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ISSN –1817 –2695

Directed Modulation of Quantum Dash Se miconductor Laser

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Received 22-2-2014 , Accepted 21-5-2014

Abstract :

A numerical study of the effect of injection current modulation on the dynamics of a quantum dash semiconductor laser is presented . The control parameters chosen to affect the temporal intensity variation are the gain , the dc and ac parts of the injection current , the modulation frequency ,carrier escape rate and ratio of carrier to photon decay rates . Various output ranging from single pulses to chaotic one produced.

Key words: Quantum dash semiconductor laser, Injection current modulation, Chaotic dynamics.

Introduction:

It is well understood today that the direct modulation of the semiconductor laser SCL adds the necessary degree of freedom (since SCLs belong to the class B lasers because the polarization relaxation rate is much larger than those of electric field and population inversion) that makes possible the occurrence of instabilities that leads to chaos [1]. The modulation response of SCLs has been studied [2]. The relaxation – oscillation frequency of SCLs usually fall in the GHz frequency domain and they show maximum response to modulation in these regimes[3] . SCLs have a good modulation bandwidth in the order of 10 GHz which makes them useful in the optical communication of ultra high bit rates .Quantum dash Q Dash SCLs dynamics needs more study on the effect of injection current modulationsince they offer many advantages over the traditional doubleheterostructure(DH)and the quantum well(QW) lasers such as largecharacteristic temperature (T_o) , low threshold current ,small line- width enhancement factor , resistance to optical feedback ,high modulation bandwidth, and ultrafast operation [4] . Their structure exhibits clear linear polarization , which is an advantage to reduce the bit rate error in device operation [5] .

Our attempt in this article is to understand the response of a Q Dash SCL by direct injection current modulation.

Laser model :

Q-Dash SCLwith direct modulation can be well represented by the following rate equations for the light intensity (I) , the occupation probability (ρ) and the number of carriers (n) in the wetting layer introduced first by O'Brien etal [6] and rewritten by Erneuxetal [7] :

$\dot{I}$=[-1+g(2ρ-1)]I…………………………………………………(1)

$\dot{\rho}$=η[Bn(1-ρ)-Rρ-ρ-(2ρ-1)I]…………………… …………(2)

$\dot{n}$=η[J-n-2Bn(1-ρ)-2Rρ]………………………………………(3)

J=J_b+J_a sin(2πft)…………………………………………………(4)

where (1-ρ) is the Pauli blocking factor , Bn describes the carrier capture with rate B, and R describes the carrier escape from the dots to the wetting layer . The factor 2 in equation (3) accounts for two fold spin degeneracy in the quantum dot energy levels and a similar factor is included in the definition of the gain (g). The parameter (η) is the ratio of the carrier and photon decay rateγ_n and γ_s respectively , (j_b) is the bias dc part of the injection current ,(Ja) is the amplitude and (f) is the frequency of the modulation or the ac part of the injection current.Over dots means differentiation with respect to a normalized time.In QD laser, the role of escape is usually negligible [8]and the damping rate is determined by two processes characterized by the capture rate (B) and the gain factor (g). In the present of escape mechanism , the rate equations (1 – 3) together with equation (4) can be used to describe the Q Dash SCLs dynamics under the effect of the injection current modulation [8].

Result and Discussion:

The rate equations (1)-(4) are solved numerically using the fourth –order Runge – Kutta method and Matlab system for certain chosen initial condition and small step size . The first (0-1000) data have been omitted to study the QDash SCL dynamics when the transient region vanishes, i.e. steady state situation. The parameter values are chosen as follows :

η=10^{-4} - 10^{-3}
g=2 - 4
f=10^{6} - 10^{12} Hz
R=30,50,70
B is taken constant (B=100)
and the injection current components, i.e. dc and ac parts are given in table (1).

Table (1) dc and ac parts of the injection current

dc (J_b)	ac (J_a)		
2	0.5	1	1.5
3	1	2	2.5
4	1	2	3

Numerical results of solving the set of equations (1-4) for the different parameter values are shown in figures (1-14). The laser intensity signal shows varieties of dynamics as follows:

1- R=30, η=10^{-3}, f_m=10^{6} - 10^{12} Hz , J_b=2, 3, 4, J_a=(0.5,1,1.5), (1, 2, 2.5), (1,2,3), g=2- 4 . The results are shown in figs (1-5) . The output intensity started with single pulse followed by multiple pulses the chaos . Some results appeared in the shape of period one , period two , period three , etc . ,and anomalous output as can be seen in fig (5.a) .

2- R=30, η=10^{-4}, f_m=10^{6} - 10^{12} Hz , J_b=2, 3, 4, J_a=(0.5,1,1.5), (1, 2, 2.5), (1,2,3), g=2- 4. The output intensity signals are shown in figures (6,7), it started with the abnormal signal (fig 6.a) then switch's to multiple pulses each have the same shape of the usual output signal that appears when the laser works autonomously. Chaos appeared in different shapes together with bifurcation scenario.

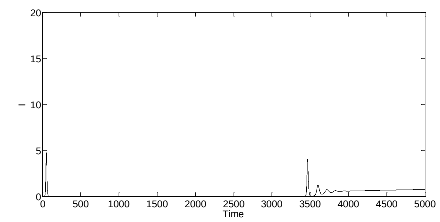
3- R=50, η=10^{-3}-10^{-4} , f_m=10^6 - 10^{12} Hz , J_b=2, 3, 4, J_a=(0.5,1,1.5), (1, 2, 2.5), (1,2,3), g=2- 4.The results are shown in figures (8-11). Once again the output of the laser appeared in different shapes. Multiple signal of different number appeared as a result of variations of the used control parameters, together with period one, period two etc.

4 - R=70, η=10^{-3}-10^{-4}, f_m=10^6 - 10^{12} Hz, J_b=2, 3, 4, J_a=(0.5,1,1.5), (1, 2, 2.5), (1,2,3), g=2- 4. Results are shown in figures(12-14).Various output appears starting with abnormal output, multiple signal output, usual output and chaos. Period one and period two.

5- It is worth to mention that the coherence collapse phenomena or the power dropout occurred as can be seen in figures(2,5,6,9,10,11)

By increasing the injection current density the relaxation oscillation and population inversion in the laser medium increases [9]. The modulation of the injection current will create a spatial grating –like distribution in thepopulation inversion ,the depth and spatial frequency of such a grating depends on the ac part of the injection current and the frequency of modulation . This situation will complicate the state of interaction between the field oscillating in the laser cavity and the population inversion .Such effect creates variations of nonlinearities that appears in different shapes of the laser output signal[3].The injection current has effects on the refraction index of the laser medium, line-width enhancement factor and the cavity length [10]. The dependence of many parameters of the laser medium and cavity on injectioncurrent, has severe effects on the intensity of the laser light and laser medium too [10] there take place both the amplitude and frequency of modulation of the laser radiation spectrum. Relaxation frequency depends on the life time of photons and pumping flux and both are proportional to the injection current density and the spontaneous emission rate .All factors can easily lead the Q Dash SCLs to a variety of dynamics ranges from single pulse, multiple pulses , the steady state behavior to instabilities and chaos.

(a)



(b)

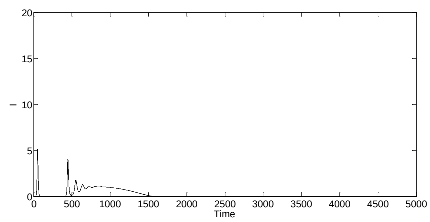


Fig (1) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)
a: R=30, g=2, η=10^{-3},f_m=10^6,J_b=2,J_a=1.5
b:R=30, g=2,η=10^{-3},f_m=10^7,J_b=2,J_a=1.5

(a) **(b)** **(c)**

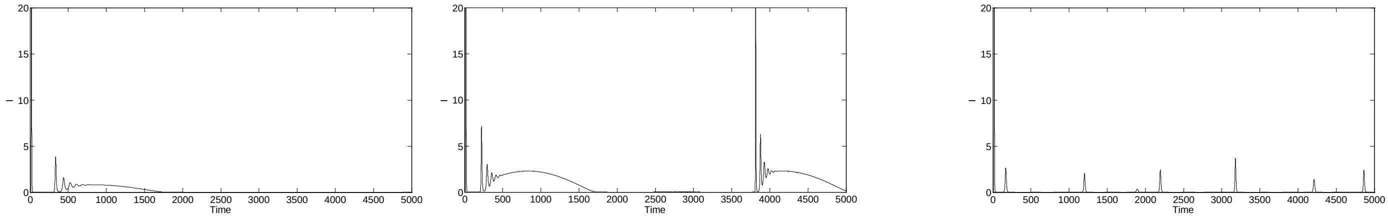


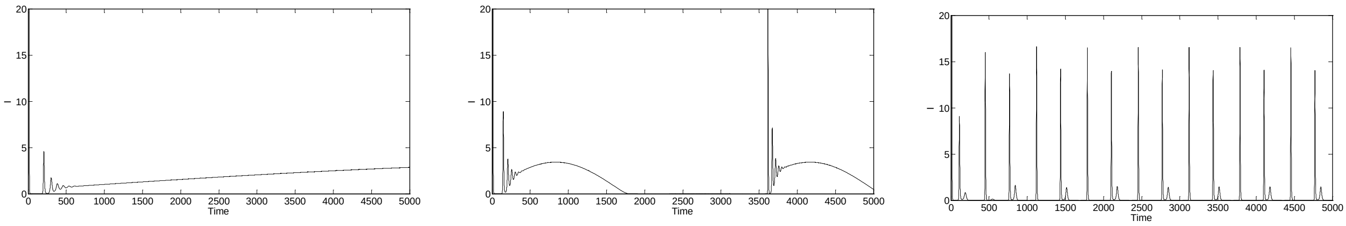
Fig (2) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

a:R=30, g=3, η=10^{-3}=10^{7},J_b=2,J_a=0.5

b:R=30, g=3, η=10^{-3},f_m=10^{7},J_b=2,J_a=1.5

c:R=30, g=3, η=10^{-3},f_m=10^{8},J_b=2,J_a=0.5

(a) **(b)** **(c)**



(f) **(e)** **(d)**

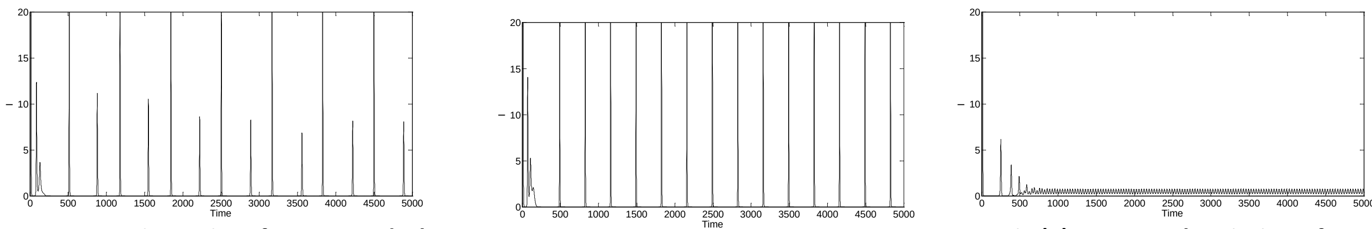
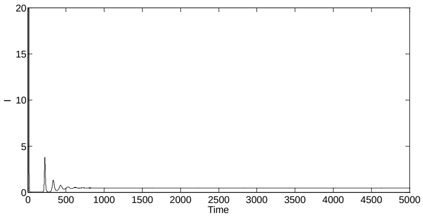


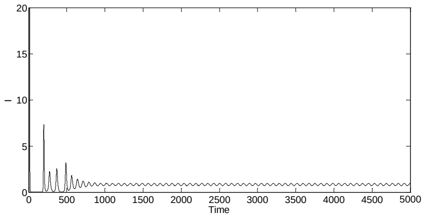
Fig (3) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

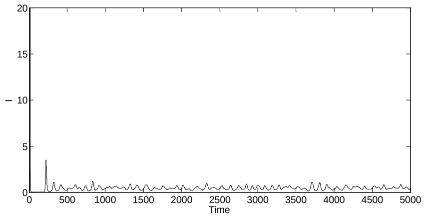
a:R=30, g=4,η=10^{-3},f_m=10^{6},J_b=2,J_a=1.5,b: R=30, g=4, η=10^{-3},f_m=10^{7},J_b=2,J_a=1.5 c: R=30, g=4, η=10^{-3},f_m=10^{8},J_b=2,J_a=0.5, d: R=30, g=4, η=10^{-3},f_m=10^{8},J_b=2,J_a=1 e: R=30, g=4, η=10^{-3},f_m=10^{8},J_b=2,J_a=1.5,f: R=30, g=4, η=10^{-3},f_m=10^{9},J_b=2,J_a=1 g:R=30,g=4, η=10^{-3},f_m=10^{10},J_b=2,J_a=1,h:R=30,g=4,η=10^{-3},f_m=10^{11},J_b=2,J_a=0.5 i:R=30,g=4,η=10^{-3},f_m=10^{12},J_b=2,J_a=0.5,j:R=30,g=4, η=10^{-3},f_m=10^{12},J_b=2,J_a=1 k:R=30,g=4, η=10^{-3},f_m=10^{12},J_b=2,J_a=1.5

Continue

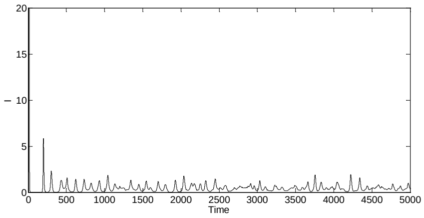
(g) **(h)** **(i)**

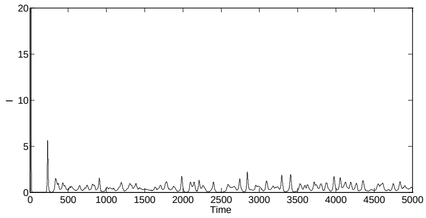






(j) **(k)**





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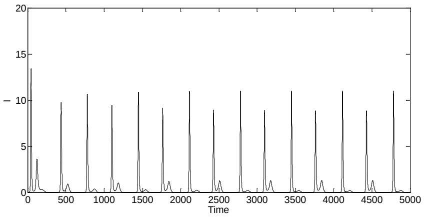
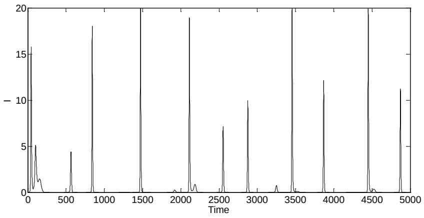
(a) **(c)** **(b)**





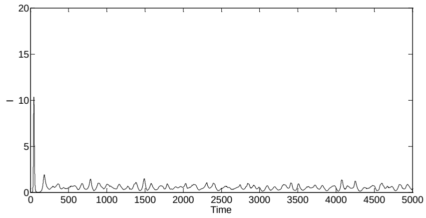
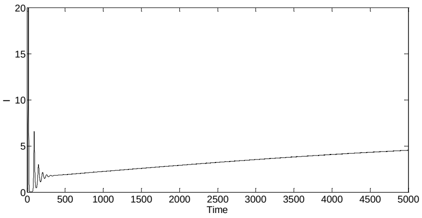


Fig (4) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

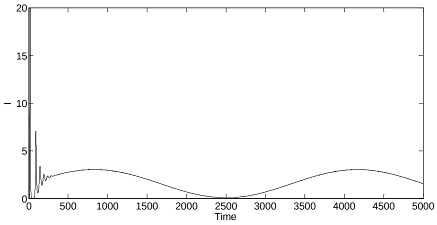
a:R=30, g=2, η=10^{-3},f_m=10^8,J_b=3,J_a=1,b:R=30, g=2, η=10^{-3},f_m=10^8,J_b=3,J_a=2

c-:R=30,g=2, η=10^{-3},f_m=10^{12},J_b=3,J_a=2.5

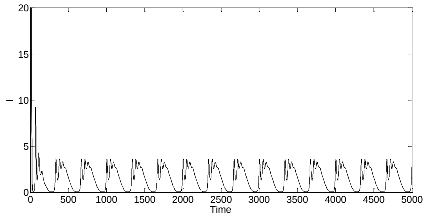
(a)



(b)

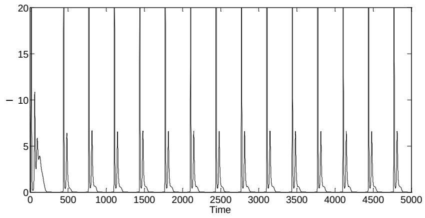


(c)

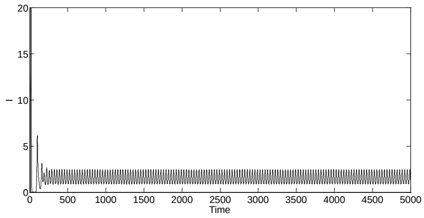


(d) (e)

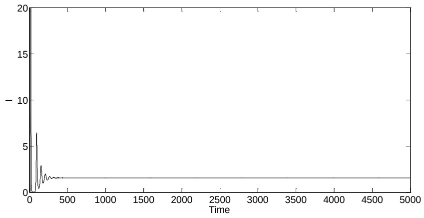
(d)



(e)



(f)



(g)

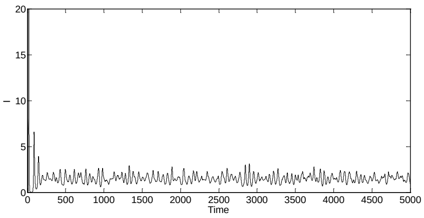
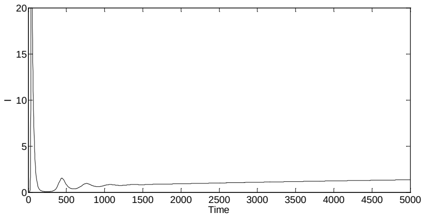


Fig (5) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

a:R=30, g=3,η=10^{-3},f_m=10^6,J_b=3,J_a=2.5,b: R=30, g=3, η=10^{-3},f_m=10^7,J_b=3,J_a=1 c: R=30, g=3, η=10^{-3},f_m=10^8,J_b=3,J_a=1, d: R=30, g=3, η=10^{-3},f_m=10^8,J_b=3,J_a=2 e: R=30, g=3, η=10^{-3},f_m=10^9,J_b=3,J_a=1, f:R=30,g=3,η=10^{-3},f_m=10^{10},J_b=3,J_a=2 g:R=30,g=3,η=10^{-3},f_m=10^{11},J_b=3,J_a=1

(a)



(b)

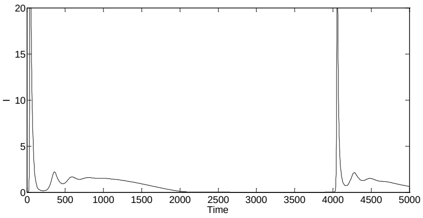
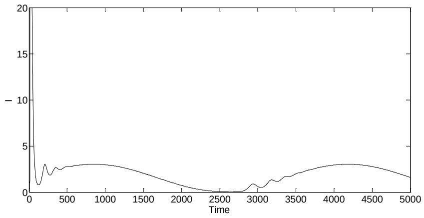


Fig (6) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

a:R=30, g=2,η=10^{-4},f_m=10^6,J_b=3,J_a=1, b: R=30, g=2, η=10^{-4},f_m=10^7,J_b= 3,J_a=1

(a)



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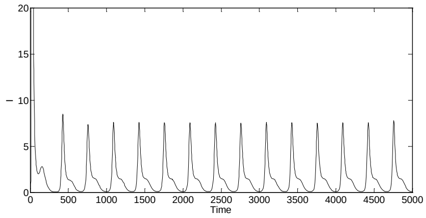
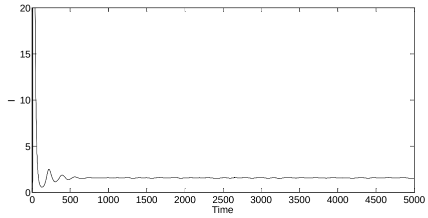


(c)



(d)

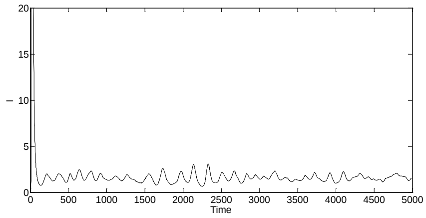


Fig (7) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

a: R=30, g=3, η=10^{-4},f_m=10^7,J_b= 3,J_a=1,b: R=30, g=3, η=10^{-4},f_m=10^8,J_b=3,J_a=1

c: R=30, g=3, η=10^{-4},f_m=10^{10},J_b= 3,J_a=1,d: R=30, g=3, η=10^{-4},f_m=10^{11},J_b=3,J_a=1

(a) **(b)** **(c)**

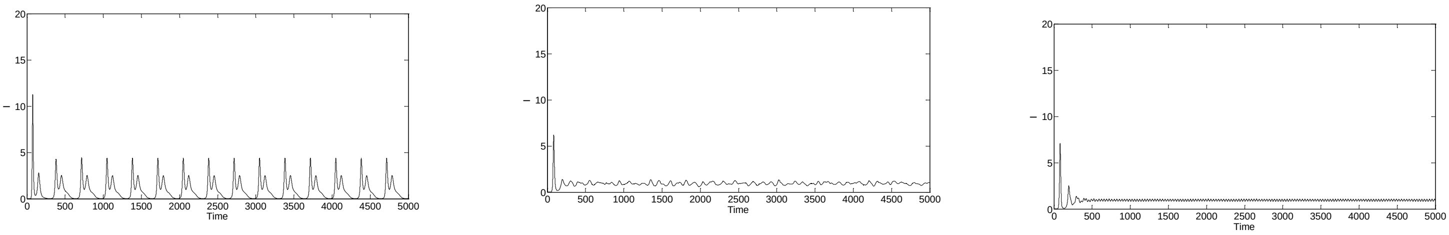


Fig (8) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

a:R=50, g=2,η=10^{-3},f_m=10^8,J_b=4,J_a=1, b: R=50, g=2, η=10^{-3},f_m=10^9,J_b= 4,J_a=1

c: R=50, g=2, η=10^{-3},f_m=10^{12},J_b=4,J_a=1

(a) **(b)** **(c)**

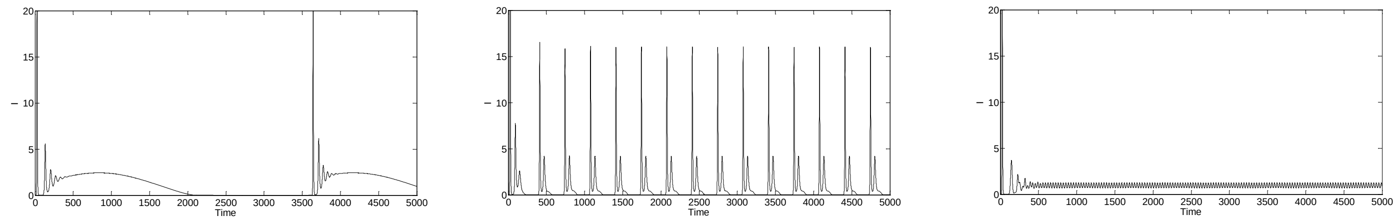


Fig (9) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

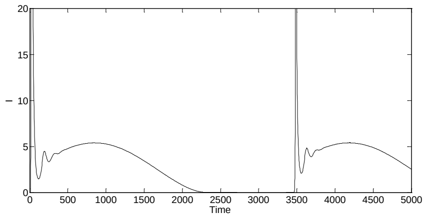
a:R=50, g=3,η=10^{-3},f_m=10^6,J_b=3,J_a=1, b: R=50, g=3, η=10^{-3},f_m=10^7,J_b= 3,J_a=1 c: R=50, g=3, η=10^{-3},f_m=10^8,J_b=3,J_a=1

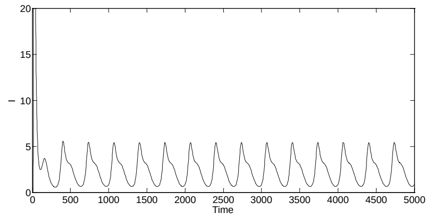
(a) **(b)**

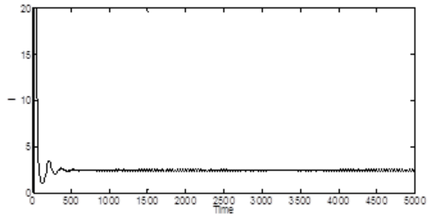
Fig (10) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

a: R=50, g=4, η=10^{-3},f_m=10^8,J_b=3,J_a=1, b: R=50, g=4, η=10^{-3},f_m=10^9,J_b=3,J_a=1

(a) **(b)** **(c)**







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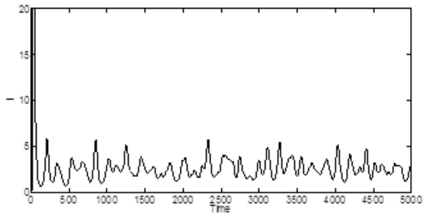
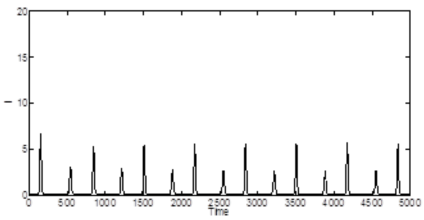


Fig (11) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

a: R=50, g=3, η=10^{-4},f_m=10^7,J_b=4,J_a=2, b: R=50, g=3, η=10^{-4},f_m=10^8,J_b=4,J_a=1

c: R=50, g=3, η=10^{-4},f_m=10^9,J_b=4,J_a=2,d:R=50,g=3, η=10^{-4},f_m=10^{12},J_b=4,J_a=3

(a) **(b)**



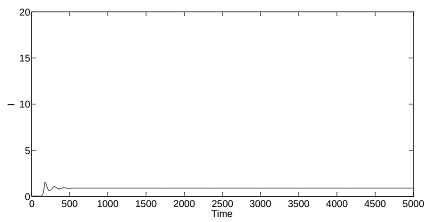


Fig (12) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

a: R=70, g=2, η=10^{-3},f_m=10^8,J_b=4,J_a=1, b: R=70, g=2, η=10^{-4},f_m=10^{11},J_b=4,J_a=1

(a) **(b)**

Fig (13) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

a: R=70, g=3, η=10^{-4},f_m=10^8,J_b=3,J_a=1, b: R=70, g=3, η=10^{-4},f_m=10^{11},J_b=3,J_a=1

(a) **(b)**

Fig (14) :Temporal variation of intensity of quantum dash semiconductor laser for various combination of (η , g , f(Hz) ,R , $J_b$and J_a)

a: R=70, g=4, η=10^{-4},f_m=10^8,J_b=3,J_a=1, b: R=70, g=4, η=10^{-4},f_m=10^{12},J_b=3,J_a=1

Conclusion :

The obtained results include the temperal variations of QDash laser intensity under the effect of injection current modulation suggested the possibility of using such lasers in the secured communication .

The QDash laser shows large number of dynamics as a result of modulating the injection current where the laser works non- autonomously. In this case the laser is described by three equations in comparison with the autonomous case where the laser can be effectively described by two equations,one for the temporal variations of laser intensity and another one the carrier population and the occupation probability. As a result the laser intensity varies in a stable manner where the laser works autonomously while in the case of injection current modulation it shows instabilities post the usual behavior of the laser output. Period one, period two, etc, and chaos appeared to occur together with power dropout or coherence collapse[25].

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التضمين المباشر للتيار في ليزر شبه الموصل نوع الشخطة الكميه

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الخلاصة:

يتضمن البحث دراسة عددية لتأثير تضمين تيار الحقن في ليزرات شبه الموصل نوع الشخطة . عوامل السيطرة المختارة لاتمام الدراسة على تغيرات الشدة مع الزمن هي التحصيل والجزئين الثابت والمتغير من تيار الحقن وتردد التضمين ونسبة أضمحلال الحاملات الى الفوتونات ومعدل هروب الحاملات من النقطة الكمية الى منطقة الترطيب نتج من الدراسة خرج فوضوي شديد ونبضات منفردة واخرى متعددة .