Dynamic Behavior of Directly Modulated Semiconductor Laser Utilizing Optical Feedback

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الخلاصة

في هذا العمل، تمت محاكاة السلوك الديناميكي في ليزر أشباه الموصلات ذات التضمين المباشر باستخدام التغذية العكسية البصرية باستخدام برنامج ماتلاب. أظهرت النتائج أن كثافة حاملات الشحنة وعدد الفوتونات تزداد عند استخدام التغذية العكسية. تمت دراسة تأثير انعكاسيه المرأة الخارجية على القدرة الخارجة، ووجد أن عند ازدياد انعكاسية المرأة يزداد خرج الليزر أيضاً. كذلك تم دراسة تأثير المسافة بين منظومة الليزر والمرأة الخارجية، حيث وجد أن أعظم قدرة يمكن الحصول عليها عند مسافة بحدود (7,0-75,0) سم.

الكلمات المفتاحية

ليزرات أشباه الموصلات، التضمين المباشر، التغذية العكسية البصرية.

Abstract

In this work, dynamical behavior of directly modulated semiconductor laser utilizing optical feedback has been simulated using MATLAB software package. The results show that the carrier density and photon numbers have been increased with external optical feedback (external cavity). The effect of external mirror reflectivity on the output power has been studied and it's found that as the reflectivity increased the output power was increased. Also, the effect of distance between semiconductor laser cavity and the optical external cavity has been studied and the maximum output power has been obtained at an external length of (0.7- 0.75) cm.

Keywords

semiconductor lasers, direct modulation, optical feedback.

1. Introduction

Directly-modulated semiconductor lasers have become one of the most efficient candidates for high-speed communication in microwave frequencies because of their compactness and relatively low fabrication cost [1]. Direct modulation involves changing the current input around the bias level above threshold [1].High speed direct modulated semiconductor laser has potential application in digital and analog transmission links. The nonlinearity occurred at a frequency less than (1) GHz for a high-frequency modulation application, the nonlinear interaction between electrons and photons in the laser cavity is the main cause for nonlinear distortion [2]. To overcome these distortions, optical feedback technique (External Mirror) can be used. External cavity diode laser system consists primarily of a semiconductor diode laser with two anti-reflections coated and a collimator for coupling the output of the diode laser, and an external mirror [3]. The mechanism of the external mirror (optical feedback) is shown in Fig. (1).

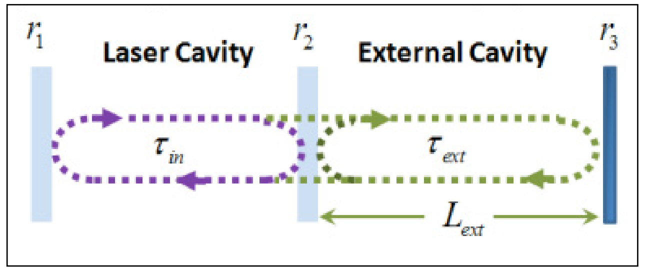

Fig.(1) Schematic of the laser diode with external mirror optical feedback [4].

The process of optical feedback can be done when the reflection part of the rays that falls on the mirror is reflected back to the laser cavity. In this work a numerical model for semiconductor laser diode that predicts laser performance in high-speed optical interconnects applications has been used. The model is based on the temporal numerical simulation of the rate equation for semiconductor laser diodes. The popular MATLAB package has been used to simulate the dynamic behavior of carrier and photon density with and without the effect of external optical feedback.

In this work, the dynamical behavior of directly semiconductor laser has been studied and the rate equations have been solved numerically using MATLAB software package. The parameters that performed the behavior of semiconductor laser namely: the amount of feedback, the facet reflectance, the pumping rate, and the distance between laser cavity and the external cavity have been examined to enhance the characteristics of the semiconductor laser.

2. Theoretical Model

The numerical model introduced in this paper is based on the semiconductor laser diode rate equations [5]. This set of two differential equations can describe the temporal interaction of the carrier density N(t) and the photon density S(t) within the laser cavity. It reveals that an injection current can cause stimulated photon emission. The operation of a single mode laser can be described by:

$$\frac{dS}{dt}=\left[\Gamma g_o(N-N_1)(1-\varepsilon S)-\frac{1}{\tau_P}\right]S+\frac{\beta N}{\tau_C}\ldots(1)$$

$$\frac{dN}{dt}=\frac{I(t)}{qV}-\frac{N}{\tau_C}-g_o(N-N_1)(1-\varepsilon S)\cdots(2)$$

Where, the variable parameters, N is the density of carrier, S the density of photon, I(t) the injection current. The constant parameters, Γ is the confinement factor, τc is the carrier lifetime, τP is the photon lifetime, N1is the transparent carrier density, g0is the differential gain, ε is the gain suppression factor, and β is the probability of spontaneous emission of a photon.

By adding the external cavity factors such as G, τ_L τ_L, τ_{ext} τ_{ext}, R_{ext} R_{ext}, L_{ext} L_{ext}, K_{ext} K_{ext}, R_{sp} R_{sp}, K_{tot} and R_{sp} R_{sp} in the rate equations (RE) model, the RE model can be expressed as [6]:

$$\frac{dS}{dt}=\frac{S}{\tau_P}(G-1)+K_{tot}R_{sp}+\frac{S}{\tau_L}K_{ext}\sqrt{S(t)S(t-\tau_{ext})}\cos(\omega_{th}\tau_{ext}+\phi(t)-\phi(t-\tau_{ext}))+F_S(t) \quad \ldots (3)$$

$$\frac{dN}{dt}=\frac{I(t)-I_{th}}{qV}-\frac{1}{\tau_C}(N-N_{th})-\frac{GS}{V\tau_P}+F_S(t) \ldots (4)$$

where G is normalized gain, τ_L τ_L is laser cavity round trip time in (ps), $F_s(t)$ $F_s(t)$ is Langevin noise, R_{sp} R_{sp} is spontaneous emission rate, K_{tot} K_{tot} is the spontaneous emission enhancement factor accounting for the finite mirror reflectivities and the lateral wave guiding and τ_{ext} τ_{ext} is external round-trip delay which is expressed as:

$$\tau_{ext}=\frac{2L_{ext}}{C} \quad \ldots (5)$$

Where L_{ext} L_{ext} is the distance between laser cavity and external cavity. K_{ext} K_{ext} is coupling coefficient between external cavity and laser cavity which is expressed as [7]:

$$K_{ext}=(1-R_1)\sqrt{\eta\frac{R_{ext}}{R_2}} \quad \ldots (6)$$

Where R_{ext} R_{ext} is reflectivity of external mirror and R_1 R_1 is facet reflectivity of mirror one.

3. Results and Discussions

The rate equations (1) and (2) has been solved numerically using MATLAB software to track the net fluctuations in both carrier density $N(t)$ and photon density $S(t)$ which are supplied by the injected current $I(t)$ and stimulated emission. Fig. (2a) represents the relation between current and time with modulation frequency (2.9)GHz, in this Fig. there is a compression and relaxation which are increased with increasing modulation frequencies due to the interaction occurs within modulation frequencies. Fig. (2b) represents the relation between carrier density and time. When the current injected in the cavity, the carriers become to operate and increase with time, so there is a compression and relaxation due to the presence of the noise in semiconductor laser. Fig. (2c) represents the relation between photon density and time with modulation frequency of (2.9)GHz and phase of (0)rad/sec. When the current injected in the cavity, the carriers become to operate and increase with time. It can be seen that the injected current reaches its threshold value and the photons becomes to operate with some of compression and relaxation due to the presence of noise in semiconductor laser, and the interaction occurring within modulation frequencies and Fig. (2d) represents the relation between power and time for one modulation frequency of (2.9)GHz and phase of (0)rad/sec. The output of semiconductor laser is increased with time above threshold.

It can be seen that as the injected current increased, the carriers became to operate and increased with time. Until the current reach its threshold value the photons became to operate and increased with time above threshold so the output power increased with time. In all these Figures there is some compression and relaxation due to the presence of some noise in SCL and the interaction occurring within modulation frequencies. To enhance the performance of SCL, an external mirror (optical feedback) has been used to reduce these noise. Fig. (3a) represents the relation between current and time with modulation frequency (2.9)GHz. Fig. (3b) represents the relation between carrier density and time with one modulation frequency of (2.9) GHz and phase of 0rad/sec. When the current is injected in the cavity, the carrier numbers become to operate and the carrier numbers are increased, while the compression and relaxation are reduced due to the effect of optical feedback. Fig. (3c) represents the relation between photon density and time with one modulation frequency of (2.9) GHz and phase of (0)rad/sec. It can be seen that the injected current reaches its threshold value, the photon numbers become to operate. The photon numbers are increased and the compression and relaxation are reduced due to the effect of optical feedback.

Fig. (3d) represents the relation between output power and time with one modulation frequency of (2.9) GHz and phase of (0) rad/sec. The output power of SCL is increased and the noise is decreased with using optical external feedback (External Mirror). In all these figures the compression and relaxation has been reduced due to the effect of optical feedback and the noise decreased using optical external feedback (External Mirror).

Fig. (4) represents the relation between output power and time for different values of external mirror reflectivities. It can be seen that as the mirror reflectivity increased the optical power was increased and the maximum output power can be obtained with R=100%.

Fig. (5) represents the relation between photon density and time at a modulation frequency of (2.9)GHz and phase of (0)rad/sec for different external cavity lengths. It can be seen that as the external length decreased the photon density increased and the maximum output power was obtained at an external length of (0.7-0.75)cm.

4. Conclusion

In conclusion, the dynamical behavior of directly modulated semiconductor laser utilizing optical feedback has been simulated numerically using MATLAB software . The results show that the effects of diode lasers can be performed depending on a number of parameters: the amount of feedback, the facet reflectance, the pumping rate, and the distance between laser cavity and the optical external cavity. The effect of external mirror reflectivity on the output power has been studied and it's found that as the reflectivity increased the output power was increased. Also the effect of distance between semiconductor laser cavity and optical external cavity has been studied and the maximum output power has been obtained at an external length of (0.7- 0.75) cm.

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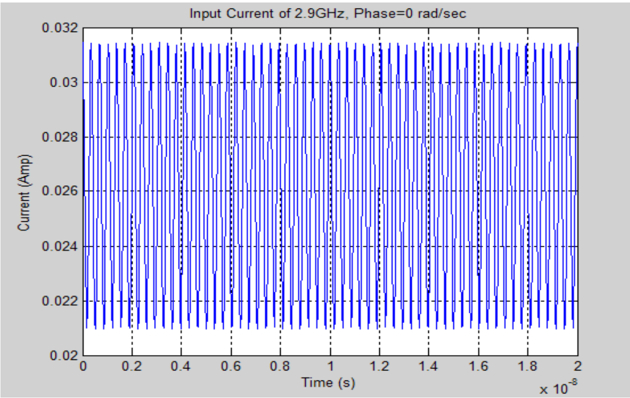
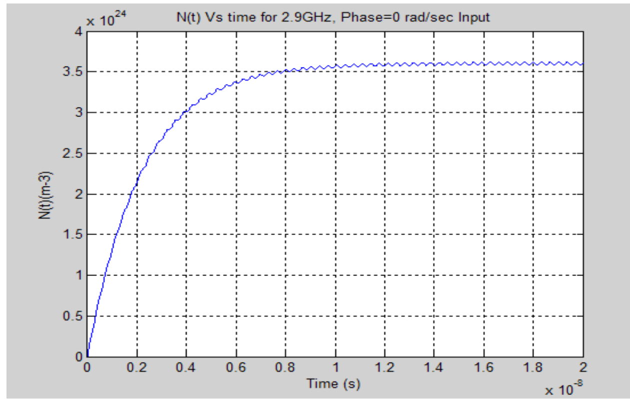
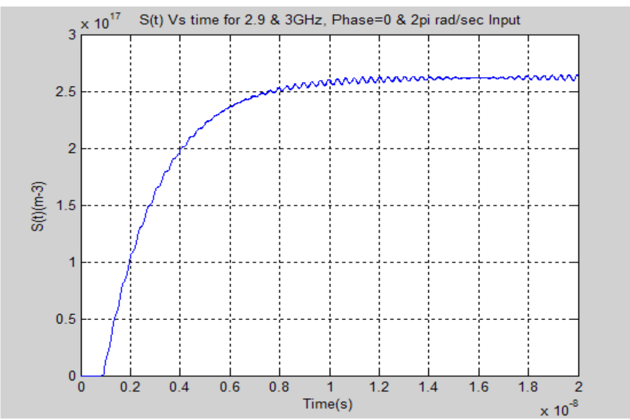


(a)



(b)



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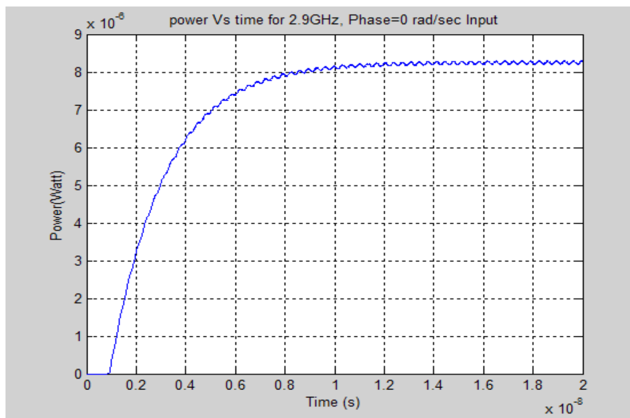
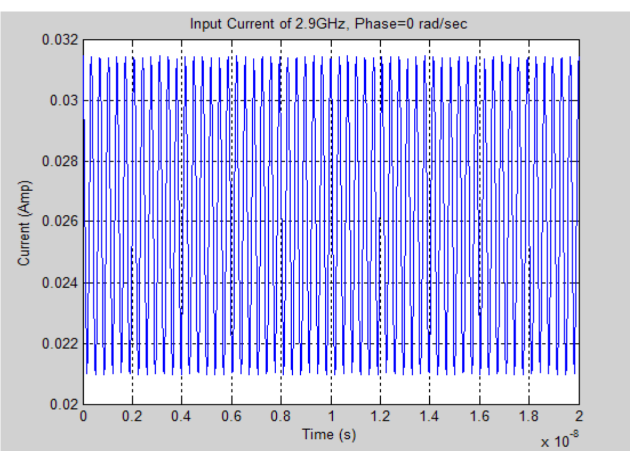
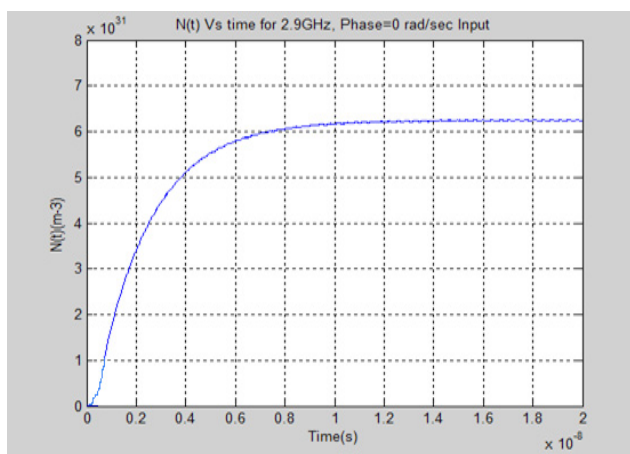


(d)

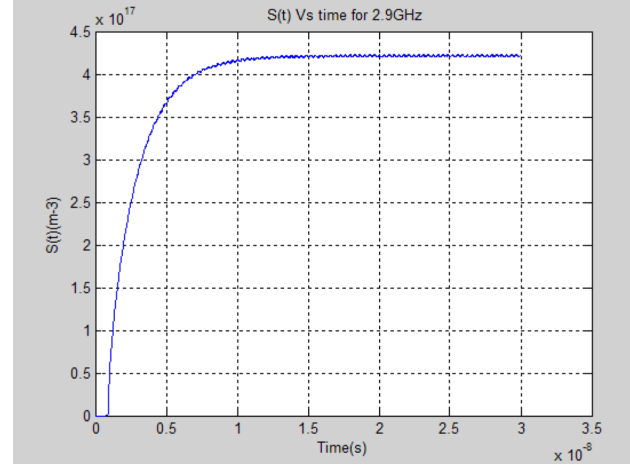
Fig.(2): outputs at modulation frequency of (2.9)GHz and phase of (0)rad/sec (without optical feedback)



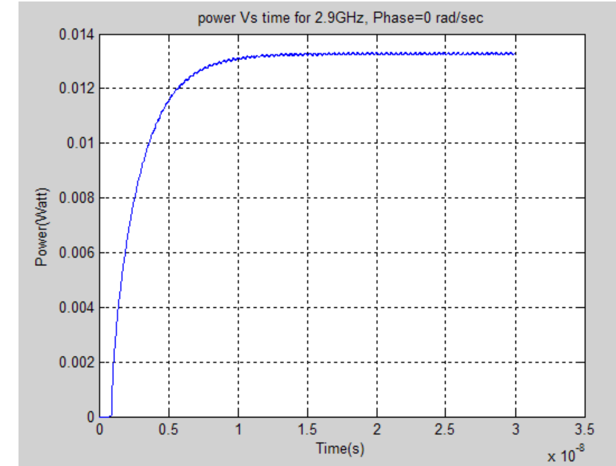
(a)



(b)



(c)



(d)

Fig.(3): outputs from SCL with modulation frequency of (2.9)GHz and phase of (0)rad/sec (with optical feedback)

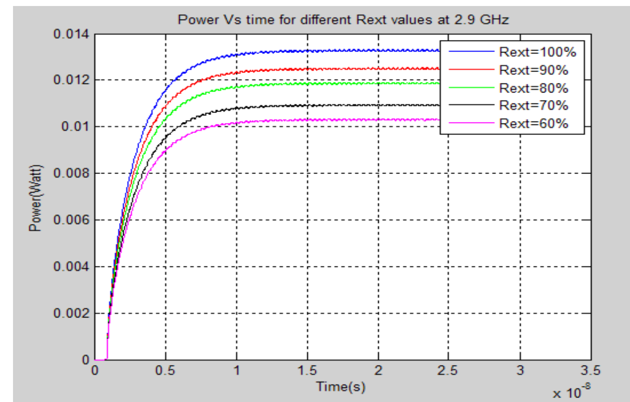


Fig.(4): Semiconductor laser output for different values of reflectivity R_{ext} Rext

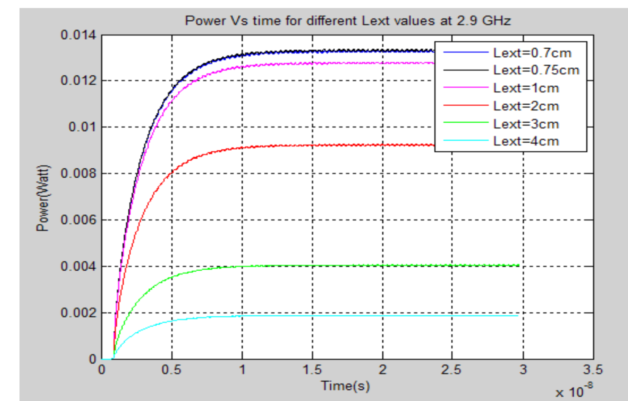


Fig.(5): Photon density as function of time for different external cavity length