Spike and Double stability on QDSEL of positive and negative optoelectronics feedback 220 ps

R H Abd Ali1, R S Abdoon2 and B A Ghalib3

1 Physics department, Science College, University of Kerbala, Karbala, Iraq
2 Physics department, Science College, University of Babylon, Babylon, Iraq
3 Laser Physics Department, Science College for Women, University of Babylon, Babylon, Iraq
E-mail: Ms.rajaahussien@gmail.com

Abstract. Nanotechnology laser is one of the fastest growing areas in many fields of science and medical applications. In this study, the behavior of quantitative point semiconductor laser was studied (quantum dot semiconductor laser QDSL) with positive and negative optoelectronic feedback (OEF) utilizing the rate equations to investigate the behavior of the delay time and its effect on the density of the photons as the values of the optoelectronic feedback were changed by the value of the time ($\tau = 220 \text{ps}$). Many different regions of stable and double spike when optoelectronic Feedback Strength values as $\zeta = (+0 .2) - (+0 .6)$ and $\zeta = (-0 .2) - (-0 .6)$.

Key words: Time delay, Dynamic Spike, Optoelectronic Feedback. positive and negative optoelectronics feedback.

1. Introduction

Semiconductor laser was one of the most important inventions in the twentieth century due to its wide variety of usages [1]. It depended on creating unbalanced qualification of electrons and gaps as well as integrating these electrons and gaps into optical injection as they motivated radioactive emissions in a semiconductor Nano consisted of particles whose size was less than 10 nanometer approximately [2]. The range of size corresponded to quantum retention system that constituted the range of electronic wave function that was comparable to the size of a dot [3]. Quantitative dots were particles of tiny semiconductors whose size did not exceed few nanometers, they had optical and electronic features that were different from large particles, they also had many applications in the fields of medicine, engineering, and electronic industries [4].

In solid crystallized substances, the reaction created among atomic energy levels led to energy ranges that provided quantum treatment in the individual electron [5]. Light was shed on laser model optoelectronic feedback. Laser dynamics could be controlled by nonlinear cavity element when using periodic formation so as to maintain constant generation of regular periodic pulses from a particular time and frequency [6,7]. Control could be achieved by laser through pumping current model via feedback. Examples include the electronic control; long or short pulses could be generated according to delay time through the circuit [8].
Multiple dot laser of semiconductors with periodic modification of pumping was studied numerically through rate equations [9]. Due to the development of information technology laser through electronic devices, some problems arose in switch modes with the help of external signal [10]. The pumping current through feedback circuit in optoelectronic system constituted a source of short light pulses, such pulses could be stable or unstable because they were related to delay periods [11]. That was considered a good feature in transferring optical data [12]. When intervals among pulses became longer than delay time, the problem of constant flow dynamics in the endless dimensions stage area could be solved [13].

Chaos is a model used to describe dynamic systems whose behavior was complicated, unpredictable, and very susceptible to primitive circumstances. When laser dimensions were not high enough, they can be raised through delay in feedback [14]. In 2016, Bejoyvarg identified the delay time through chaos intensity of laser output. The quantity dot as well as optical feedback were determined using the theoretical and numerical technologies and information of four quantities: self-bonding function, delay of exchanged information, entropy, and complicated statistics. Detailed comparisons among those quantities and feedback and delay rates were held [15]. In 2018 Nada Allawi Fadhl, et al., conducted a study to examine the effect of inclusion frequency on quantum dot semiconductor laser as well as optical feedback and chaos behavior in case of delay time, a similar behavior in density of photons, in addition to distribution among photon density, probability, and transitions density as a time function [16].

In 2017, Ivan Bahnam Karomi conducted a study in which the original quantitative dot substance (IHASP) was introduced and described as a laser substance that would have future applications in biphotonic and monolithic mode-locking. This substance was used to transfer emissions into wavelengths [17].

2. Delay Time

Systems stability with variant delay time attracted more attention to stability standards that depended on linear and nonlinear delay systems [18,19]. Those standards were achieved within a frequent range or style function in time domain. Studies related to those standards used a fixed system to transform the model due to styles of frequency system [20]. Lyapunov function was used to draw time-independent stability standards. The problem of stability depended on delay in systems, namely, delay time in a varied way [21]. That function was a numerical function that could be used to prove balance. It played an important role in stabilizing dynamic systems and control theory as long as delay was common among a wide variety of control systems and that was considered a main source of instability [22]. In addition, those standards had a role in examining free parameters. It was noteworthy that deducing a stability standard that depended on delay time with doubts by varying time was a difficult state [23,24]. Transformations of a fixed mode were used to investigate that problem, yet the transformations themselves imposed some constraints, so it was preferable to find better standards. However, many studies showed independently that delay and standards based on it were strongly stable in the fixed time [25]. Systems subjected to nonlinear disturbances used transformations with eigen value; and inequality was used to improve delay conditions [26]. A definite chaos time chain was produced by nonlinear time delay; a longer unpredictable period whose behavior was similar to random signals resulted from random operations. This similarity explained the interest of statistical operations in studying the characteristics of time chain [27]. Within time delay system, the existence of the term “feedback delay” led to adopting nonlocal time in developing variables. This means that if there were a time scale whose main purpose was to develop individual time with varied state, it would be discovered through extent for the diagram depending on the function type of function [28,29].
3. Dynamics Spike

In the existence of semiconductor dot laser and nonlinear optoelectronic feedback, behaviors of stability, chaos, and spike used to appear periodically. This was called stimulation that had great importance in a variety of systems in different fields including the medical field [30]. This mode was characterized by the existence of a state of stability followed by a state of a spike then a stability state again or disturbance due to external motivators. That behavior appeared in diversities. Phase spaces of high dimensions allowed more variety and complicated dynamics. Large pulses were separated through irregular periods of time within the system [31]; the matter that led to small chaotic vibrations. Empirical studies showed that dynamics displayed two kinds of vibrations: harrow spike, and pulses accompanied by endless ripples on the upper and lower sides of the wave [32].

4. Rate Equations

Rate equation relevant to time were applied to light and optoelectronic laser devices in order to obtain highly precise dynamic description. The behavior of quantitative dots involved in chaotic behavior as well as charge transitions should be put into consideration. Consider the following relations [33]:

\[ \frac{dE}{dt} = E \left(-\frac{1}{2\tau_s} + \frac{g_o U}{2}(2\rho - 1)\right) + \frac{\gamma}{2} E(t - \tau) + R_{sp} \]  

(1)

\[ \frac{d\rho}{dt} = -t_a \rho - g_o (2\rho - 1)|E|^2 + CN^2(1 - \rho) \]  

(2)

\[ \frac{dN}{dt} = J - \frac{N}{t_d} - 2n_d CN^2(1 - \rho) \]  

(3)

Where \( P \) is the occupation probability in a dot, \( n_d \) is the two-dimensional density of dots; and \( J \) is the pump. \( N \) is the carrier density in the well, \( C \) is Auger carrier capture rate. Equations (1-3) which are derived from Huyet are utilized this steady current with a modification to study the dynamics of the (QDSL).

In the Optical feedback, the electric field component exists while in Optoelectronic feedback the intensity equation of the photons or transducers exists as shown in the following equations [33].

\[ \frac{dS}{dt} = S \left(-\frac{1}{2\tau_s} + \frac{g_o U}{2}(2\rho - 1)\right) + R_{sp} \]  

(4)

\[ \frac{d\rho}{dt} = -t_a \rho - g_o (2\rho - 1)|S|^2 + CN^2(1 - \rho) \]  

(5)

\[ \frac{dN}{dt} = J (1 + \zeta(t - \tau)) - \frac{N}{t_d} - 2n_d CN^2(1 - \rho) \]  

(6)

where \( g_0 \) effective gain factor, \( v_g \) Group velocity, this found, \( R_{sp} \) is a spontaneous emission factor , \( \zeta \) optoelectronics feedback strength. \( \tau \) time delay Other parameter are mention in ref.[16,33]

5. Results and Discussion

MATLAB program was applied to know the behavior of ( positive and negative) optoelectronic feedback, and the output of semiconductor dot laser at a fixed delay time ( \( \tau = 220 \text{ ps} \) ), and to know the periods of
more stability, disturbance, or spikes in all forms that shared one value and depended on delay time \( (\tau = 220 \, \text{ps}) \) and \( \zeta = (+0.2) - (+0.6) \) and \( \zeta = (-0.2) - (-0.6) \) for optoelectronic feedback strength. A spike period appeared at (10-10.6ns) for every positive and negative optoelectronic feedback strength \( \zeta \).

Figure (1) shows at the value \( (\zeta = +0.2) \) there were three periods of stability, a period of chaos and a period of spike, whereas at value \( (\zeta = -0.2) \) there were two periods of stability, a period of chaos, and a period of spike. And a period of spike at the value \( (\zeta = 0.3) \) and that was similar to the negative part at the value \( (\zeta = -0.2) \).

\[\text{Figure 1.} \quad \text{Photon density of (QDSL) as a function of time for optoelectronics feedback a: positive, b: negative when } (\zeta = +0.2, -0.2), (J_{\text{cur}} = 1.3J_{\text{th}}).\]

Figure (2) shows the existence of three periods of stability, a period of chaos and a period of spike at the value \( (\zeta = 0.3) \), in addition of two periods of stability, a period of chaos, and a period of spike at the value \( (\zeta = 0.3) \), and that was similar to the negative part at the value \( (\zeta = 0.2) \) in which a semi spike period appeared, but at the value \( (0.3) \) no implied spikes appeared.

\[\text{Figure 2.} \quad \text{Photon density of (QDSL) as a function of time for optoelectronics feedback a: positive, b: negative when } (\zeta = +0.3, -0.3), (J_{\text{cur}} = 1.3J_{\text{th}}).\]
Figure (3) showed the same spike period in the positive and negative parts \((\zeta = \pm 0.4)\) at the value \((10-10.6\text{ns})\). That was the same period in previous and subsequent figures. A new spike period appeared in both parts at the value \((18.9\text{ns})\) for the positive side, and \((19.3\text{ns})\) for the negative side, in addition of two periods of doubled stability and a period of chaos.

![Figure 3](image1.png)

**Figure 3.** Photon density of (QDSL) as a function of time for optoelectronics feedback a: positive, b: negative when \((\zeta = +0.4, -0.4), (J_{\text{curr}} = 1.3J_{th})\).

Figure (4) shows three periods of double stability at the value \((\zeta = \pm 0.5)\), whereas there are three periods of spike in the positive part at the value \((\zeta = +0.5)\), and two periods of chaos. In the negative part, there were one period of spike at the value \((\zeta = -0.5)\), and a period of chaos.

![Figure 4](image2.png)

**Figure 4.** Photon density of (QDSL) as a function of time for optoelectronics feedback a: positive, b: negative when \((\zeta = +0.5, -0.5), (J_{\text{curr}} = 1.3J_{th})\).
Figure (5) illustrates the presence of three periods of stability in the positive and negative parts at the value $(\zeta = \pm 0.6)$, and a period of spike, and a period of chaos. That was similar when values were $\zeta = +0.2$ and $\zeta = +0.3$.

![Figure 5](image_url)

**Figure 5.** Photon density of (QDSL) as a function of time for optoelectronics feedback a: positive, b: negative when $(\zeta = +0.6, -0.6)$, $(J_{\text{curr}} = 1.3J_{th})$.

Table 1. shows the periods of stability and periods of chaos and spike at values $(\zeta = +0.2 \text{ to } \zeta = +0.6)$

| Feedback strength $\zeta$ | Stability region (ns) | Spike region (ns) | Chaos region (ns) |
|---------------------------|-----------------------|-------------------|------------------|
| 0.2                       | 2.8-9.5,11.1-16.6,18.3-25 | 10-10.6           | 16.8-18          |
| 0.3                       | 2.8-9.5,11-16.6,19.2-25  | 10-10.6           | 16.9-18.9        |
| 0.4                       | 2.8-9.5,10.8-16.4       | 10-10.6,18.8-19.2 | 16.9-18.6,19.5-25|
| 0.5                       | 2.8-9.5,11.1-16.6,22-25 | 10-10.6,17.4-17.7,19.2-19.6 | 18.1-19.1,19.9-21.6 |
| 0.6                       | 2.8-9.5,11.1-16.6,17.6-25| 10.10.6           | 16.9-17.4        |

Table 2. showed periods of stability, chaos, and spike at values $(\zeta = -0.2 \text{ to } \zeta = -0.6)$

| Feedback strength $(\zeta)$ | Stability region (ns) | Spike region (ns) | Chaos region (ns) |
|-----------------------------|-----------------------|-------------------|------------------|
| -0.2                        | 2.8-9.5,10.8-16.5     | 10-10.6           | 16.9-25          |
| -0.3                        | 2.8-9.5,11-16.6,      | 10-10.6           | 16.9-25          |
| -0.4                        | 2.8-9.5,10.9-16.4     | 10-10.6,19.3-19.7 | 16.9-19.2,20-25 |
| -0.5                        | 2.8-9.5,11.1-16.6,20.7-25 | 10-10.6     | 16.8-20.6        |
| -0.6                        | 2.8-9.5,11.1-16.6,19.7-25 | 10-10.6           | 16.9-19.3        |
Table 1 and 2 represent the periods of stability, spike, and chaos for positive and negative optoelectronic feedback. It is clear that the first spike period was equal for all values of optoelectronic feedback. The difference in spike period appeared at values \( \zeta = +0.4 \) and \( \zeta = +0.5 \) in the first table, and \( \zeta = -0.4 \) in the second table. The periods of doubled stability and chaos were displaced too for the values \( \zeta = \pm 0.2 \) and \( \zeta = \pm 0.6 \).

**Table 3.** represented the order of stability, chaos, and spike periods for positive and negative optoelectronic feedback.

| Status description                          | Feedback strength(\( \zeta \)) |
|---------------------------------------------|--------------------------------|
| Stable-spike stable-chaos-stable            | 0.2                            |
| Stable-spike-stable-chaos                   | -0.2,-0.3                     |
| Stable-spike-stable-chaos-stable            | 0.3                            |
| Stable-spike-stable-chaos-stable            | 0.4                            |
| Stable-spike-stable-chaos-stable            | 0.5                            |
| Stable-spike-stable-chaos-stable            | 0.6                            |
| Stable-spike-stable-chaos-stable            | -0.4                           |
| Stable-spike-stable-chaos-stable            | -0.5                           |
| Stable-spike-stable-chaos-stable            | -0.6                           |

6. Conclusions

Behaviors of quantum dot they had discovered semiconductor laser output through positive and negative optoelectronic feedback, and location of stability, chaos, and spike periods. A similarity was noticed at \( \zeta = \pm 0.2 \) and \( \zeta = \pm 0.3 \) spike period was detected. At \( \zeta = +0.4 \), two stability periods, chaos period and a spike period were detected. A small and indefinite spike period was detected at \( \zeta = -0.4 \) with an included chaos period. Three stability periods were detected at \( \zeta = \pm 0.5 \), two periods of spike and chaos were detected at \( \zeta = +0.5 \), one period of spike and chaos were detected at \( \zeta = -0.5 \). Three stability periods, one period of spike and chaos were detected at \( \zeta = \pm 0.6 \). In this part identity was clear in the number of periods in the positive and negative parts of feedback strength \( \zeta \). It was noticed that the chaos period detected at \( \zeta = -0.6 \) was bigger than the chaos period detected at \( \zeta = 0.6 \). Chaos period detected at \( \zeta = -0.2 \) is bigger than the chaos period detected at \( \zeta = +0.2 \). These results were obtained at a fixed delay time \( (\tau = 220 \text{ ps}) \).

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