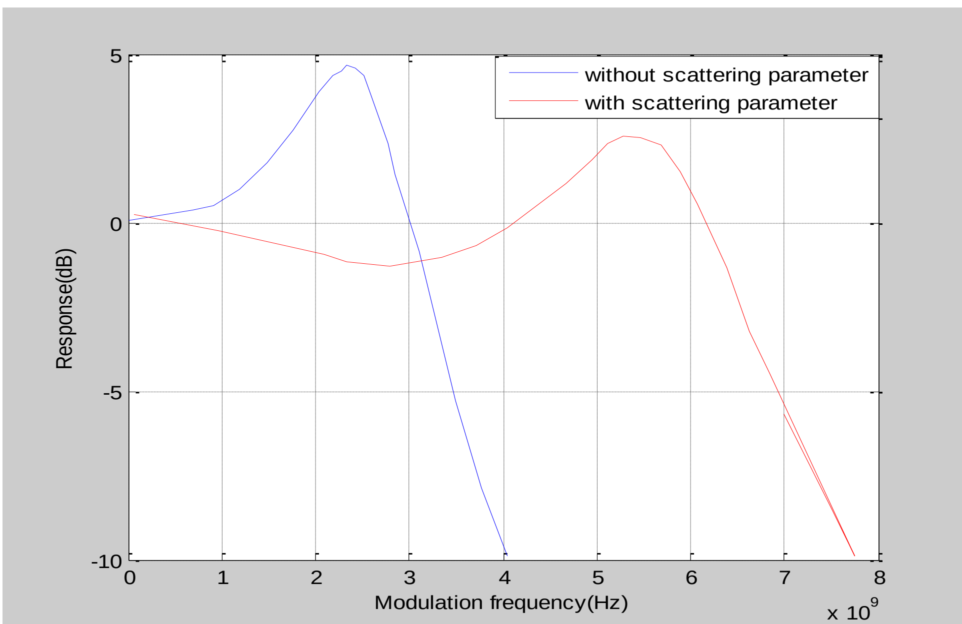

Fig.4 The Response a function of the Modulation frequency

V. Conclusions

The single mode semiconductor lasers were characterized under small signal modulation. The modulation response is limited due to the scattering parameter that this is appeared in the small signal analysis where this is effected on amount of the quantum confinement carrier density where the part of this carriers will loss in the active region . In addition , this effect leads to the appearance the nonlinear gain effects, where this effects will reduce the damping rate and the response frequency. This means the performance of the modulation for semiconductor lasers will limit.

References

[1] S. L. Chuang, Physics of Optoelectronic Devices. New York: Wiley Interscience, 1995.

[2] L. A. Coldren and S. W. Corzine, Diode Lasers and Photonic Integrated Circuits.New York: Wiley Interscience, 1995.

[3] Agilent, Application Note AN 154, pp. 3-6, 2000.

[4] T. R. Chen, B. Zhao, L. Eng, Y. H. Zhuang, J. O'brien, and A. Yariv, "Very high modulation efficiency of ultralow threshold current single quantum well InGaAs lasers," Electronics Letters, vol. 29, pp. 1525-1526, 2006.

[5] C. Carlsson, H. Martinsson, R. Schatz, J. Halonen, and A. Larsson, "Analog modulation properties of oxide confined VCSELs at microwave frequencies," Journal of Lightwave Technology, vol. 20, no. 9, pp. 1740-1749, 2002.

[6] A. N. Al-Omari and K.L. Lear, "Polyimide-planarized vertical-cavity surfaceemitting lasers with 17.0-GHz bandwidth," IEEE Photonics Technology Letters, vol. 16, no. 4, pp. 969-971, 2004.

[7] E. W. Young, "A comprehensive study of hybrid vertical-cavity surface-emitting lasers," Ph.D. dissertation, University of Illinois at Urbana-Champaign, 2002.

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