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THEORETICAL STUDY OF QD SEMICONDUCTOR LASER DYNAMICS UNDER OPTICAL FEEDBACK

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ABSTRACT

In the present work, we study the dynamics of QD semiconductor laser under optical feedback such as the time behavior of the carriers in wetting layer, the output photons intensity and Occupation probability for the QD active region. When studying the effects of these variables the dynamics are more complex when increasing the optical feedback strength and linewidth enhancement factor at different values of time delay. These dynamics are appeared the nonlinearities and chaos behavior output of laser and these results agree with other results of other researches

KEYWORDS: Quantum Dot Laser, Optical Feedback, Chaotic Output

INTRODUCTION

Nowadays, semiconductor lasers and amplifiers play a key role for many technological applications as for example high bit rate optical communication, optical interconnects, and electro-optic sampling [1].

Semiconductor lasers (SCL) have become the most important class of lasers, they are used in applications [1, 2]. Quantum dot (QD) semiconductor lasers have already demonstrated many interesting properties such as temperature insensitive low threshold current densities [3], high modulation bandwidths [2, 3], and a strong resistance to optical feedback [5], therefore showing great prospects towards realizing uncooled, isolator-free, directly modulated semiconductor lasers. Further, they are of importance for biomedical applications as, for instance, optical coherence tomography. Optical feedback can increase emission noise broaden or narrow the laser linewidth under specific conditions. The coherence length of the laser emission can be reduced to as little as a few centimeters as high feedback level [5].

One particularity of QD semiconductor lasers is their low tolerance to optical feedback, which can be of disadvantage for technological applications [4, 5]. For example, to use semiconductor lasers as transmitters in optical networks, expensive optical isolators are needed to avoid back reflections that can lead to temporal instabilities of the lasers (coherence collapse) [5]. However, there are also several applications that take advantage of the rich dynamics induced by optical feedback [6]. QD semiconductor lasers subject to optical feedback are of high interest, because the optical feedback introduces a delay into the system [7,8]. The delay in turn induces a high dimensionality, which results in a rich phenomenology, ranging from multistability, bursting, intermittency, irregular intensity dropouts, and fully developed chaos [7].

THEORY

Semiconductor quantum dot active region takes full advantage of the quantum confinement effect. The three-dimensional quantum confinement of the carriers results in discrete carrier energy level structure in a quantum dot (QD) active region [1-3]. In general, the SC laser have important in the applications of optoelectronic and optical feedback in the optical communications and in the CD players of computers and especially for QD that have large important with the effect of the optical feedback operation [8-10].

The model used in this work to study the dynamics of quantum dot laser under the effect of feedback is based on the work of E.A. Viktorov et al [11].QD laser under optical feedback is considered to consist of a gain section of length L_α that contains the layers of self organized QDs as the active medium, and a feedback section given by a mirror at a distance l with respect to the end facet of the QD laser, reflecting back the light into the gain region (see figure 1 [12]).

QD laser device with optical feedback from external cavity is shown in figure 1.

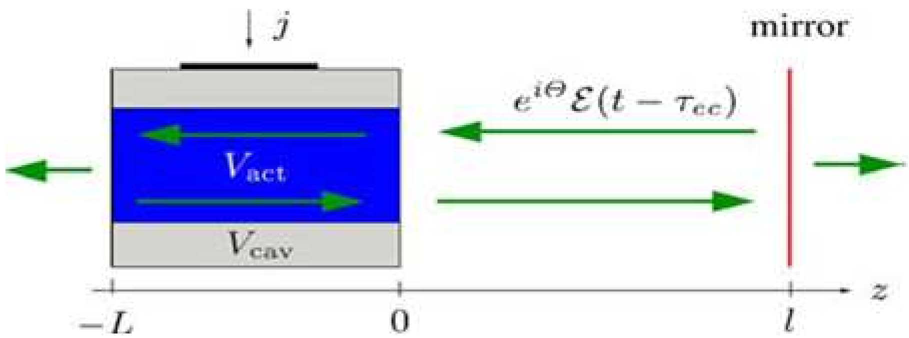

Figure 1: QD Laser Device with Optical Feedback from External Cavity [12]

The rate equations method, includes a set of three coupled equations; one for the electric field (E), occupation probability for QD active region (ρ) and the carrier density in wetting layer (N). They are given in equations (1-3) shown below [11].

$$\frac{\partial E(t)}{\partial t} = -\gamma E(t) + \gamma\sqrt{k}e^{gL_a(1-i\alpha)(2\rho(t-\tau_{ec})-1)}E(t-\tau_{ec}) \quad (1)$$

$$\frac{\partial \rho(t)}{\partial t} = -\gamma_r \rho + BN(1-\rho) - R^{esc}\rho - (e^{2gL_a(2\rho(t)-1)} - 1)|E(t)|^2 \quad (2)$$

$$\frac{\partial N(t)}{\partial t} = N_o - \Gamma N - 2BN(1-\rho) + 2R^{esc}\rho \quad (3)$$

E is the complex amplitude of the electric field in the cavity, normalized to the photon density $S = |E|^2$.

Where G(t) is the normalized gain :

$$\gamma\ G(t) = 2gL_\alpha[2\rho(t) - 1] \quad (4)$$

γ : is the dimensionless bandwidth of the cavity.

L_α : is the length of gain medium.

g: is the differential gain.

τ_{ec} : Time delay (roundtrip time with external mirror)

α : line width enhancement factor

K: optical feedback strength

Γ : is the carrier relaxation rate in the wetting layer.

γ_r : is the carrier relaxation rate in the dots.

N_0 : is the dimensionless parameter which describes the pumping processes in the gain section.

The factor 2 in equation (4) refers to the twofold spin degeneracy in the QD energy levels.

$F(\rho, N)$: is the function that describes the carrier exchange rate between the wetting layer and the dots:

$F(\rho, N) = R^{cap}(1-\rho) - R^{esc}\rho$ Where $R^{cap} = BN$ which describes the carrier capture from the wetting layer to the dots with the rate B

R^{esc} : represents the carriers escape from the dots to the wetting layer which this coefficient is dependent on the temperature.

RESULTS AND DISCUSSIONS

The set of equations (1-3) describes the overall dynamics of an QDL under the effect of feedback. QDL system is studied under the effects of these parameters using the explicit Runge-Kutta method of integration (order 23) known as (dde23) using MATLAB language with certain initial conditions. The control parameters in this study are time delay (roundtrip time with external mirror) τ_{ec}, linewidth enhancement factor α and optical feedback strength (K). In the results of this paper we note on the time behavior of the variables of the system viz time series of the (E, ρ, N) where time (T) is normalized.

Table (1) Represents the Parameters of the System that are Used in the Simulation

Table 1: Parameters Used in Simulation [11]

Symbol	Value
gL_α	3
γ	0.1
N_0	4
Γ	0.01
γ_r	0.01
R^{esc}	0.05
B	2

The gain in the presence of optical feedback depends on the round trip time τ_{ec} and it changes periodically for the variation of the external cavity length[13,14]. The effect of the round trip time in the results when we choose two values of τ_{ec} at different groups of cases.

The Effect of Feedback Strength, K

When varying K in the range (0.15-0.6) and keeping τ_{ec} =50and α =3, the followings were noticed: the system flow to the complex nonlinearities with chaos behavior which can be interested in the optical secure communications and other applications. These results are shown in figures (2-4)

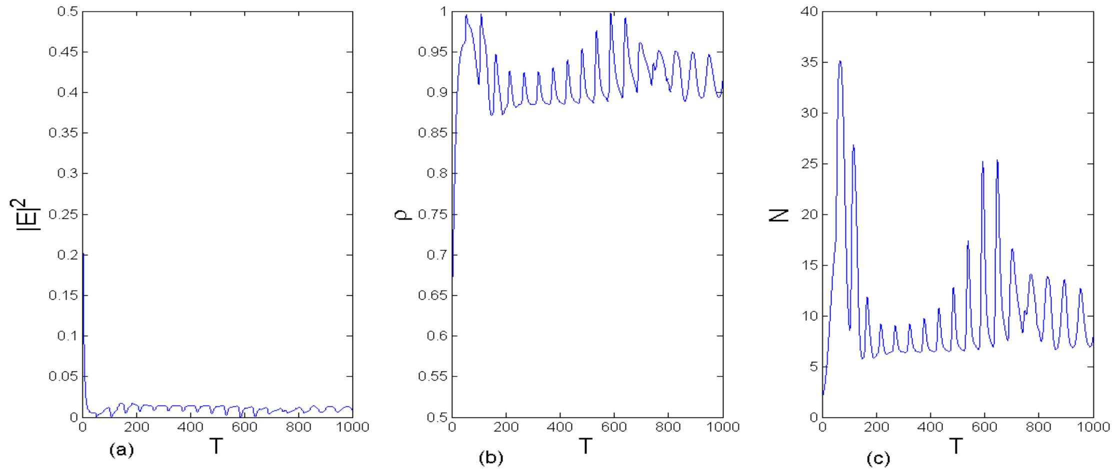

Figure 2: Time Series of (A) the Output Photon Density ($S = |E|^2$), (B) Occupation Probability for the QD Active Region (ρ) and (C) Carrier Density in Wetting Layer (N) When (α =3, τ_{ec} =50 and for K=0.15)

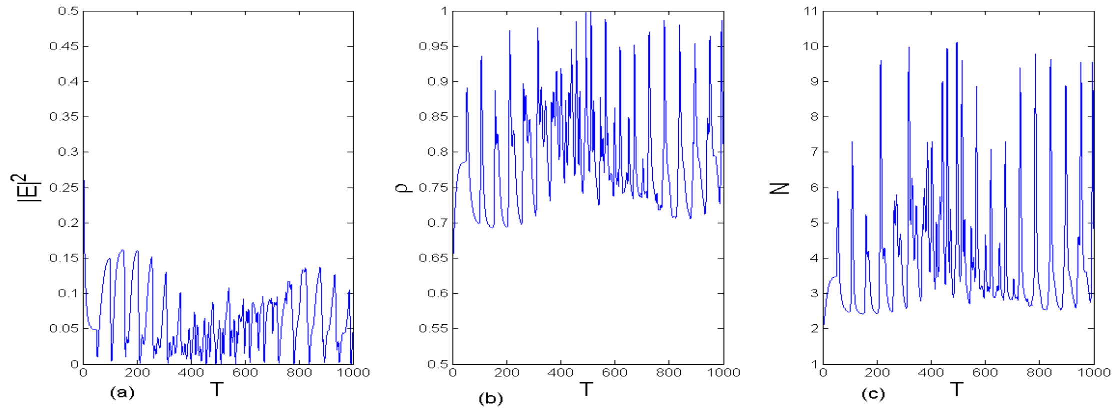

Figure 3: Time Series of (A) the Output Photon Density ($S = |E|^2$), (B) Occupation Probability for the QD Active Region (ρ) and (C) Carrier Density in Wetting Layer (N) When (α =3, τ_{ec} =50 and for K=0.4)

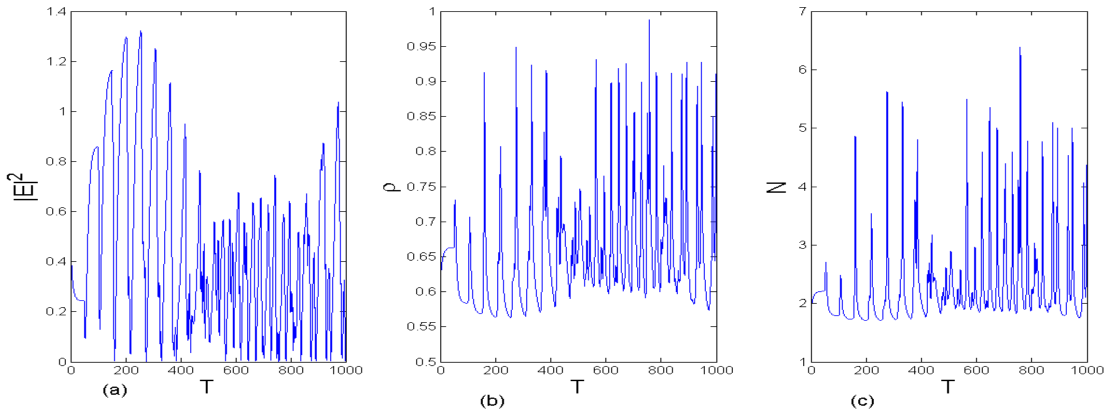

Figure 4: Time Series of (A) the Output Photon Density ($S=|E|^2$), (B) Occupation Probability for the QD Active Region (ρ) and (C) Carrier Density in Wetting Layer (N) When (α =3, τ_{ec} =50 and For K=0.6)

Varying K in the range (0.15-0.6) and keeping τ_{ec} =100and α =3, the system flow to the complex nonlinearities with chaos behavior but these dynamics appear at different value of time delay. Figures (5-7) represent this effects of increasing of τ_{ec}

To 100 with the same previous parameters in Table (1)

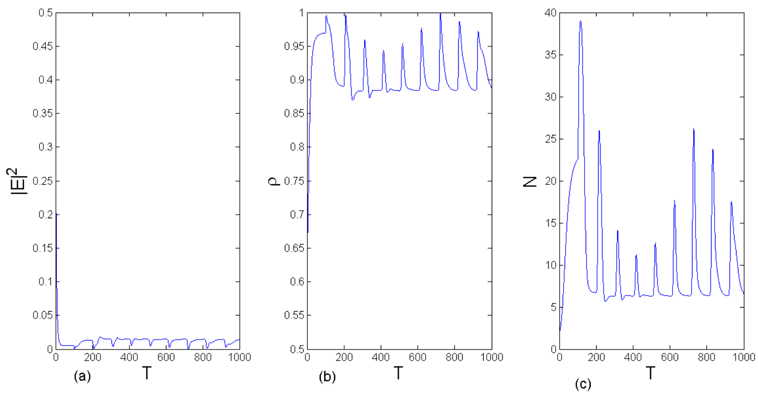

Figure 5: Time Series of (A) The Output Photon Density ($S=|E|^2$), (B) Occupation Probability for the QD Active Region (ρ) and (C) Carrier Density in Wetting Layer (N) When (α =3, τ_{ec} =100 and for K=0.15)

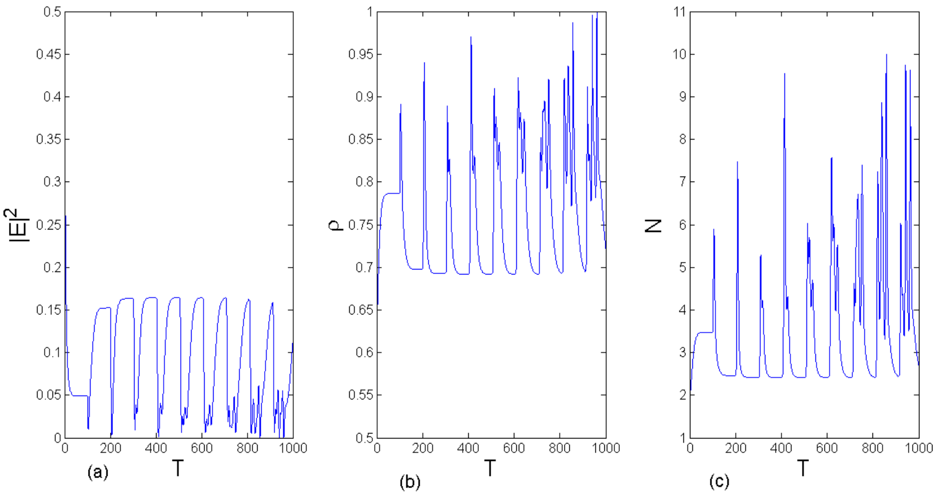

Figure 6: Time Series of (A) The Output Photon Density ($S = |E|^2$), (B) Occupation Probability for the QD Active Region (ρ) and (C) Carrier Density in Wetting Layer (N) When (α =3, τ_{ec} =100 and for K=0.4)

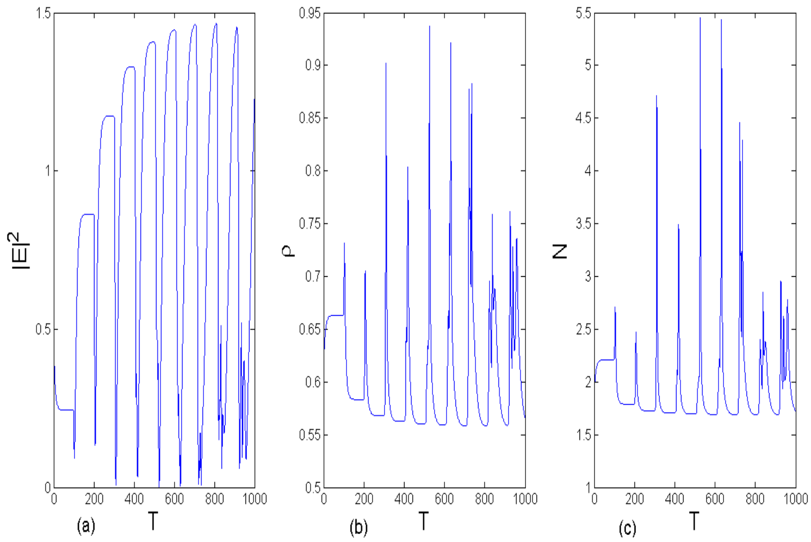

Figure 7: Time Series of (A) The Output Photon Density ($S = |E|^2$), (B) Occupation Probability for the QD Active Region (ρ) and (C) Carrier Density in Wetting Layer (N) When (α =3, τ_{ec} =50 and for K=0.6)

The Line Width Enhancement Factor, α

When changing α in the range (2-5) and keeping τ_{ec} =50 and K =0.15, the system appeared chaotic behavior with increasing value of α and in the high value leads to complex chaotic behavior. The figures (8-10) show to the effect of increasing the linewidth enhancement factor on the dynamics of the variables of system.

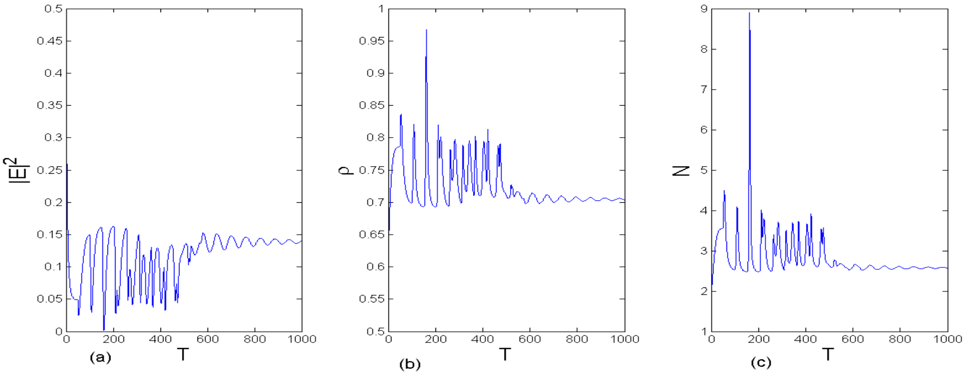

Figure 8: Time Series of (A) The Output Photon Density ($S = |E|^2$), (B) Occupation Probability for the QD Active Region (ρ) and (C) Carrier Density in Wetting Layer (N) When (α =2, τ_{ec} =50 and for K=0.15)

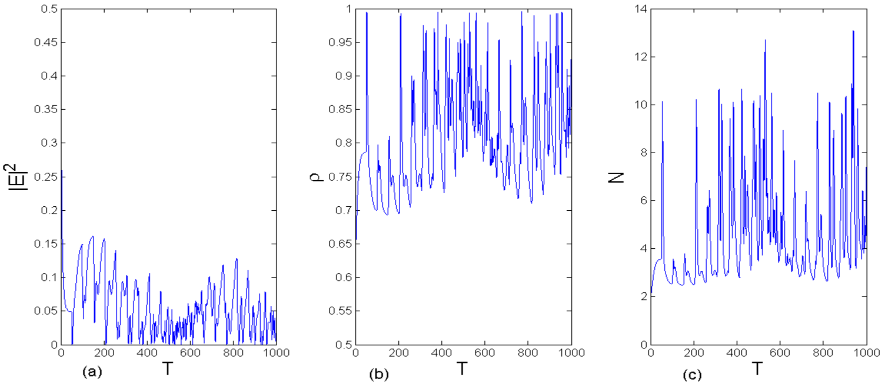

Figure 9: Time Series of (A) The Output Photon Density ($S = |E|^2$), (B) Occupation Probability for the QD Active Region (ρ) and (C) Carrier Density in Wetting Layer (N) When (α =4, τ_{ec} =50 and for K=0.15)

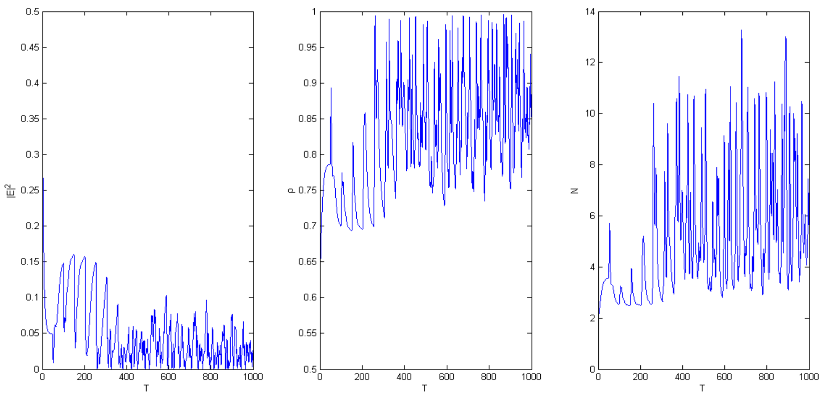

Figure 10: Time Series of (A) The Output Photon Density ($S = |E|^2$), (B) Occupation Probability for the QD Active Region (ρ) and (C) Carrier Density in Wetting Layer (N) When (α =5, τ_{ec} =50 and For K=0.15)

CONCLUSIONS

We note in the results of this work that the system appears different dynamics of variables. The output photon density (S) appears complex behaviors such as chaotic behavior. The output mainly the usual QD laser output which increased in level of complexity in nonlinearities for increasing K. We see that the increasing of linewidth enhancement factor leads to appearance the chaos. All behaviors in the results of this paper introduce different cases of output photon density with different degree of chaos complexity that has benefit in the applications of optical fiber communications and decryption.

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