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Carrier Densities Population of QD in Ground and Excitation States of InGaAs/GaAs Quantum Dot Laser

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Abstract : *The This a study of controlling effect of some basic system parameters on the dynamical properties of the quantum dot laser carriers. This work started from the theoretical model which based on the master equations. The assumption of this model is that the micro cavity of the laser is a quantum dot of InGaAs/GaAs type, with wavelength of 1.3µm. We do numerical solution of these equations and do simulated simulations.*
Keywords: *Quantum Dot laser; QD exited (ground) state; carrier densities population; InGaAs/GaAs laser.*

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I. Introduction

The carriers in Quantum Dot Laser (QDL) system have a fundamental role to determining the efficiency and stability of the system. One of most important practical aspects which are the enumeration of carriers (in both ground and excited states) plays the primary affected of the light-current curve (LCC).

The operational properties were studied of the quantum dot lasing, and discussed the internal loss dependent on the carrier density at the upper limit of operating temperatures [1-3]. This loss restricts the depth of the quantum well potential with a less volume of QD. This loss can be greatly limiting the output in a laser system with one layer of QDs [4].

By using quantum mechanics, there is a very accurate description of a wide range of systems in which a great effort was devoted to the development of alternative cooling techniques. [5,7]. The emission characteristics were studied of the single-dot within the microcavity of semiconductors as a function of the pumping rate in the system [8,9]. The possibility of achieving emissions has been verified in a system with strong coupling with the onset of stimulated emissions, and the existence of independent variables for the photon population or emitted spectrum. A detailed analysis of the potential role of the excitation charge in various deflections of sources and with various quantum dot transitions was performed. [10,11].

Analytical approach presented to describe multi-level lasers in quantum dot laser systems. That shows the extent of the main role of the electron / hole rate of capture [12]. If it below a certain critical value, the full refluxes of the laser ground state takes the highest place at injection levels. The variation in experimental results was also explained and contrasted with the traditional rate equation model. Researchers were discovered the possibility of directing the quantum light emitted from the InGaAs self-assembly of GaAs at the top of the guide [4]. The effect of excited cases on the inclusion of the ground state bandwidth in QDL is efficient [5]. Direct and indirect snoring of the carriers was also studied in the ground state by Ref. [10].

V. V. Korenev & etc., conducted an analytical study showing that the capture of carriers and the mobility of carriers at quantum dots play an important role in the case of duplication. The synchronization of the gap and the electron allows the observed cooling of the ground state, which plays a role in the quantum dot lasers at the high injection area. On the other hand, the detailed analysis of the charge of the carrier's motion at the single quantum dot is not able to describe the properties of light and its main temperature is observed [14-16].

Other researchers are found that in sometimes the increase in the pumping current is observed at the cooling intensity of the ground state, and the reasons for this have been investigated. They also studied through an analytical approach relying on temperature, gain and electron symmetry the gap [5]. Also that discovered there is a new way that the InGaAs / GaAs may turn the enumeration into a single pulse. In contrast that to the traditional way of reversing a two system through Rabi oscillation.

By use photovoltaic technology, Xing Ding & ect. were requires single photonic sources and at the same time high levels of purity. Through the single photon source, combines for the first time between highly efficient properties and levels close to purity. That was opened the way for multiple photon experiments at the quantum dot of semiconductors [8,17].

II. Mem Model Of Qd Lasers

The The QD laser master equations model (MEM) is instructive to study relaxation oscillations in semiconductor QD Lasers. In the following, we take several some theoretical assumptions [18,19]:

1st: Considering the resonant excitation state contributions from identical QDs.

2nd: there are modules of the time delay process of the turn-on dynamics of the field in QD Lasers appear.

3rd: To describe the carrier-generation rate in the laser-transition level, we can use the pumping rate $J_{tot} = N\,\gamma_{\perp}^{e,h}\left(1 - f_{e,h}^{E}\right) n_{e,h}^{G}$.

4th: Coulomb interaction contributions to the carrier dynamics of electrons and holes are very weak.

5th: If one considers correlations between photons with the same circular polarization, can find they are linked to states for which only one electron or hole per exited state of QD are available. Under the assumption that super radiance is weak in the system [20,21].

The MEM of QDL is:

$$\frac{d}{dt} f_{ph} = \frac{2}{\hbar}\left[-k\, f_{ph} + \frac{\tilde{N}}{\beta}\tilde{C}\; \mathcal{O}_s\right] \qquad \ldots(1)$$

$$\frac{d}{dt}\mathcal{O}_s = -\frac{1}{\hbar}\left[(k+\varrho)\mathcal{O}_s - f_e^E f_h^E + (1 - f_e^E - f_h^E) f_{ph}\right] \qquad \ldots(2)$$

$$\frac{d}{dt} f_{e,h}^{E} = -2\,\frac{\mathcal{G}\,\tilde{C}}{\hbar}\mathcal{O}_s - \gamma_s(1-\beta) f_e^E f_h^E + \gamma_{\perp}^{e,h}\left(1 - f_s^{e,h}\right) f_p^{e,h} \qquad \ldots(3)$$

$$\frac{d}{dt} f_{e,h}^{G} = J_{tot}\left(1 - f_e^G - f_h^G\right) - \gamma_p f_e^E f_h^E - \gamma_{\perp}^{e,h}\left(1 - f_{e,h}^{E}\right) f_{e,h}^{G} \qquad \ldots(4)$$

Where J_{tot} is the pump rate, f_{ph} is the photon population, $f_{e,h}^{E}$ $(f_{e,h}^{G})$ is electron / hole population of exited (ground) state, $\gamma_{s,p}$ is exited (ground) state spontaneous emission rate into non-lasing modes $\gamma_{\perp}^{e,h}$ is electron / hole spontaneous emission rate into lasing modes, k is cavity loss coefficient, ϱ is phenomenological dephasing coefficient , $\mathcal{G}$ is delay factor and β is spontaneous emission rate into lasing modes.

In the following, we shall use the site of QD semiconductor laser MEM equations. (1) -(4) to compute numerically to study the turn-on dynamic of field with contribution of photon-assisted polarization in InGaAs /GaAs QD Lasers.

The ordinary differential system MEM equations.(1)-(4) includes the time variation of photon population f_{ph} in the QD laser cavity, photon-assisted polarization $\mathcal{O}_s$ excitation / ground carriers populations of electron and hole ($f_{e,h}^{E}$ and $f_{e,h}^{G}$ respectively). These variables are functions to various parameters (i.e. control parameters). Table (1) constitutes these parameters with their values and units which are used in the present work. The pump rate is one of the important time dependent parameter.

III. Control Parameters Result

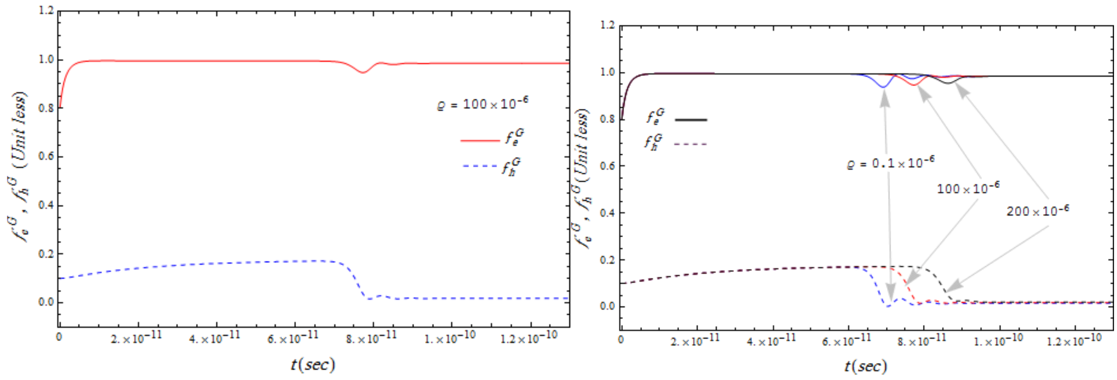
In this work, we will study the density of carriers at the laser (ground and excited) levels of the InGaAs / GaAs laser model, which operates at a wavelength of 1.3μm. We solved the mathematical model equations numerically and simulating the results using the Mathmatica. The affect of the various factors of the system for control are examine and within the parameters of the coefficients listed in Table (1).

TABLE I the values of control parameters from [22].

Symbol	Value	Unit
K	20	μev
C	6	μev
β	0.02	
τ_{re}	1	ps
τ_{rh}	5	ps
τ_{sp}	50	ps
τ_{psp}	2	fs
Δt	10	ps
r_{th}	10	
J_{th}	3.146	ps-1
N_{e}	20	

Phenomenological dephasing Coefficient effect (ϱ) on $f^G_{e,h}$ and $f^E_{e,h}$

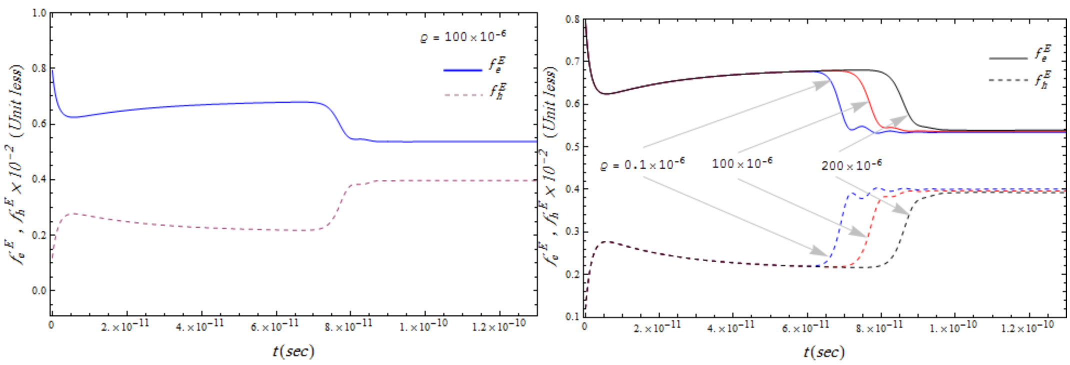
As The semiconductor coupling factor is an effective compound factor in the efficient cavity of the laser QD. It contributes directly to determining the degree of complexity and stability of the system. Through the results in Figure 1(a), that is observed that the density of the carriers increases over time until the occurrence of the laser action. The theoretical results observe a decrease in the curves $f^G_{e,h}$. The results of the depletion of a number of carriers at the laser level it's as a result of the outgoing radiation. This will deplete a value of ground carriers and a significant shortage of carriers of this level. Figure 1(b) shows that increasing the coefficient of deflation will affect the delay time. With the increase of this factor ρ we can notice an increase in delay time and a slight increase in the number of carriers.



(a) **(b)**

Fig. 1 (a) variations of the carrier density with time at the ground level are connected curve for f^G_e, and the dashed curve for f^G_h with ϱ = 100 ×10 - 6. (b) The time variation of the different values of ϱ =(0.1 , 100 , 200) ×10 - 6. Other parameters values as listed in Table (1) .

The effect of increasing the ϱ coefficient on the curves $f^E_{e,h}$ is similar to its effect in the ground state $f^G_{e,h}$ where are observe that with the increase of this coefficient ϱ will increase the delay time, While the number of carriers increases slightly.

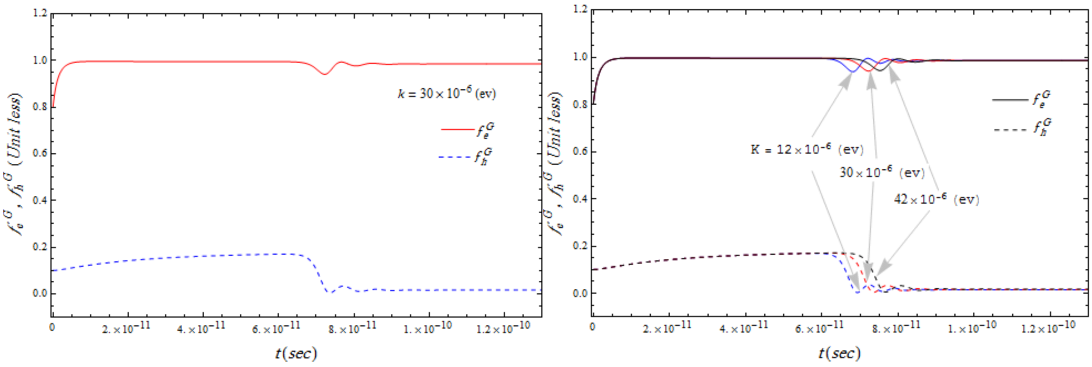


(a) **(b)**

Fig. 2 a) variations of the carrier density with time at the ground level are connected curve for f^E_e, and the dashed curve for f^E_h with ϱ = 100 ×10 - 6. (b) The time variation of the different values of ϱ =(0.1 , 100 , 200) ×10 – 6.

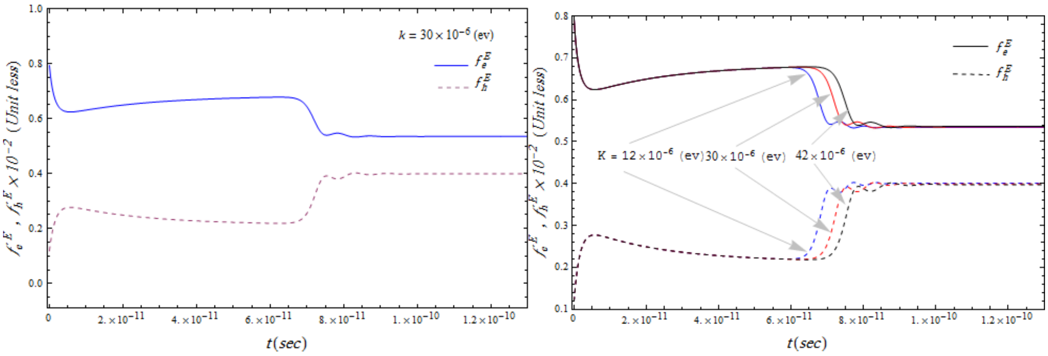
Cavity Loss Coefficient effect (k) on $f^G_{e,h}$ and $f^E_{e,h}$

The loss coefficient k has a role in determining the QD laser output. The increase of this coefficient is given a result of an effect on the delay time. As well as, it's of the number of carriers in both the ground and the exited states. That is increasing the delay time and the number of carriers slightly for both ground and precipitate conditions as shown in Figures (3 and 4).



(a) **(b)**

Fig. 3 (a) variations of the carrier density with time at the ground level are connected curve for f_e^G, and the dashed curve for f_h^G with k = 30×10 – 6ev. (b) The time variation of the different values of k =(12 , 30 , 42) ×10 – 6ev.



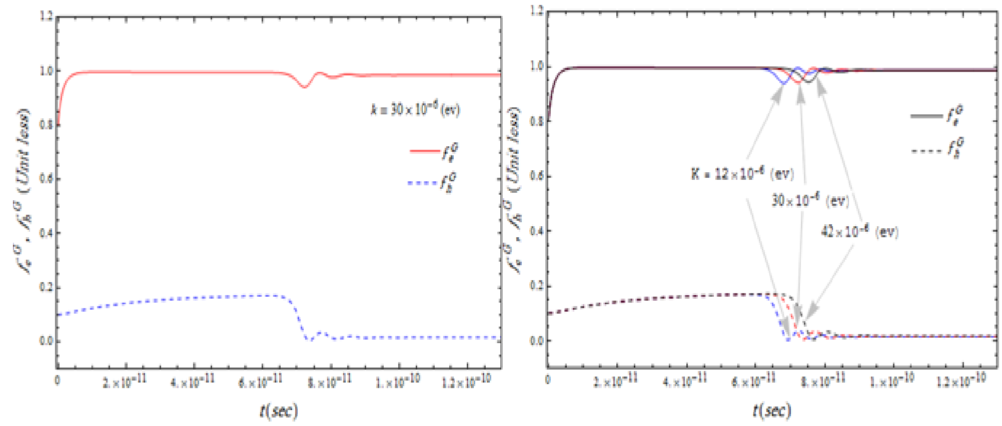
(a) **(b)**

Fig. 4 a) variations of the carrier density with time at the ground level are connected curve for f_e^E, and the dashed curve for f_h^E with k = 30×10 – 6ev. (b) The time variation of the different values of k =(12 , 30 , 42) ×10 – 6ev.

Spontaneous Emission Coefficient effect (β) on $f_{e,h}^G$ and $f_{e,h}^E$

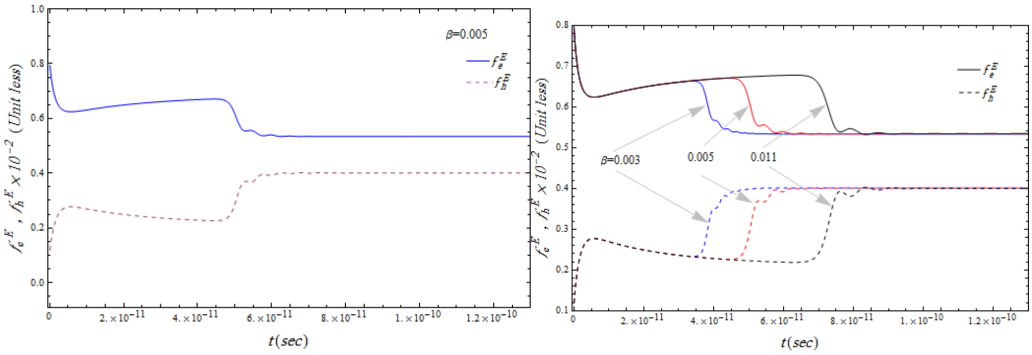
When a photon is emitted as a result of the electron transition from the excited state to the ground state, the emitted photon energy is equal to the difference between the two energy levels. When the β parameter is increased, the number of photons emitted automatically increases. Figure (5) shows the effect of the emission factor β on f_e^G and f_h^G curves. We can note that any increase of this parameter β affects the delay time and the number of carriers and also affects the oscillation.

The effect of β increase is seen it in significantly increases of the delay time and increasing the carriers population. While it reducing the oscillation in the number of carriers per level. The results of Figure (6) show the effect of increasing this coefficient on the excited state. The increase of the emission factor β show a delay time increases while the number of carriers is not affected by both the electrons and the holes of the excited state.



(a) (b)

Fig. 5 (a) variations of the carrier density with time at the ground level are connected curve for f_e^G, and the dashed curve for f_h^G with β = 0.005. (b) The time variation of the different values of β =(0.003, 0.005, 0.011).

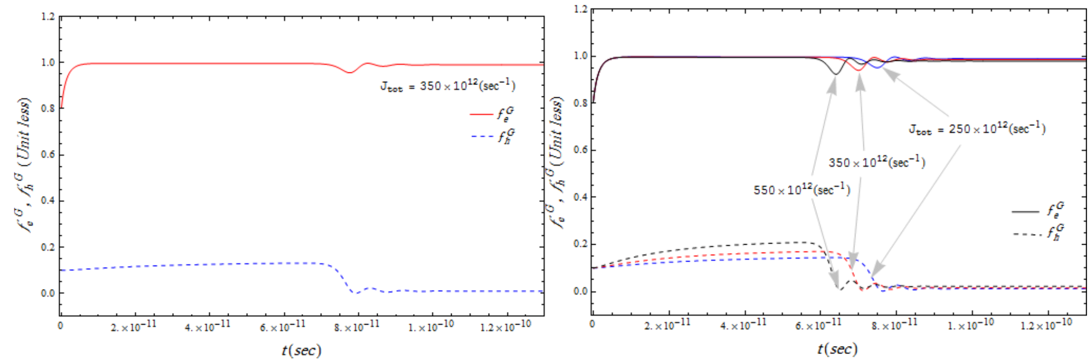


(a) (b)

Fig. 6 a) variations of the carrier density with time at the ground level are connected curve for f_e^E, and the dashed curve for f_h^E with β = 0.005. (b) The time variation of the different values of β =(0.003, 0.005, 0.011).

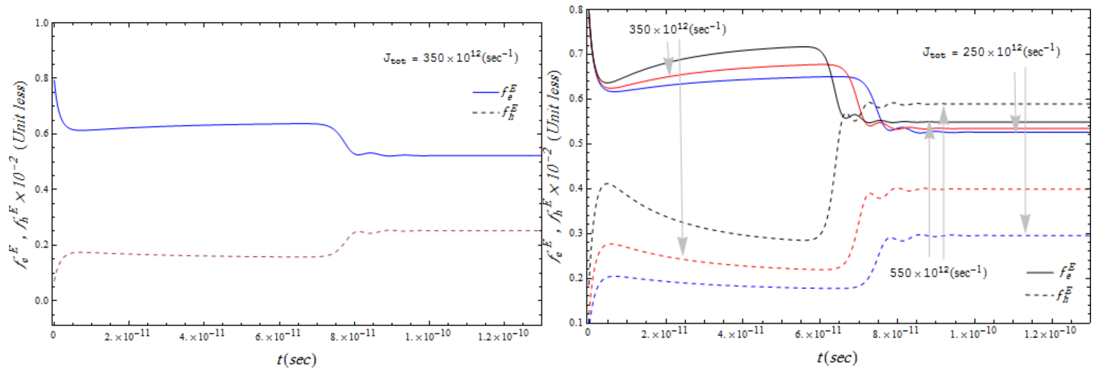
Pump Rate effect (j_{tot}) on $f_{e,h}^G$ and $f_{e,h}^E$

The transferring energy process to the effective QDL generated is depend on the type of the microcavity effective medium, the mode of operation and the nature of the matrix element. Also it's depends on the spectrum of absorption spectra of the pump beam. The pumping ratios play as a key role in determining QDL properties. Fig. 7 shows the effect of the pump rate on the curve f_e^G and f_h^G. Any increase of the pump rate (J_{tot}), that decreases the delay time of each curve. The number of carrier increases of f_h^G with a great change of f_e^G. Either the exited state as shown in the results of Fig. 8, when increasing the rate of J_{tot} effect on the excited state curves. It is increases in delay time, and the number of carriers of f_e^E and f_h^E.



(a) (b)

Fig. 7 (a) variations of the carrier density with time at the ground level are connected curve for f_e^G, and the dashed curve for f_h^G with J_{tot} =350×1012 (sec-1). (b) The time variation of the different values of J_{tot} =(250, 350, 550) ×1012(sec-1)



(a) (b)

Fig. 8 a) variations of the carrier density with time at the ground level are connected curve for f_e^E, and the dashed curve for f_h^E with J_{tot} =350×1012 (sec-1). (b) The time variation of the different values of J_{tot} =(250, 350, 550) ×1012(sec-1).

IV. Conclusion

There are a special effect of some basic system parameters on the dynamical properties of the quantum dot laser carriers of a InGaAs/GaAs type with wavelength of 1.3μm that have behavior variation with time. The carrier-density-dependent on phenomenological dephasing, cavity loss and spontaneous emission coefficients considerably reduces delay time of variations of the carrier density with time. While the pump rate effect decreases the delay time of the electron / hole population of exited (ground) state and photon population

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