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Quantum Well Laser: Simulation for Dynamics

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Abstract

In the present article,we simulate the type of semiconductor laser through the dynamics of quantum well laser by using Matlab program withRungeKutta method for the rate equation system. The resultsproduce the synchronization between the photon and carriers densities behaviors at the same time of the laser.We find that the system is produced stability and more periodicity dynamics at different values of parameters.The system of QW laser has affecting in its variables dynamics at varingparameters in the QW laser.

Keywords:Quantum well laser,Carrier dynamics, Synchronization.

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ليزر البئر الكمي : محاكاة الحركيات

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الخلاصة

في الدراسة الحالية , قمنا بمحاكاة نوع من ليزر شبه الموصل من خلال حركيات ليزر البئر الكمي باستخدام برنامج ماتلاب وبطريقة رانج-كوتا لنظام معادلات المعدل. النتائج انتجت التزامن بين كثافة الفوتونات وكثافة الحاملات عند نفس الزمن لليزر. وجدنا ان النظام يبدي حركيات استقرارية وحركيات اكثر دوريةعند قيم مختلفة من المعاملات. نظام ليزر البئر الكمي تتاثر متغيراته بتغيرمعاملات هذا الليزر.

1. Introduction

Quantum well lasers (QWLs)have attracted a great deal of attention by their many advantages such as high modulation rate,low threshold current density, excellent temperature feature, and wavelength adjustability. These types of devices were evolved anddeveloped constantly in the direction of integration and size reduction. A quantum well laser improves the functional characteristics of laser diodes through direction of low thresholdcurrent and narrow emission band as well as emitting wavelength dependence on the quantum size effect of nanostructuredimension [1]. A quantum well laser is a structure in which the active region is so narrowthat quantum confinement occurs, according to quantum mechanics [1-3]. The wavelength of quantum well laser is determined by the width of the active region ratherthan the band gap of material from which the device is realized. In consequence, muchshorter wavelengths can be obtained by quantum well lasers than from conventional laserdiodes using a specific semiconductor material[7-10]. A quantum well laser efficiency isgreater than a conventional laser diode due to a stepwise form of its density of statesfunction.

For the application of quantum well such as single-mode, and low-chirp lasers are highly desirable for long-haul and high-bit-rate optical communications [3,4]. The importance of semiconductor laser diodes is continuously increasingfrom different applicationareas and are becoming necessary and irreplaceablecomponents of modern optoelectronic and photonicsystems[5-11]. They have many advantages of other lasersystems in terms of high power conversion efficiency,excellent reliability, and compact size. Because of itsspecial properties, quantumwellsemiconductorlaser diodes have gained so much attentionbased on their broad commercial applications likepumping sources for fiber amplifiers and solid statelasers [1,2], material processing [3], different medicalapplications [4,5], and free space optical communications[6].The important parameters for QWlasersare the modal peak gain, refractive index change and linewidth enhancement factor [7,8].

This work aims to present and analyzeof modeling techniques for quantum well lasers by using the rate equations.This method is useful to determine the effects the various parameters of the laser diode operation.

2. Theoretical Model

In operation of QW laser, effects are involved that can impact a variety of performance parameters of the device. In some cases is crucial to get a transparent picture of how a laser works in varied conditions or parameters. A good laser model that permits calculation and testing of certain parameters of the device is an important result. The main models of laser with quantum wells are depending on onthe description of the semiconductor lasers using the rate equations formalism. The charactererstics of QW laser can be simulated using rate equations model which is written as follows [12]:

$$\frac{dN}{dt} = J - g(N,S)S - R_{sp} \qquad (1)$$

$$\frac{dS}{dt} = \Gamma g(N,S)S + \Gamma \beta R_{sp} - S / R_{sp} \qquad (2)$$

Equation1 expresses the changing rate in carrier concentration $n$to the injection current density J, and equation (2)represents thechanging rate in photon density S to the photonsdensity. Where $\Gamma$is the optical confinement factor, R_{sp} is spontaneous recombination (where $R_{sp} = BN^2$), B is temperature-dependent constant, Γ is opticalconfin- ementfactor,$\beta$is the spontaneous emission factor and τ_P is the phono lifetime andτ_n is the carrier lifetime . The optical gain $g(N,S)$ is given by:

$$g(N,S) = g_0(N - n_{tran})/(1+\varepsilon S) \qquad (3)$$

Where $g_o$is thegain coefficient, n_{trans} is the optical transparency density, $\varepsilon$is the gain saturation factor[12].

3. Results and discussion

From the theoretical model and by using the parameters are given inTable 1. By using Matlabprogram with ode45method. The results are summarized in figures(1) and (2)show as (a) the time behavior of carriers' density; (b)Time behavior of photon density, (c)Attractor between photon density and carrier density and (d)Three dimensional plot for time series photon density and carrier density at photon lifetimes (2ps) and (4ps), respectively.Figures (3) and (4) show the time behavior of the shapes of pervious dynamics (3ps) and (6ps) respectively.In figure (5), we show the synchronization behavior for photon density with carrierdensity.We note that when increasing of τ_P and τ_n lead to more periodicity in the output laser.The threshold the injection current densit $J_{th} = 2.5\times10^5\ mA/cm^2$.

Table 1: The used parameters in simulation of quantum well laser[11].

Symbol	Value
Γ	0.03
β	10×10^{-4}
g_o	$1.9\times10^{-3}\ cm^3s^{-1}$
n_{tran}	$3.58\times 10^{16}\ cm^{-3}$
τ_{ph}	$2\ ps$
τ_n	3 ns
ϵ	$10\times 10^{-19}\ cm^3$
B	$1.43\times 10^{-7}\ cm^3s^{-1}$

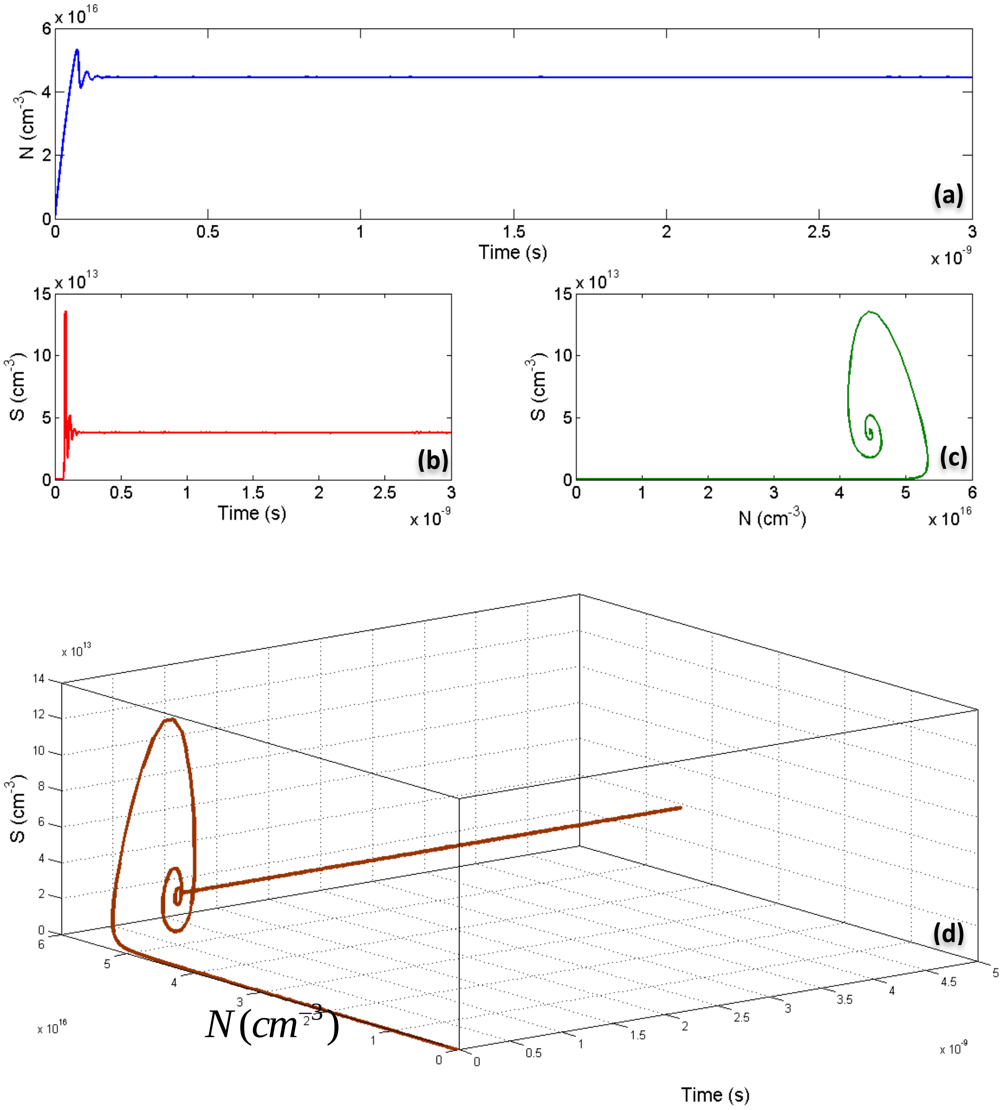
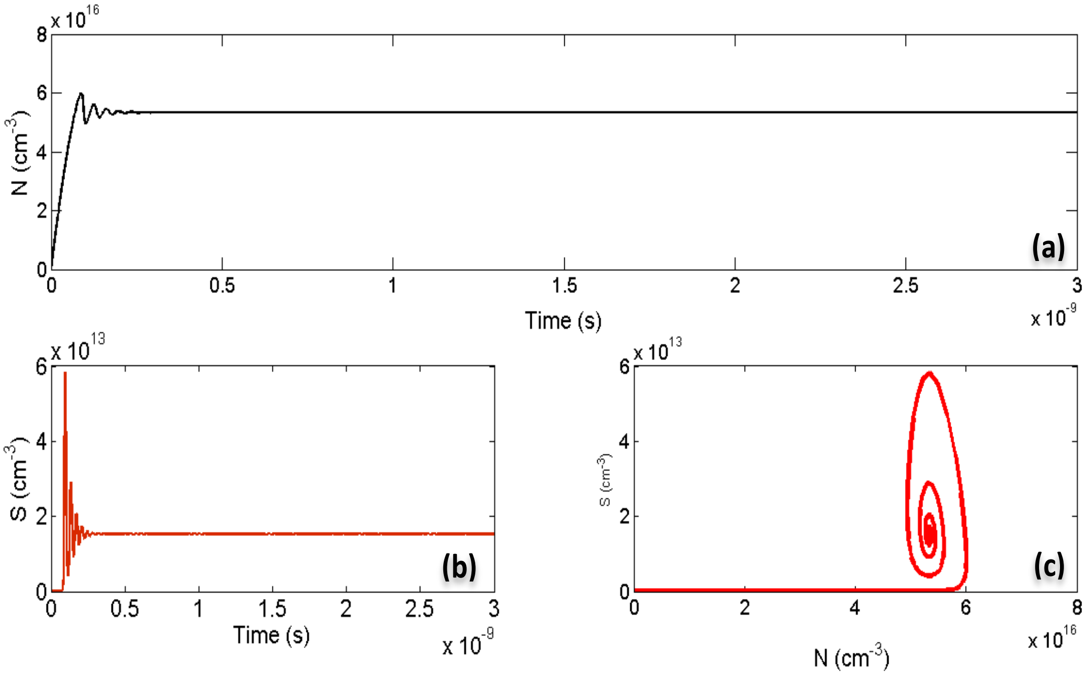


Fig.1:(a) Time behavior of carriers density, **(b)** Time behavior of photon density, **(c)**Attractor of photon and carriers densitiesand**(d)**Three dimensional plot for photon density and carriers density for ($\tau_p = 2\,ps$).


x 10^16
N (cm^-3)
0
2
4
6
8
0
0.5
1
1.5
2
2.5
3
Time (s)
x 10^-9
(a)
x 10^13
S (cm^-3)
0
2
4
6
0
0.5
1
1.5
2
2.5
3
Time (s)
x 10^-9
(b)
x 10^13
S (cm^-3)
0
2
4
6
0
2
4
6
8
N (cm^-3)
x 10^16
(c)

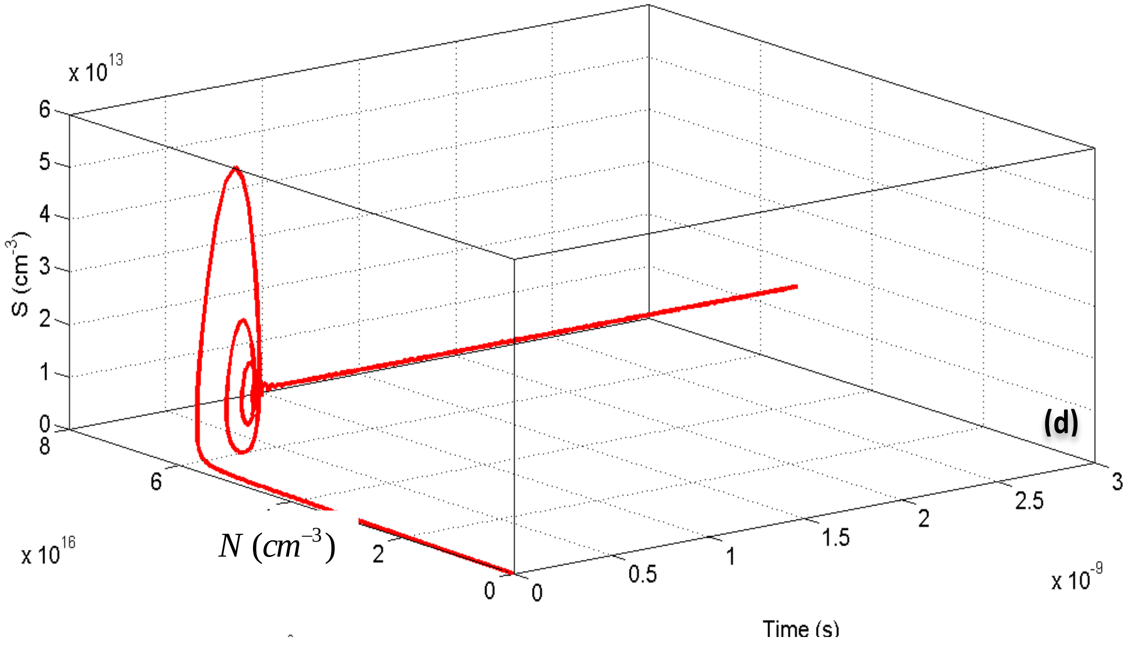

x 10^13
S (cm^-3)
0
1
2
3
4
5
6
8
6
2
0
x 10^16
N (cm^-3)
0
0.5
1
1.5
2
2.5
3
x 10^-9
Time (s)
(d)

Fig. 2:(a) Time behavior of carriers density, **(b)** Time behavior of photon density, **(c)** Attractor of photon and carriers densities and **(d)** Three dimensional plot for photon density and carriers density for ($\tau_p = 4\, ps$).

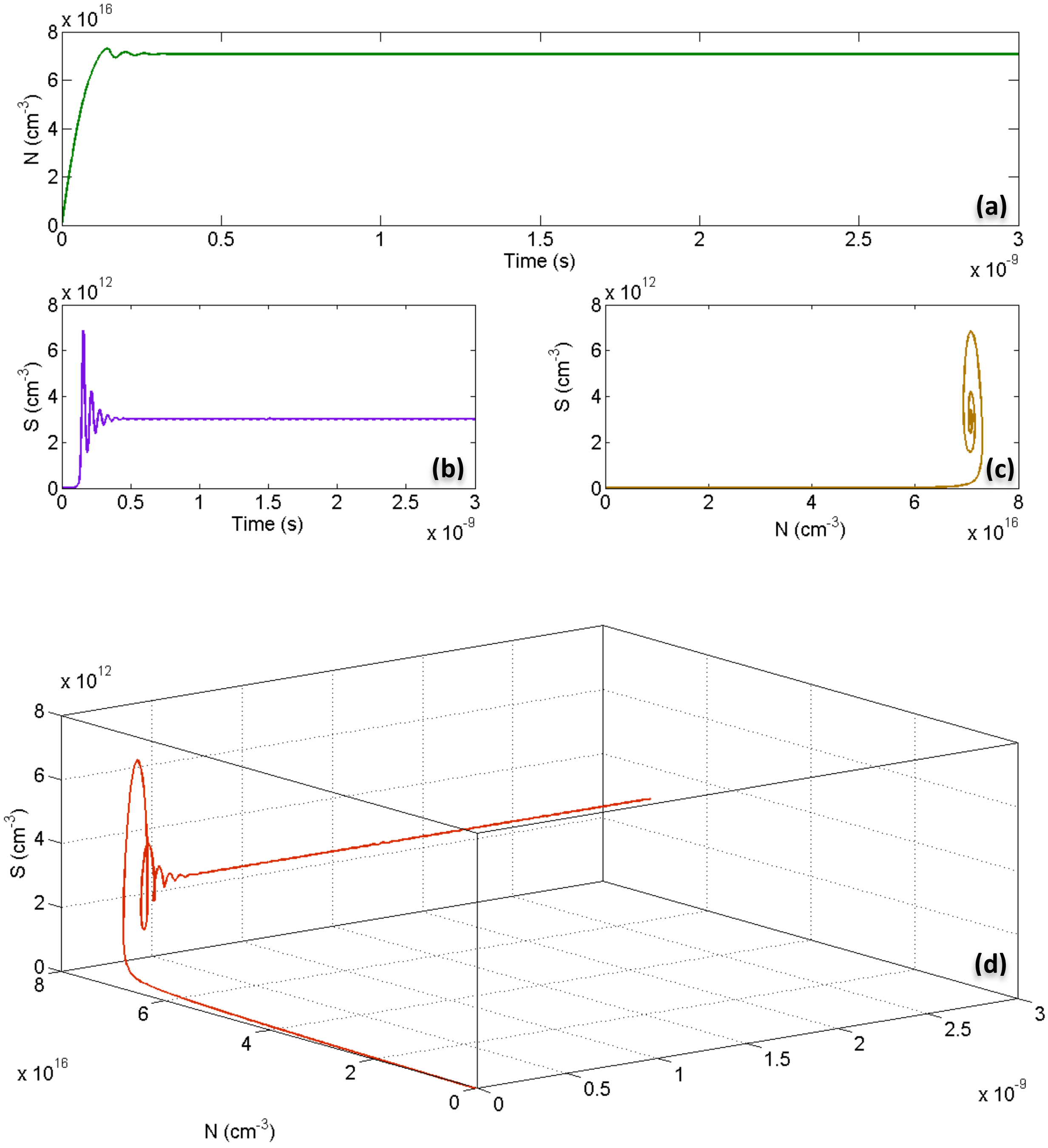


Fig. 3:(a) Time behavior of carriers density, **(b)** Time behavior of photon density, **(c)** Attractor of photon and carriers densities and **(d)** Three dimensional plot for photon density and carriers density)for ($\tau_n = 3ps$).

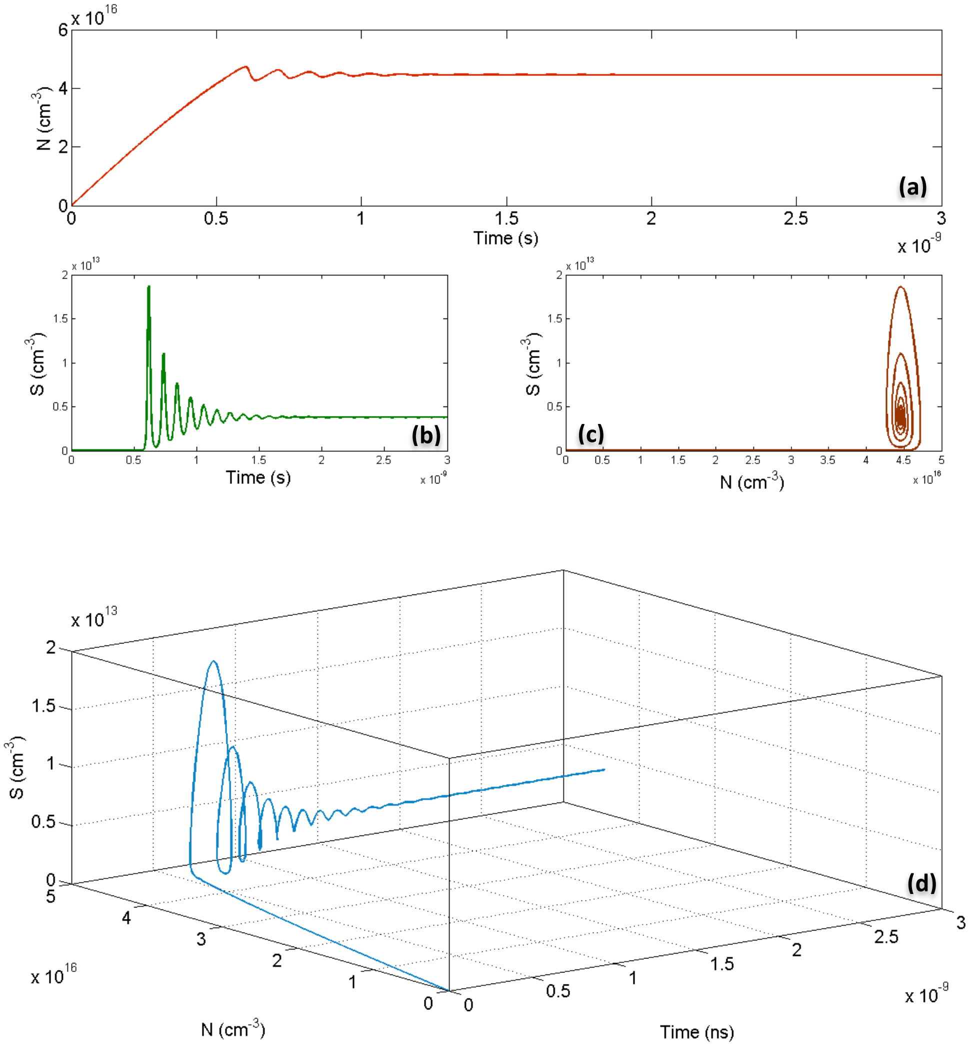


Fig. 4:(a) Time behavior of carriers density, **(b)** Time behavior of photon density, **(c)** Attractor of photon and carriers densities and **(d)** Three dimensional plot for photon density and carriers density for ($\tau_n = 6\, ps$).

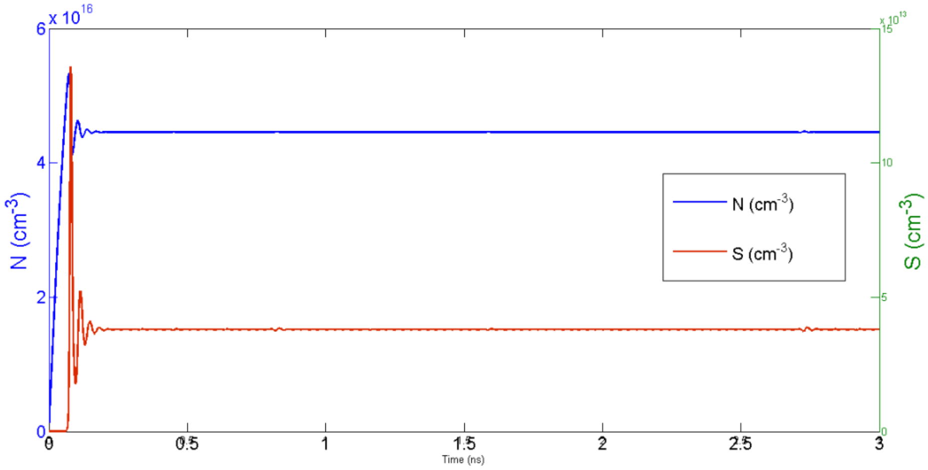


Fig. 5: Synchronization between photon and carriers densities in quantum well laser.

4. Conclusions

The changing of carrier and photon life times can lead to varieties of the output of quantum well semiconductor laser.The results show to turn on laser at different values of photon lifetime and carrier lifetime with various types of attractors and phase space. From these results one concludesthe synchronization between the photon and carriers densities.Thus, we conclude that the system of QW laser has affecting in its variables dynamics at varingparametrs in the QW laser.

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