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Crisis Route regions on Synchronization of Quantum Dot Semiconductor lasers mutual coupling system with optical feedback

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Abstract: **Quantum Dot Semiconductor lasers (QDSL) with optical feedback have been intensively used a mutual coupling of communication system. This system consists of transmitter and receiver quantum dot lasers. Rate equations for two lasers are solved to study relation between photon density and time. Time delay of the feedback has been chosen to provide suitable condition for intermittent dynamics and crisis regions. The effect of long external cavity of QDSL on synchronization in a mutual coupling system is studied with enhancement factor of** $(\alpha=3)$**.**

1. Introduction

For the control of chaos in different dynamical systems, Chaotic synchronization has attracted more interest for applications in the field of private communication[1]. Since the past few years synchronization phenomena in quantum dot laser, chaotic has been a topic of increasing interest. This interest for sensitive to external perturbation as optical feedback. Many studies expected benefits including elimination of lasers [2].

Crisis-induced intermittency is a dynamical phenomenon seen throughout various domains of physics and is characterized by the sudden appearance of irregular bursts from a regular evolution when the value of a control parameter is varied. The system is then governed by an alternation of two dynamics, corresponding to intermittent evolutions on two distant sub-attractors (attractor expansion) or two coexisting attractors (attractor merging) [3].

Quantum Dots (QDs) are a semiconductor particles in order of few nanometers (2-10 nm) such confined electrons and holes in three dimensions [4]. The idea of chaos synchronization between two nonlinear systems was proposed by (Pecora and Carroll), They used a Lorenz system with three variables for the demonstration [5]. the characteristic of quantum dot semiconductor laser (QDSL) are high characteristic temperature, Low threshold current density and small linewidth enhancement factor (LEF) [6]. Therefore, the synchronization scheme is called complete chaos synchronization and it is distinguished from generalized synchronization of chaotic oscillations [7].

quantum dot (QD) Nano structures used on telecommunication applications due to the carrier confinement in three dimensions[8,9].The output of QD laser under optical feedback is known carrier dynamics [10] and optical injection[11] crucially.

When used with optoelectronic feedback circuits, QDSLs are more sensitive to time delay changes than other SLs [12]. Two different origins of chaos synchronization in nonlinear delay differential systems, complete and generalized chaos synchronization. In generalized chaos synchronization, the receiver outputs a synchronized wave form immediately after it receives the transmitter signal, therefore there is a time lag between the two outputs. On the other hand, a synchronous chaotic signal in the receiver is generated in advance to receiving the transmitter signal for complete chaos synchronization. The time lag for signal transmission between the transmitter and receiver systems is larger than the complete chaos synchronization [13].we looking for complete chaos with synchronization, that's a Good result for communications.

2- Rate equation of Quantum Dot Laser:

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). Carriers at first are injected into a wetting layer before actuality captured into a dot at a capture rate that depends strongly on the dot population. The rate equations are given in (1-3) shown below [14, 15].Thus, rate equations that commonly describe carrier dynamics of QD materials read [16],

$$\frac{dE_{(T,R)}}{dt}=E_{(T,R)}\left(-\frac{1}{2t_s}+\frac{g_o\upsilon}{2}(2\rho_{(T,R)}-1)\right)+\frac{\gamma}{2}E_{(T,R)}(t-\tau_{(T,R)})+\frac{\gamma}{2}E_{(T,R)}(t-\tau_c)+R_{sp} \quad (1)$$

$$\frac{d\rho_{(T,R)}}{dt}=-t_n\,\rho_{(T,R)}-g_o(2\rho_{(T,R)}-1)\left|E_{(T,R)}\right|^2+CN^2_{(T,R)}(1-\rho_{(T,R)}) \quad (2)$$

$$\frac{dN_{(T,R)}}{dt}=J_{(T,R)}-\frac{N_{(T,R)}}{t_d}-2n_d\,CN^2_{(T,R)}(1-\rho_{(T,R)}) \quad (3)$$

where $N^{(T,R)}$ is the carrier density in the well for two lasers, $E^{(T,R)}$ is the complex amplitude of the electric field for two lasers, $\rho_{(T,R)}$ is the probability in a dot for two lasers, t_s is the photon lifetime; t_n and td are the carrier lifetime in the well and the dot, respectively; n_d is the 2D density of dots; and $J_{(T,R)}$ is the pump. γ and $\tau_{T,R}$ describe the feedback level and delay time for transmitter and receiver lasers respectively , where τ =2L/c is the time delay of light within the external cavity (L) and c velocity of light[15] . C is Auger carrier capture rate [16].
In this work we analyze theoretically, mutual coupling system; may be consist of one of two type of synchronization as complete and general for transmitter and receiver quantum dot semiconductor lasers with optical feedback. Same two laser on linewidth enhancement factor (equal to 3), current density, and different on coupling time delay between two lasers transmitter and receiver τ_c.

3- Results and Discussion:

The account both photon density, occupation probability, carrier number and attractor using the fourth-order Runge-Kutta numerical method and Matlab.
Fig (1-a) shows the photon density of (QDSL) as a function of time when $\alpha=3$, ($\tau=130\,ns$) photon density reach to ($18*10^{20}$ m^{-2}) and reduced to a stable at steady state. Not periodic behavior for transmitter and receiver of (QDSL) and attractor between photon density of receiver laser and transmitter laser is clearly not periodic with complete synchronization in Fig (1-b).Fig (1-c,e) time series for photon density of transmitter and receiver (QDSL) laser when $\alpha=3$, ($\tau=132\,ns$) chaotic behavior and periodic at steady state. Fig (1-d,f) chaotic attractor with no synchronization and complete synchronization respectively. From Fig (1-a,c,e) notice that change on time delay by (3ps),that good results to use on application.

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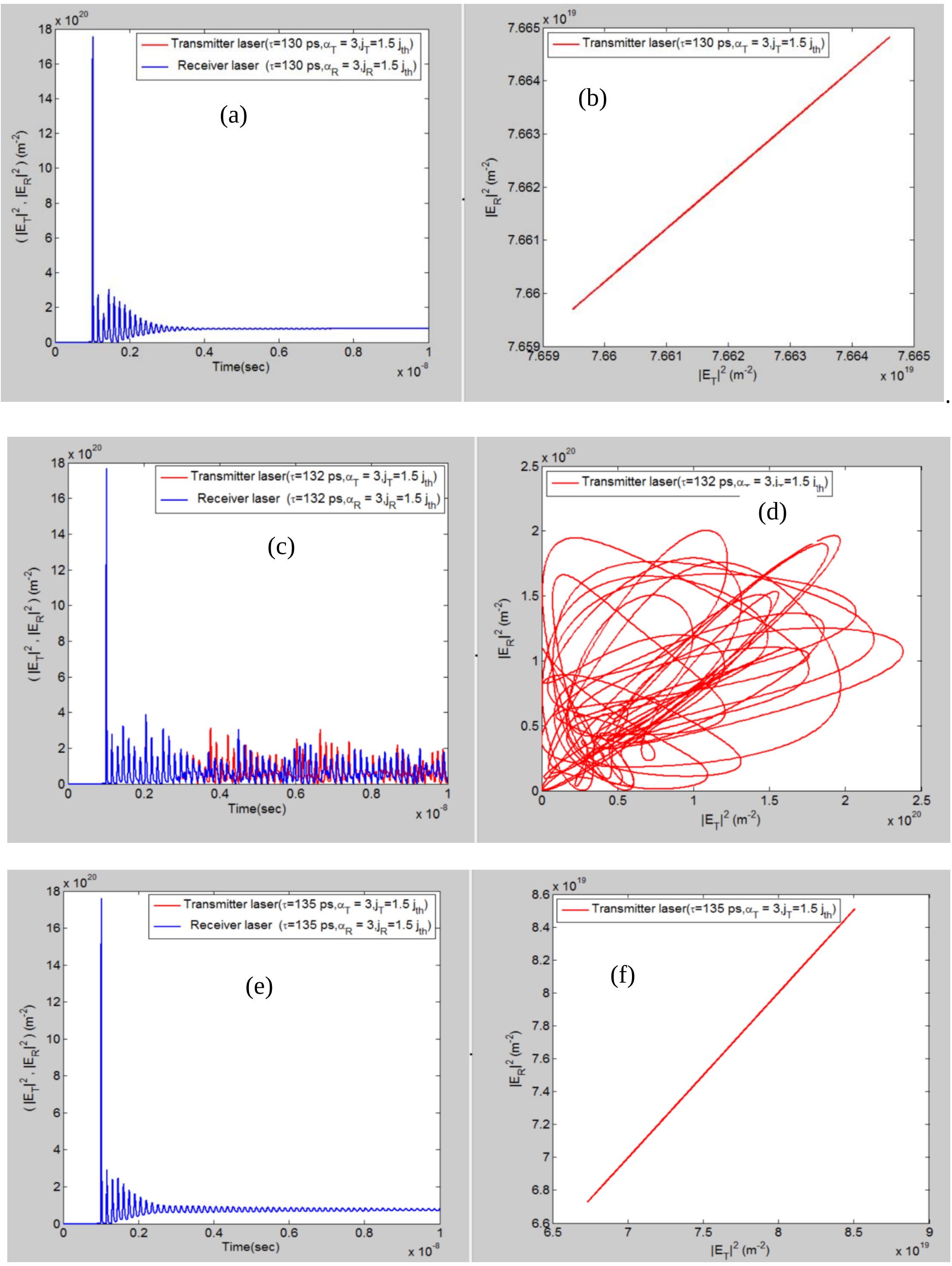

Fig.(1): Photon density of transmitter and receiver (QDSL) as a function of time at various value of time delay as in (a,c,e) ,stable, chaotic attractor, stable for Photon density of transmitter as a function of photon density of receiver (QDSL) as in (b)complete synchronization,(d) chaotic, (f) complete synchronization.

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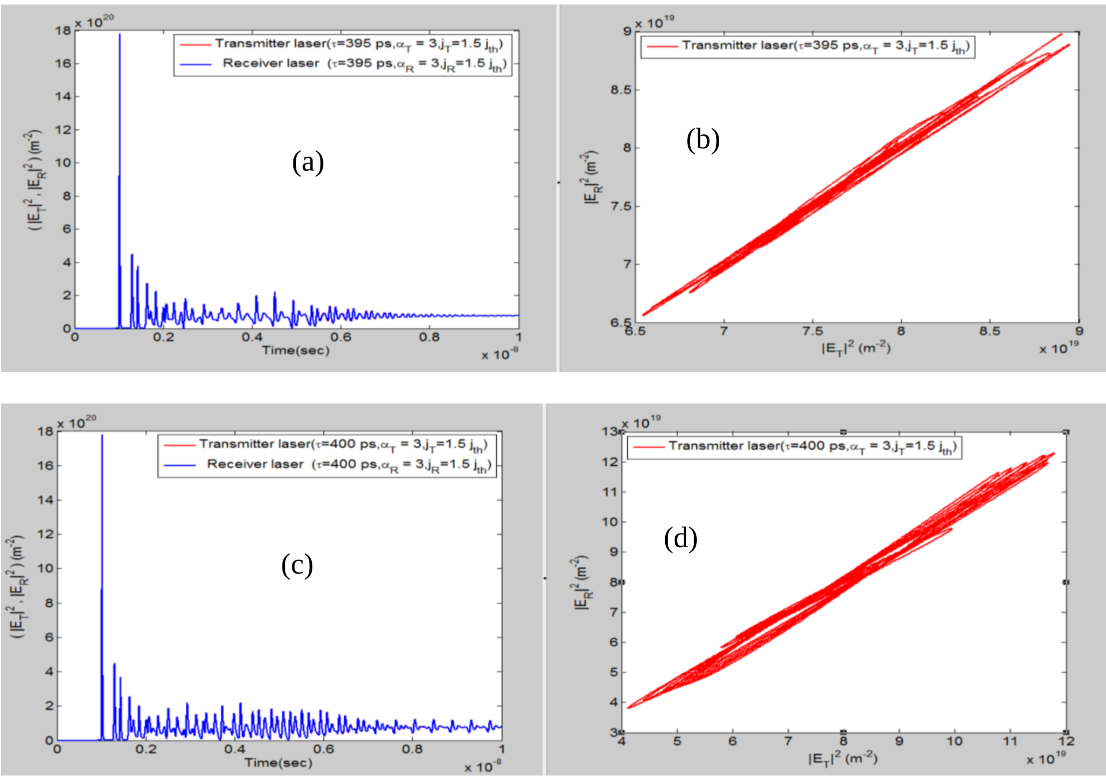
Fig (2-a) shows the photon density of (QDSL)as a function of time when $\alpha=3$, $(\tau=395ns)$, photon density reach to ($18*10^{20}$ m^{-2}) and chaotic behavior for transmitter and receiver of (QDSL) and attractor between photon density of receiver laser and transmitter laser is clearly chaotic with unsynchronization in Fig (2-b). Multi chaotic behavior for transmitter and receiver of (QDSL) and attractor between photon density of receiver laser and transmitter laser is clearly chaotic with unsynchronization in Fig (2-c,d) when $(\tau=400ns)$.A good chaotic behavior for transmitter and receiver of (QDSL) and attractor with complete synchronization between photon density of receiver laser and transmitter laser is clearly in Fig (2-e,f) when $(\tau=410ns)$. Change on time delay by (5ps), that good results to use on application. When $(\tau=415ns)$and$(\tau=420ns)$, chaotic behavior in Fig (2-g,i) and general synchronization and complete synchronization in Fig (2-h,j).A good results when$(\tau=410ns)$ *and* $(\tau=420ns)$ with complete synchronization.



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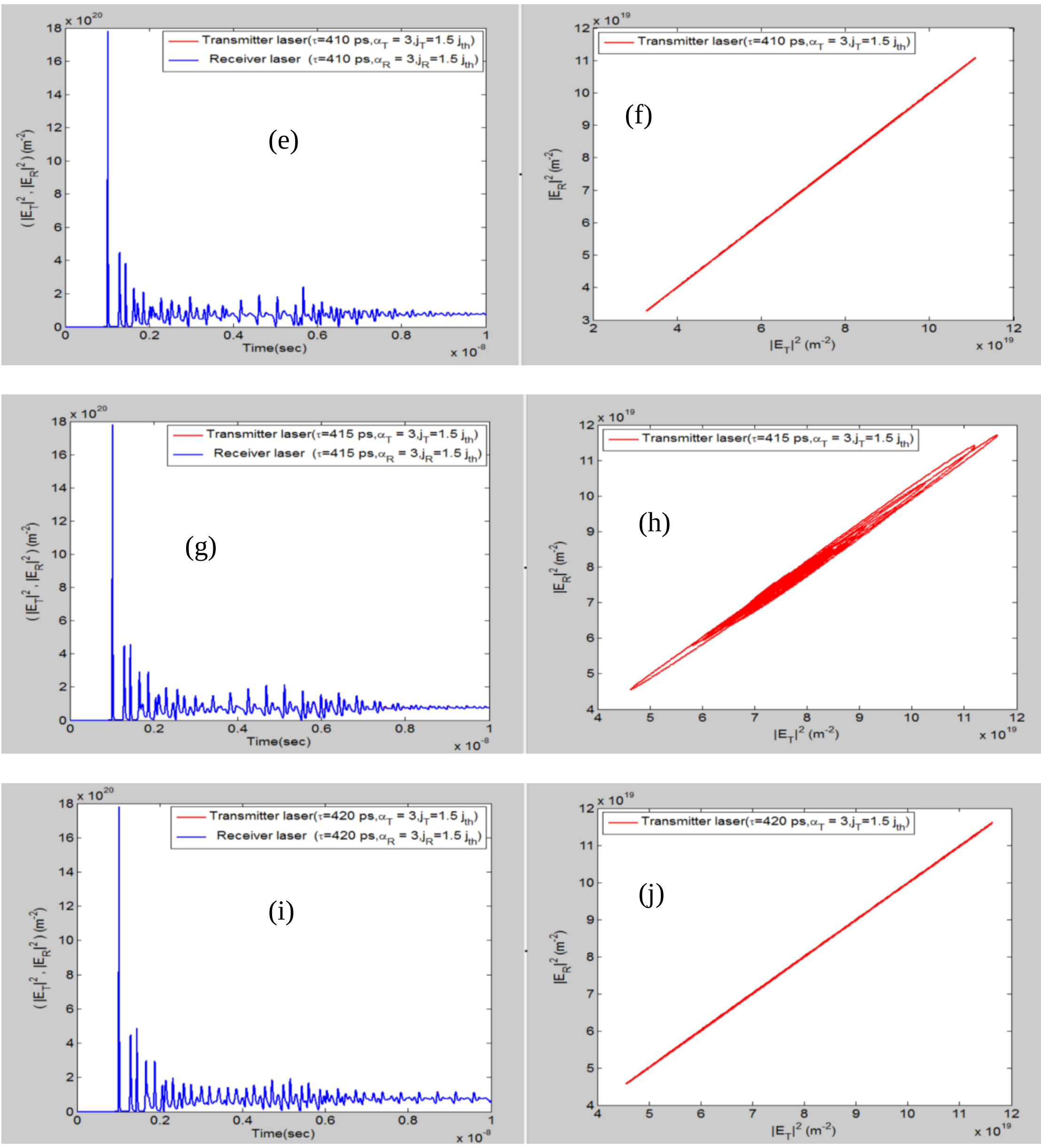

Fig.(2): Photon density of transmitter and receiver (QDSL) as a function of time at various value of time delay as in (a,c,e,g) ,(b,d,h): chaotic attractor, (f,j):complete attractor synchronization for Photon density of transmitter as a function of photon density of receiver (QDSL) .

From table (1), first region crisis Confined between $(\tau = 110\,ps)$ and end at time delay $(\tau = 120\,ps)$ by different change of time delay (5,2,1ps) respectively. Many type of synchronization (general and complete) with different behavior of photon density (periodic, multi periodic and chaos) depend on change of time delay.

Table (1) first region of crisis.

$[\tau_T = \tau_R\ (ps)]$	$(J_T = J_R)$	$(\alpha_T = \alpha_R)$	Remark	Type of synchronization
100	$1.5J_{th}$	3	synchronization	Complete (periodic)
105	$1.5J_{th}$	3	No synchronization	Chaos (multi periodic)
110	$1.5J_{th}$	3	synchronization	stable
112	$1.5J_{th}$	3	No synchronization	Chaos
115	$1.5J_{th}$	3	synchronization	stable
117	$1.5J_{th}$	3	synchronization	stable
118	$1.5J_{th}$	3	No synchronization	General (multi periodic)
119	$1.5J_{th}$	3	No synchronization	Chaos (multi periodic)
120	$1.5J_{th}$	3	synchronization	Complete (periodic)

Second region crisis Confined between $(\tau = 120\,ps)$ and end at time delay $(\tau = 135\,ps)$ by different change of time delay (5ps). One type of complete synchronization with different behavior of photon density (stable, chaos) depend on change of time delay as in table (2).

Table (2) second region of crisis.

$[\tau_T = \tau_R\ (ps)]$	$(J_T = J_R)$	$(\alpha_T = \alpha_R)$	Remark	Type of synchronization
125	$1.5J_{th}$	3	No synchronization	chaos
130	$1.5J_{th}$	3	synchronization	Complete (stable)
132	$1.5J_{th}$	3	No synchronization	Chaos
135	$1.5J_{th}$	3	synchronization	Complete (stable)

Third region crisis Confined between $(\tau = 138\,ps)$ and end at time delay $(\tau = 140\,ps)$ by different change of time delay (2ps). Two type of synchronization (general and complete) with different behavior of photon density (periodic and chaos) depend on change of time delay. Table (3) show that synchronization of all values of time delay except $(\tau = 138\,ps)$.

Table (3) third region of crisis.

$[\tau_T = \tau_R\ (ps)]$	$(J_T = J_R)$	$(\alpha_T = \alpha_R)$	Remark	Type of synchronization
138	$1.5J_{th}$	3	No synchronization	General chaos
140	$1.5J_{th}$	3	synchronization	Complete(period)
142	$1.5J_{th}$	3	synchronization	General (period)
143	$1.5J_{th}$	3	synchronization	Complete
145	$1.5J_{th}$	3	synchronization	General (period)

Fourth region crisis Confined between $(\tau = 150\,ps)$ and end at time delay $(\tau = 161\,ps)$ by different change of time delay (1,5,1ps) respectively . Two type of synchronization (general and complete) with different behavior of photon density (periodic, quasi period and chaos) depend on change of time delay. Table (4) show that synchronization of all values of time delay except $(\tau = 153ps)$ and $(\tau = 160ps)$.

Table (4) fourth region of crisis.

$[\tau_T = \tau_R\ (ps)]$	$(J_T = J_R)$	$(\alpha_T = \alpha_R)$	Remark	Type of synchronization
150	$1.5J_{th}$	3	synchronization	Complete
151	$1.5J_{th}$	3	synchronization	General (period)
152	$1.5J_{th}$	3	synchronization	General (period)
153	$1.5J_{th}$	3	No synchronization	General (chaos)
154	$1.5J_{th}$	3	synchronization	General (period)

155	$1.5J_{th}$	3	synchronization	Complete
160	$1.5J_{th}$	3	No synchronization	Chaos
161	$1.5J_{th}$	3	synchronization	General (quasi period)

Fifth region crisis Confined between $(\tau = 165\,ps)$ and end at time delay $(\tau = 250 ps)$ by different change of time delay (5,10,50 ps) respectively . Two type of synchronization (general and complete) with different behavior of photon density (multi period and chaos) depend on change of time delay as an table (5).

Table (5) fifth region of crisis.

$[\tau_T = \tau_R\ (ps)]$	$(J_T = J_R)$	$(\alpha_T = \alpha_R)$	Remark	Type of synchronization
165	$1.5J_{th}$	3	synchronization	Complete
170	$1.5J_{th}$	3	synchronization	Complete
190	$1.5J_{th}$	3	synchronization	General
195	$1.5J_{th}$	3	synchronization	General (multi periodic)
200	$1.5J_{th}$	3	No synchronization	General (chaos)
250	$1.5J_{th}$	3	No synchronization	(chaos)

Table (6) six region of crisis.

$[\tau_T = \tau_R\ (ps)]$	$(J_T = J_R)$	$(\alpha_T = \alpha_R)$	Remark	Type of synchronization
300	$1.5J_{th}$	3	synchronization	Complete
305	$1.5J_{th}$	3	synchronization	General (multi periodic)

310	$1.5J_{th}$	3	synchronization	Complete
350	$1.5J_{th}$	3	No synchronization	Chaos

Table (7) seven region of crisis.

$[\tau_T = \tau_R\ (ps)]$	$(J_T = J_R)$	$(\alpha_T = \alpha_R)$	Remark	Type of synchronization
390	$1.5J_{th}$	3	No synchronization	Chaos
400	$1.5J_{th}$	3	No synchronization	General (multi periodic)
410	$1.5J_{th}$	3	synchronization	Complete
415	$1.5J_{th}$	3	synchronization	General (multi periodic)
420	$1.5J_{th}$	3	synchronization	Complete

4- Conclusions:

The effect of time delay on Quantum Dot Semiconductor lasers with Optical Feedback dynamics are studied in this search with one value of Linewidth enhancement factor (3), seven regions of crisis route on synchronization of quantum dot semiconductor laser by mutual system coupling, these region depend on time delay. Critical behaviour of chaotic when long external cavity and good complete synchronization. A good results use applications communication by coding and decoding signal when $(\tau = 410\,ps)$ *and* $(\tau = 420\,ps)$ **with complete synchronization.**

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