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Stabilization of an External Cavity Quantum Dot Semiconductor lasers dynamics with Optical Feedback

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Abstract : Stability of an Short External Cavity (SEC) of Quantum Dot Semiconductor lasers(QDSEL) dynamics with Optical Feedback is studied**.** The effect of short external cavity length and linewidth enhancement factor of Quantum Dot Semiconductor lasers(QDSEL) are studied.The rate equations describing QDSEL dynamics are solved numerically. The simulation shows that the photon density are sensitive to short external cavity length. The study proves that QDSEL dynamics is strongly affected of short External cavity length and linewidth enhancement factor with optical feedback in chaos communication lasers.
Keywords : Quantum dot, semiconductor laser, optical feedback, linewidth nhancement factor, short external cavity length.

Introduction :

External-cavity semiconductor lasers (ECSLs) are a feasible means of meeting this requirement Coherent light-wave transmission and high-bit-rate single-mode fiber communication systems require stable lasers with narrow line widths[1]. External cavity semiconductor lasers are a feasible means of meeting this requirement. The intensity and phase-noise power spectral densities of semiconductor lasers in the presence of weak optical feedback have been studied by Spano et al[1]. External cavity semiconductor lasers have been a subject of extensive research during the past 15 years because of the importance of optical feedback phenomena in technical applications such as optical data storage or optical fibre communications[2]. Weak feedback can either narrow or broaden the laser emission line, depending on the length of the external cavity, whilst higher levels of feedback can result in a dramatic broadening of the linewidth[3]. The flexibility of Quantum Dot (QD) structure engineering, chip design, external cavity layout and diverse approaches to continuous wave and mode−locked operation have resulted in a significant variety of laser systems, is studied by (Stephanie E. White and Maria Ana Cataluna)[4]. the first hybrid integrated External Cavity Semiconductor Laser consisting of a Quantum Dot (ECQDSL) reflective semiconductor optical amplifier and a silicon-on-insulator chip is studied by (Shuyu Yang,a,b et.el.)[5].

Quantum Dot Semiconductor lasers have already demonstrated many interesting properties such as high modulation bandwidths[6,7], and a strong resistance to optical feedback[8]. All of these features originate from the quantum confinement that usually characterizes atoms or molecules in contrast to semiconductor materials. Indeed bulk and quantum well semiconductor materials have a large density of states at high energy and, as a result, the maximum gain suffers a blue shift with increasing carrier density[9,10].

Quantum dot rate equation:

The rate equations method, includes a set of at least three coupled equations; carrier density (N), photon density (E) and the other for the occupation probability (ρ). They are given in equations (1-3) shown below[11,12].

In QD semiconductor devices, the carriers are first injected into a wetting layer before being captured into a dot at a capture rate that depends strongly on the dot population. Thus, rate equations that commonly describe carrier dynamics of QD materials read[13],

$$\frac{dE}{dt} = E\left(-\frac{1}{2t_s} + \frac{g_o \upsilon}{2}(2\rho - 1)\right) + \frac{\gamma}{2}E(t-\tau) + R_{sp} \quad (1)$$

$$\frac{d\rho}{dt} = -t_n \rho - g_o(2\rho - 1)|E|^2 + CN^2(1-\rho) \quad (2)$$

$$\frac{dN}{dt} = J - \frac{N}{t_d} - 2n_d CN^2(1-\rho) \quad (3)$$

where N is the carrier density in the well, E is the complex amplitude of the electric field ρ is the occupation probability in a dot; ts is the photon lifetime; t_n and td are the carrier lifetime in the well and the dot, respectively; N_d is the two-dimensional density of dots; and J is the pump. γ and τ describe the feedback level and delay time, where τ =2L/c is the round trip time of light within the external cavity (L) and c velocity of light[14], C is Auger carrier capture rate[15], rate equation (1,2,3) are solved by using matlab.

Table (1) Parameters used in the calculation for QDSEL[13].

Definition	Symbol	Value	Units
Photon life time	ts	3.4	ps
Carrier life time well	t_n	1	ns
Electronic charge	q	1.6 x10^{-19}	C
Carrier life time dot	t_d	1	ns
Linewidth enhancement factor	α	2 , 4	-
Velocity of light	c	3 x10^{8}	m/sec
Spontaneous recombination factor	β	3 x10^{-5}	-
Group velocity	v_g	7.14 x10^{9}	cm/s
Confinement factor	Γ	0.03	-
Photon decay rate	γ_p	5 x10^{11}	sec^{-1}
Number of carrier at transparency	N_{tr}	1.8 x10^{18}	cm^{-3}
Effective gain factor	g_0	0.414*10-16	
Density of Quantum Dot	N_d	$2*10^{14}$	cm^{-3}

In this work we analyze theoretically, the performance of a short cavity of quantum dot semiconductor laser with optical feedback. The values of external short cavity in this search depend on suggested values (1.5,2.25,3,4.5,6 and 7.5cm) and experimental data (10 cm)[16].

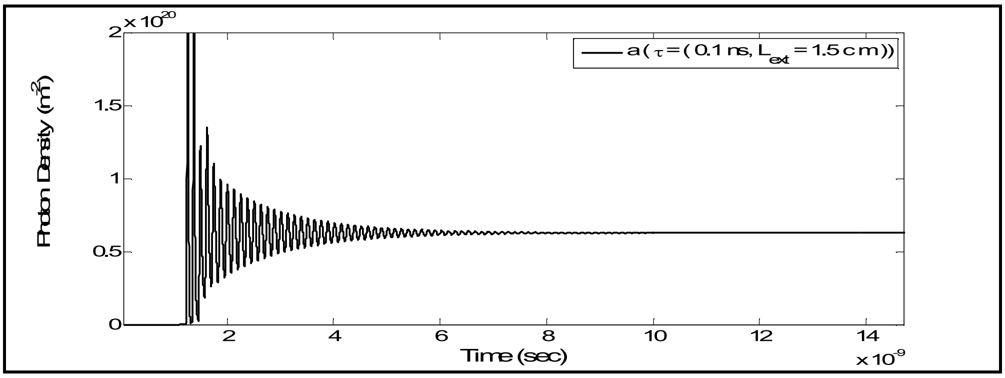
Results and Discussion:

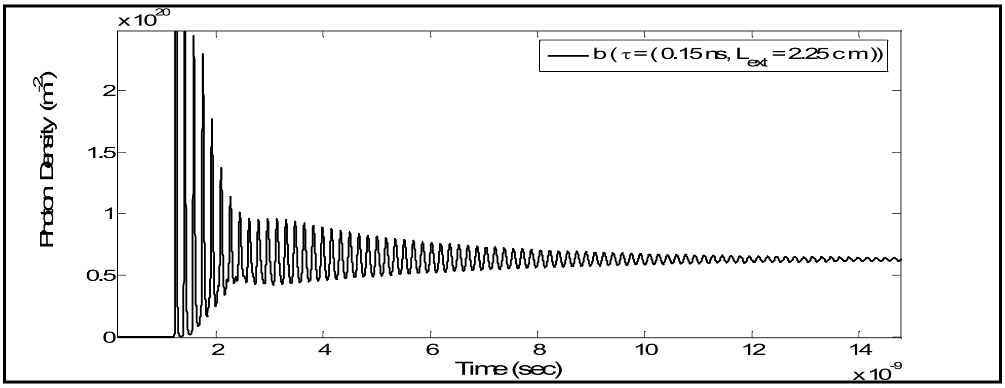
The dynamics of QDSL under the effect of short External cavity length and linewidth enhancement factor of Quantum Dot Semiconductor lasers(QDSL) are studied by solving the set of rate equations (1-3) that takes into account both photon density, occupation probability and carrier number using the fourth-order Runge-Kutta numerical method and Matlab.

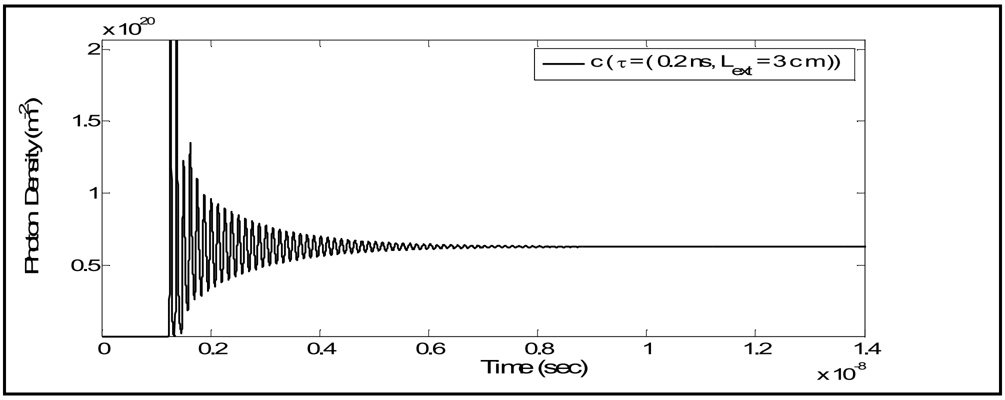
The External cavity semiconductor laser investigated here by two value of linewidth enhancement factor (α=2,4)and change external cavity round-trip time. For a small delay time (0.1- 0.66 ns, L_{ext}= 1.5-10 cm) that means short external cavity. the effect of the optical feedback on the dynamics is not distinct and the feedback increases the laser output slightly over that in the free-running condition. With the increase of the delay time, the laser output shows regular pulsing with constant pulse peak intensity.

Short External cavity (when $\alpha=2$):

Fig (1-a) shows the photon density of (QDSL) as a function of time when $\alpha=2$, ($\tau=0.1ns$, $L_{ext}=1.5cm$), photon density reach to ($13.7*10^{20}$ m^{-2}) and reduced to ($1*10^{20}$ m^{-2}) at steady state. the behavior is similar to Figure (1-b,c) when ($\tau=0.15ns$, $L_{ext}=2.25cm$), ($\tau=0.2ns$, $L_{ext}=3cm$) respectively . on Figure (1-d) show output photon density not stable after (1ns), chaotic behavior to (5 ns) when, ($\tau=0.3ns$, $L_{ext}=4.5cm$) and small different behavior on Figure (1-e). for Figures (1,f,g) output photon density not stable after (1ns to 8 ns and 1ns to 15 ns) ($\tau=0.5ns$, $L_{ext}=7.5cm$), ($\tau=0.66ns$, $L_{ext}=10cm$) respectively.







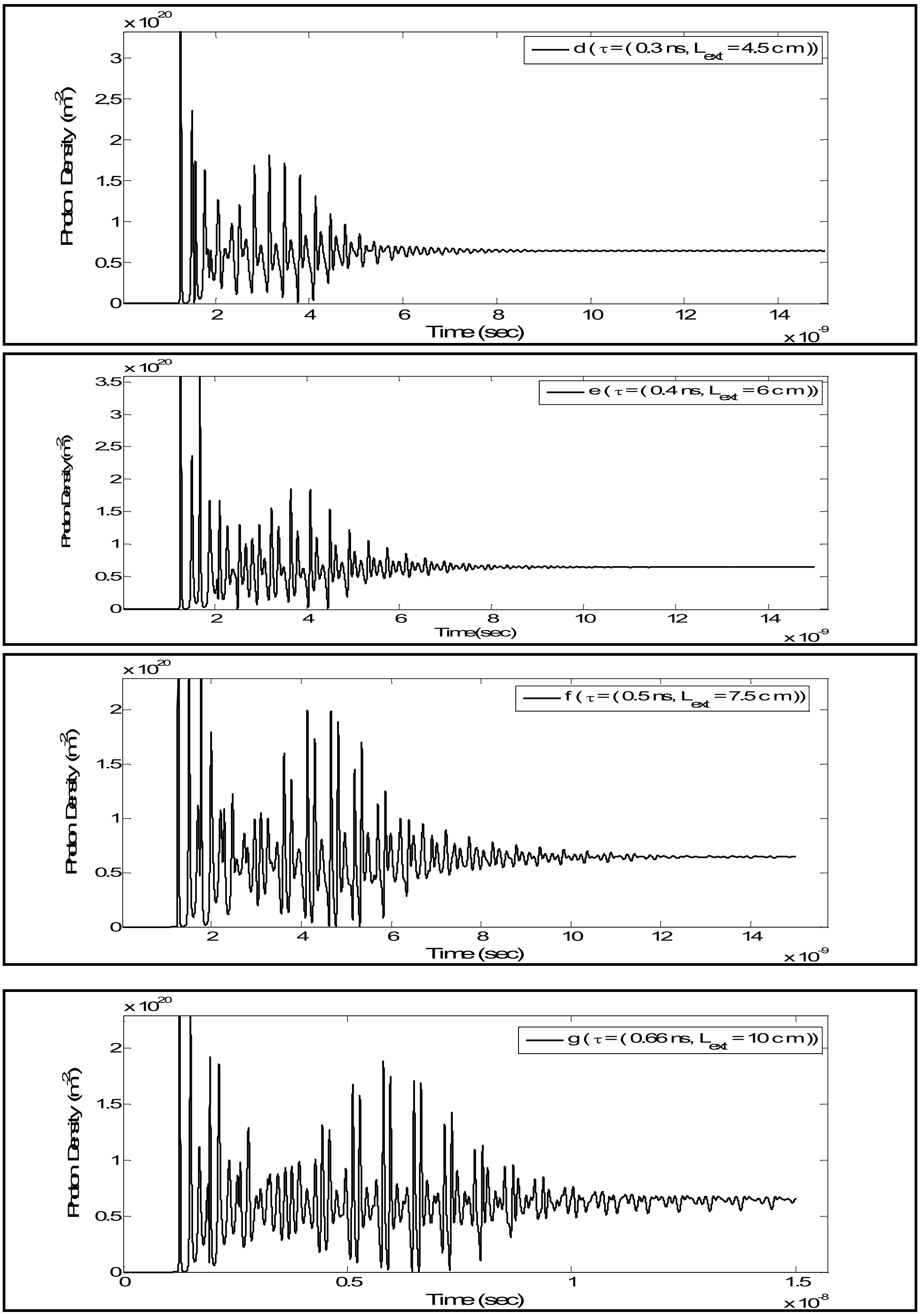


Fig.(1-a,b,c,d,e,f,g): Photon density of (QDSL) as a function of time at various value of external cavity when $\alpha = 2$.

Figures (**2**-h,k) show output photon density with occupation probability when $(\tau = 0.5ns\ , L_{ext} = 7.5cm\ , \alpha = 2)$ and $(\tau = 0.66ns\ , L_{ext} = 10cm\ , \alpha = 2)$ respectively. The behavior of output photon density in Fig.(1-g,h) is a chaotic behavior as a results from Fig.(1-f,k), same behavior of occupation probability when $(\tau = 0.5ns\ , L_{ext} = 7.5cm\ , \alpha = 2)$ and $(\tau = 0.66ns\ , L_{ext} = 10cm\ , \alpha = 2)$ respectively, that mean one used these results for applications field like chaos communication.

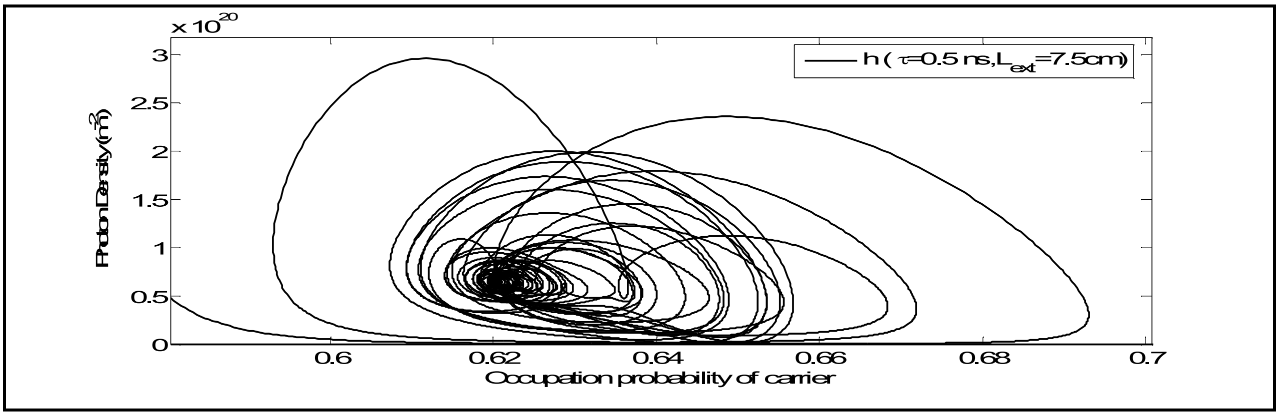


Fig.(2-h) Photon density of (QDSL) as a function of Occupation probability . when $(\tau = 0.5ns\ , L_{ext} = 7.5cm\ , \alpha = 2)$.

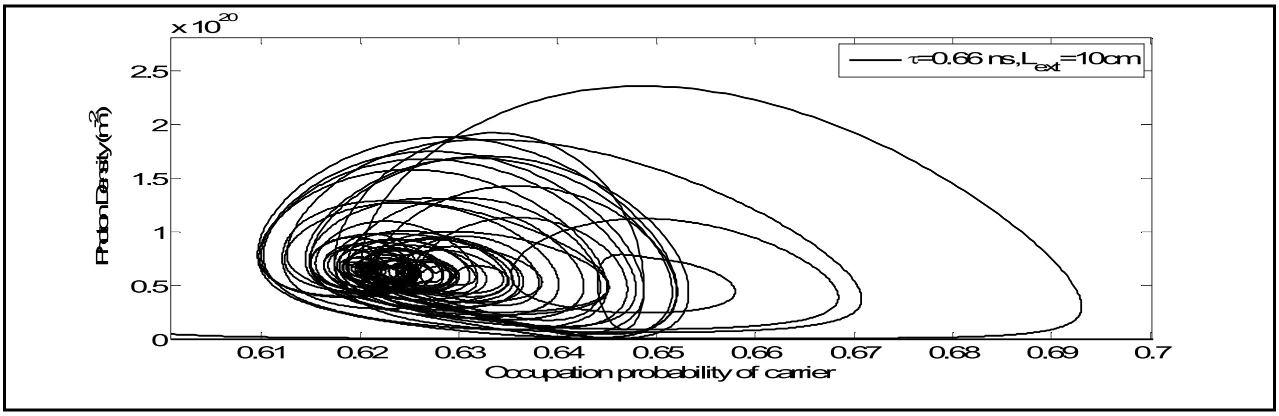
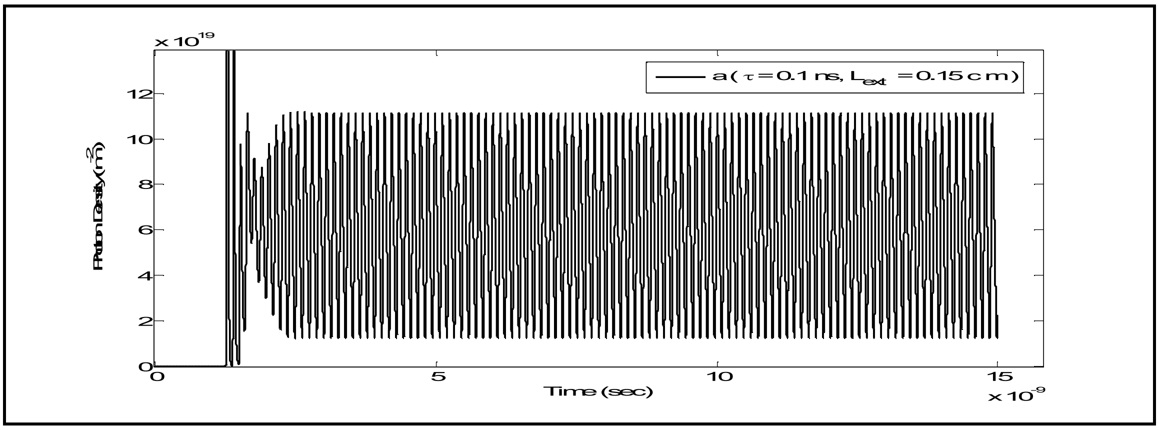
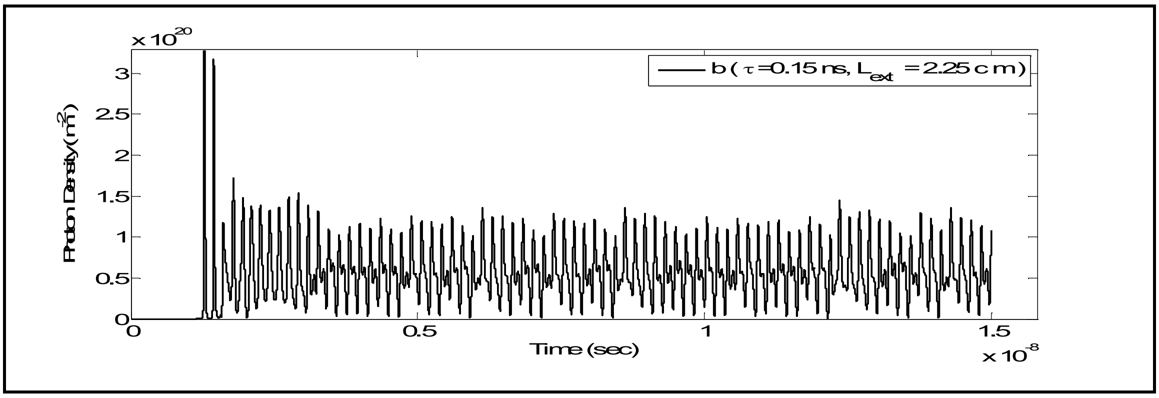


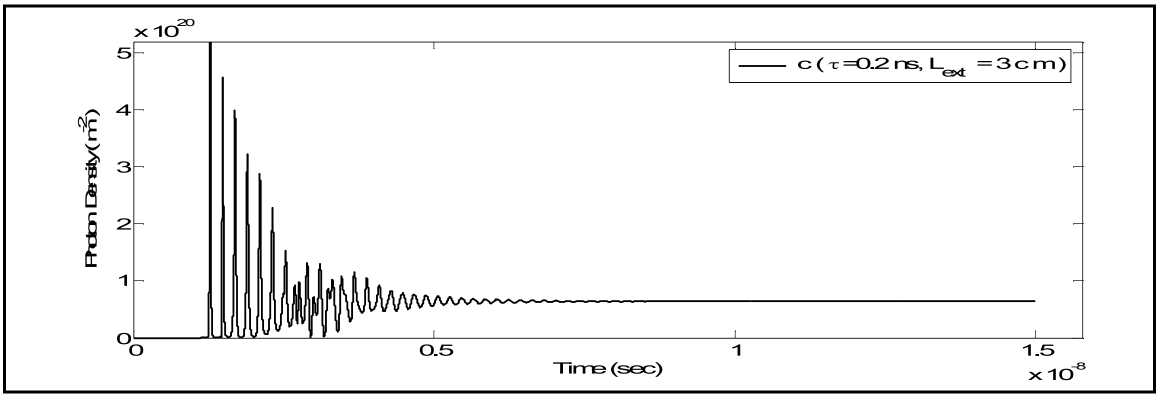
Fig.(2-k) Photon density of (QDSL) as a function of Occupation probability . when $(\tau = 0.66ns\ , L_{ext} = 10cm\ , \alpha = 2)$.

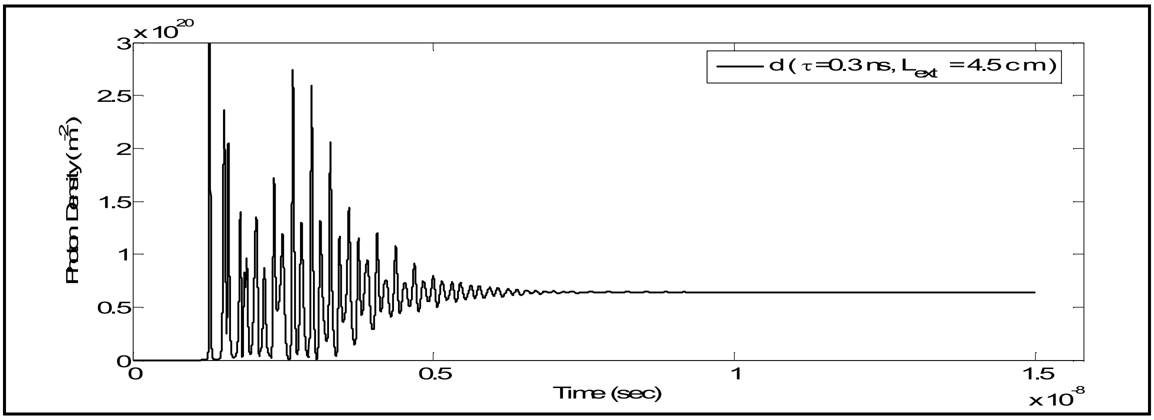
1- Short External cavity (when $\alpha = 4$):

We choose same values of external cavity in (cm), delay time of (ns) and change value of linewidth enhancement factor of Quantum Dot Semiconductor lasers(QDSL) $\alpha = 4$. For the sake of simplicity and numerical purpose, we notice different change for dynamic of output photon density, occupation probability and carrier number. Fig (3-a) shows the photon density of (QDSL) as a function of time when $\alpha = 4$, $\tau = 0.1ns$, $L_{ext} = 1.5cm$, photon density reach to (13.9*10^{20} m^{-2}) and reduced to (1.1*10^{20} m^{-2}) at steady state behavior stable after (2 ns). chaotic behavior in Figure (3-b) when $\alpha = 4, \tau = 0.15ns$, $L_{ext} = 2.25cm$ and no stable steady state, Fig (3-b) is a special state for chaotic behaviour, this result benefit to choose good values of parameter for application in communications. In Fig (3-c,d) show output photon density stable after (5,7 ns), a weak chaotic for $\tau = 0.2ns$, $L_{ext} = 3cm$ and $\tau = 0.3ns$, $L_{ext} = 4.5cm$ respectively. Fig (3-e,f,g) show output photon density for $(\tau = 0.4ns\ , L_{ext} = 6cm\ , \tau = 0.5ns\ , L_{ext} = 7.5cm\ , \tau = 0.66ns\ , L_{ext} = 10cm\ )$ respectively, chaotic behavior is clearly on these Figures after (1.2 ns) for a short external cavity and the results are in agreement with our conclusions from the above results, when $\alpha = 2$.


x 10^19
Photon Density (m^-2)
a (τ =0.1 ns, L_ext =0.15 cm)
Time (sec)
x 10^-9


x 10^20
Photon Density (m^-2)
b (τ =0.15 ns, L_ext =2.25 cm)
Time (sec)
x 10^-8


x 10^20
Photon Density (m^-2)
c (τ =0.2 ns, L_ext =3 cm)
Time (sec)
x 10^-8


x 10^20
Photon Density (m^-2)
d (τ =0.3 ns, L_ext =4.5 cm)
Time (sec)
x 10^-8

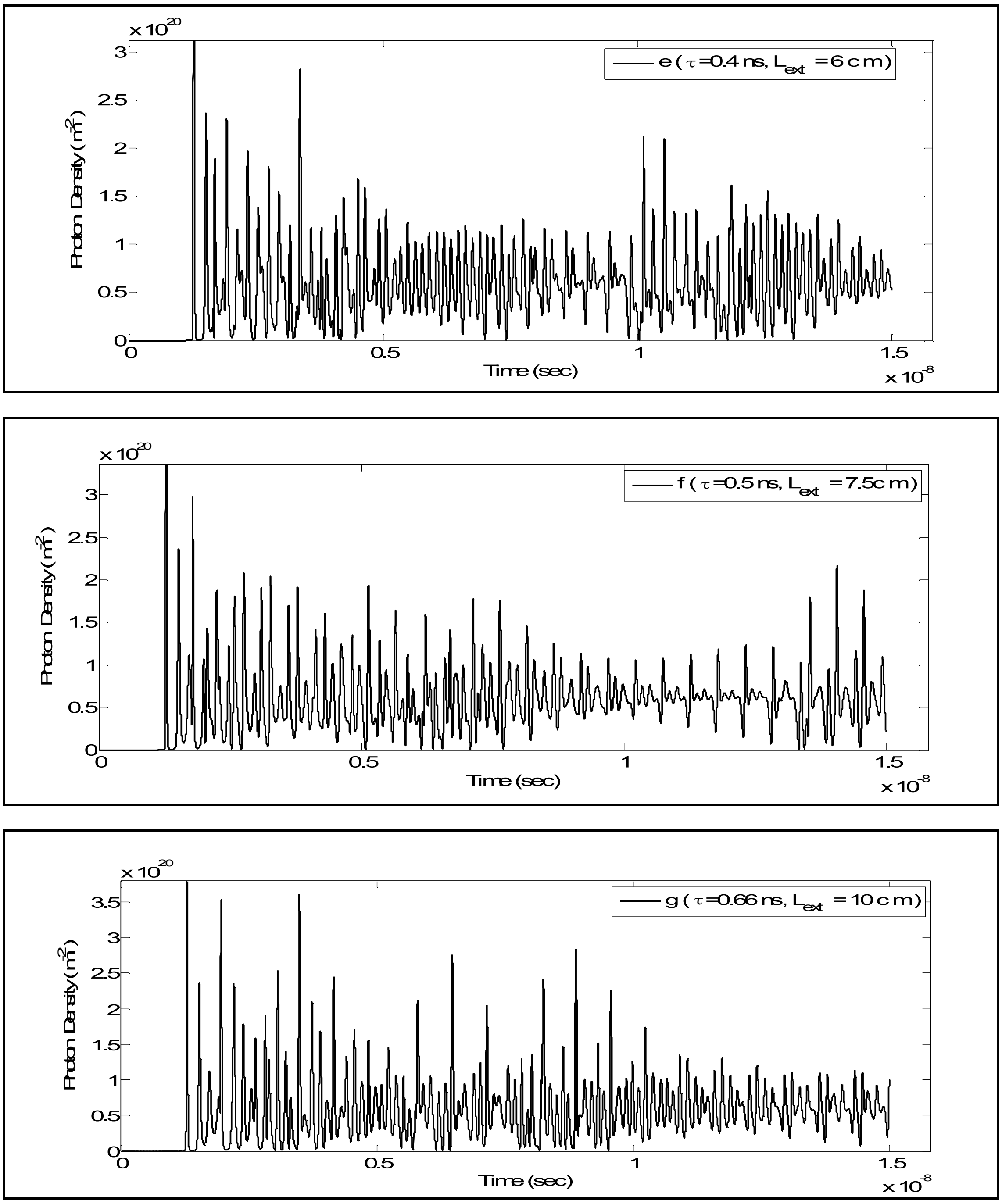


Fig.(3-a,b,c,d,e,f,g): Photon density of (QDSL) as a function of time at various value of external cavity when $\alpha = 4$.

Figure (3-h,k) show relation between output photon density when $(\tau = 0.5ns\ , L_{ext} = 7.5cm\ , \alpha = 4)$ and $(\tau = 0.66ns\ , L_{ext} = 10cm\ , \alpha = 4)$ respectively, chaotic behavior on Figures and cant determined exact value of output photon density[17-34],it is oscillate at a long values of occupation probability, that means values of occupation probability not stable and agree result with Fig.(2-h,k) .

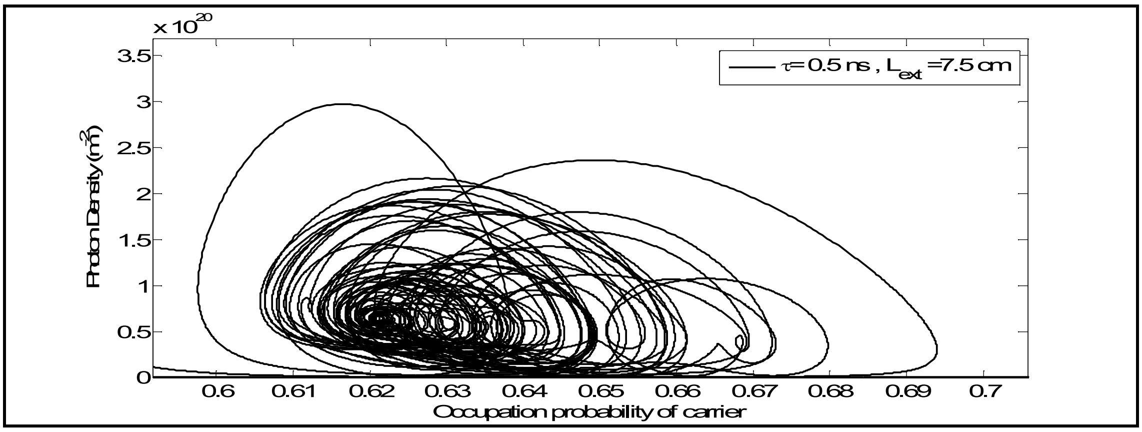


Fig.(3-h) Photon density of (QDSL) as a function of Occupation probability . when $(\tau = 0.5ns\,, L_{ext} = 7.5cm\,, \alpha = 2)$.

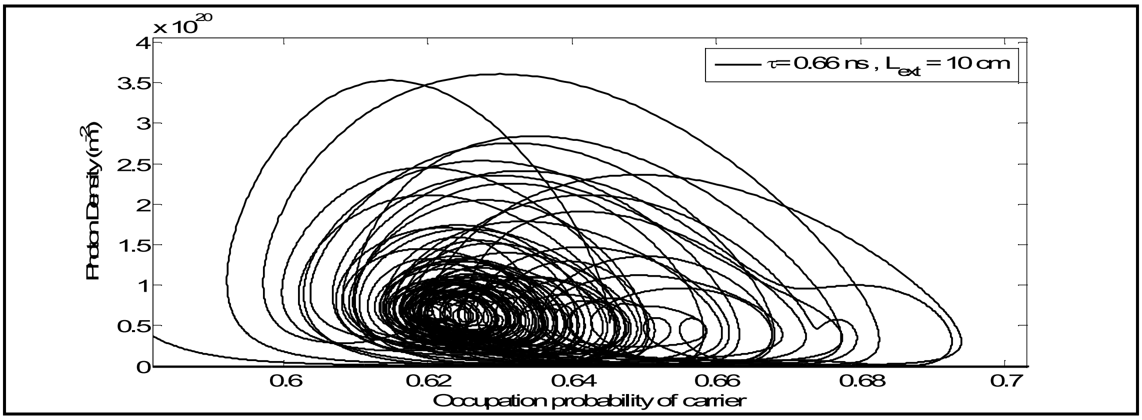


Fig.(3-k) Photon density of (QDSL) as a function of Occupation probability . when $(\tau = 0.66ns\,, L_{ext} = 10cm\,, \alpha = 2)$.

Conclusions:

The effect of short External cavity length on Quantum Dot Semiconductor lasers with Optical Feedback dynamics are studied in this search with two values of Linewidth enhancement factor (2,4) ,a good behaviour of chaotic when short external cavity (L_{ext}=7.5 and 10 cm) for Linewidth enhancement factor =2, and (L_{ext}=2.25,6,7.5 and 10 cm) for Linewidth enhancement factor =4.

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