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Dynamics of QD Laser with chaotic dynamics under optical feedback

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Abstract

In this study, we investigate the dynamics of quantum dot lasers under optical feedback. In this system of rate equations, the output laser exhibits nonlinear behavior such as chaotic dynamics at different values of the parameters. Change parameters such injection current and optical feedback strength. Finding the frequencies with fast Fourier transform (FFT) for different values of parameters. The rate equation is solved numerically using the delay differential method (dde23) in the MAT LAB program.

Key words: Dynamics, Optical Feedback effect, FFT, Chaotic behavior.

1. Introduction

Delay-related instabilities are well known in semiconductor physics. In optical feedback, nonlinear dynamics of the output behavior of semiconductor lasers are observed [1].

The output is characterized by intensity dropouts, and the average time between successive dropouts is much longer than the relaxation oscillation (RO) period or beat time of the characteristic mode [2]. This phenomenon has been extensively studied experimentally and numerically[3]. Although the importance of the multimode characteristics of laser radiation has been demonstrated in several experiments [3], a relatively simple delay differential equation model derived by Lang and Kobayashi (LK) in 1980 [4]. It provides an excellent qualitative explanation for most experimental observations. Feedback behavior depends on the distance of the external mirror. The orbital period is the main feature of Lang and Kobayashi's laser beam model. From this model came various areas of complex mechanics. His first experiments with quantum dot (QD) lasers under optical feedback showed various instabilities [5]. This low sensitivity to optical feedback is relatively low and may be advantageous in some applications. Linewidth gain factor of QD laser [6-8]. The optical feedback behavior of QD semiconductor lasers is of great importance in many applications such as optical security communications, medical devices, and other applications. Chaotic optical communication system is a unique communication method that utilizes chaotic light waveforms. Its potential applications include secure communications and spread spectrum communications [9,10.In this paper, we note that the effect of optical feedback appearing with fast Fourier transform with other methods for testing the chaotic behaviors such as time behavior and attractors.

2. Quantum dot laser model under feedback

QDs under optical feedback If the laser consists of an amplifying section of length L with a layer of self-assembled QDs as the active medium and a feedback section formed by a mirror located at a distance l from its end face. Think about it. can. QD lasers reflect light back into the amplification region. Figure 1 shows the schematic structure [9].

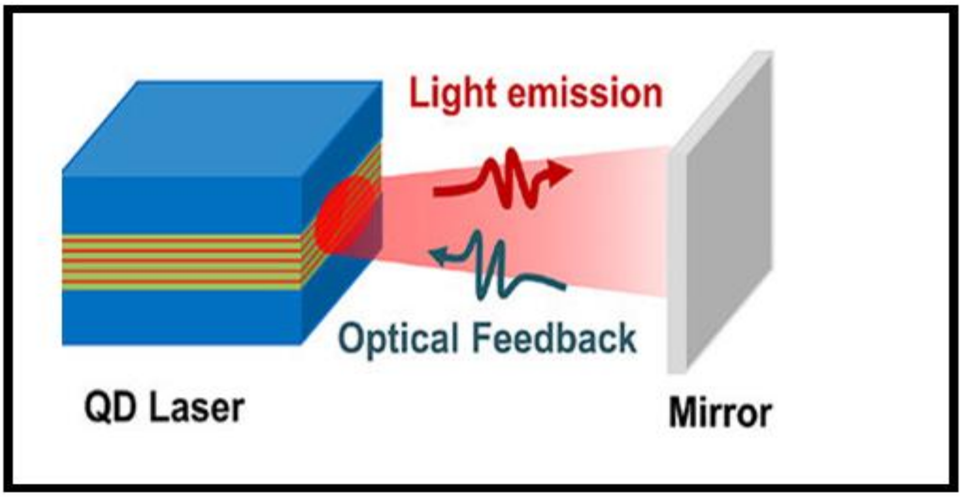

Fig. (1): Schematic of the QD laser device with optical feedback from external cavity.

The gain section of the QD laser is modeled by based rate equation system [9].

QD laser models are considered an ideal evolution of semiconductor lasers. The theoretical model is given as follows [10]. By introducing a dimensionless time t' , the number of carriers in the reservoir per QD n, and electric field E , according to $t' = t/\tau_p$, $n = N/N_{QD}$, $\boldsymbol{E} = \sqrt{g_0\tau_s}\,E$. If we consider the rate equations (1)– (4), in terms of the normalized intensity I and the phase φ of the field $E = \sqrt{I}\,exp(i\varphi)$, the equations can be rewritten as[10]:

$$I' = \left[-1 + g(2\rho - 1)\right] I + 2k\sqrt{I(t' - \tau)I(t')}\cos(-C + \phi(t' - \tau) - \phi), \quad (1)$$

$$\phi' = \frac{1}{2}\left[-1 + g(2\rho - 1)\right]\alpha + k\sqrt{\frac{I(t' - \tau)}{I(t')}}\sin(-C + \phi(t' - \tau) - \phi), \quad (2)$$

$$\rho' = \gamma\left[Bn(1 - \rho) - \rho - (2\rho - 1)I\right], \quad (3)$$

$$n' = \gamma\left[J - n - 2Bn(1 - \rho)\right]. \quad (4)$$

The parameter $\gamma \equiv \tau_p/\tau_s$ is the ratio of the photon lifetime and the carrier recombination time. The relaxation rates of ρ and n are assumed equal for mathematical simplicity. *J* is the electrically injected pump current per dot, and it is the control parameter. The nonlinear term $Bn(1 - \rho)$ describes the carrier exchange rate between the reservoir and the dots. $B \equiv \tau_s/\tau_{cap}$ is the dimensionless capture rate, and $1-\rho$ is the Pauli blocking factor. The three parameters B, γ, and (g – 1) control the time-dependent response of the solitary QD laser. The last term in eqs. (1 and 2) represents the contribution of the delayed optical feedback. k and τ are the dimensionless feedback rate and round-trip time laser-mirror-laser, respectively, and C is the feedback phase. [4].

3. Results and discussion:

Choosing specific values for each of the alpha (α), gamma (γ γ) and the delay time (τ τ) in the ranges [$\alpha = 1-5$; $k = 0.01-0.3$ *and* $\tau = 120$ *ps and* 140 *ps*].Other parameters are recorded from other sources[10].

The note follows:

1- When $\tau = 120\ ps$, $\alpha = 3$ and the choosing values for $k = 0.01-0.3$, observed turning the system form steady-state (Turn-on laser),then the dynamics begin to fluctuate at the oscillation continues to increase k for the same as the previous parameters for both α and delay time τ, to continue the volatility as shown figure (2). And start the attracters by increasing the periodic fluctuation as figure (2) .Down to the chaos state at $k = 0.3$.

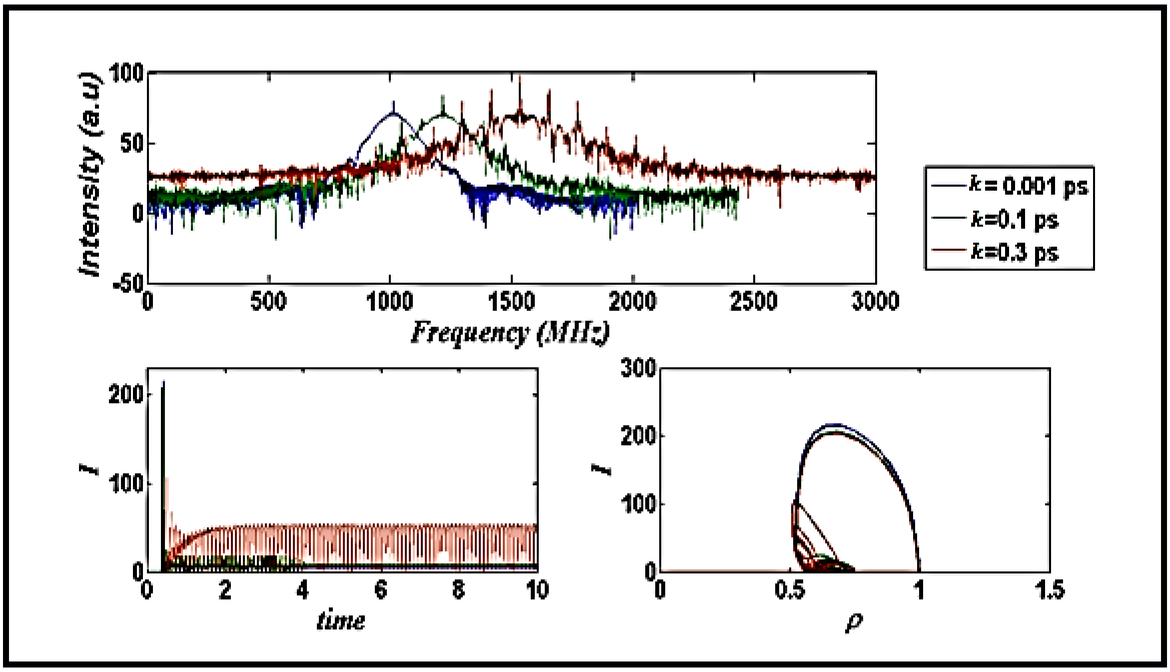

Fig. (2): Behaviors of laser and optical feedback for[(a) FFT, (b) Time behavior of intensity, (c) ρ and intensity attractor, with different values of optical feedback strength.

at (τ=140ps, α=3, k= 0.3).

2- At $\tau = 140\ ps$, $\alpha = 3$ and the values of $\boldsymbol{k}$ don't change within the same as the pervious range ($k = 0.2$). Notice that the system has started the same previous behavior .i.e. any stable output, them increasingly $\boldsymbol{J}$ go towards the oscillation mixed with stabilization, that increases the amount of fluctuation down to multiple periodicals, access to arrival the start of chaos, as in figs. (3 and 4). Notes from previous results that the system has maintained the same as the previous behavior. In other words, going toward chaos was repeated at roughly.

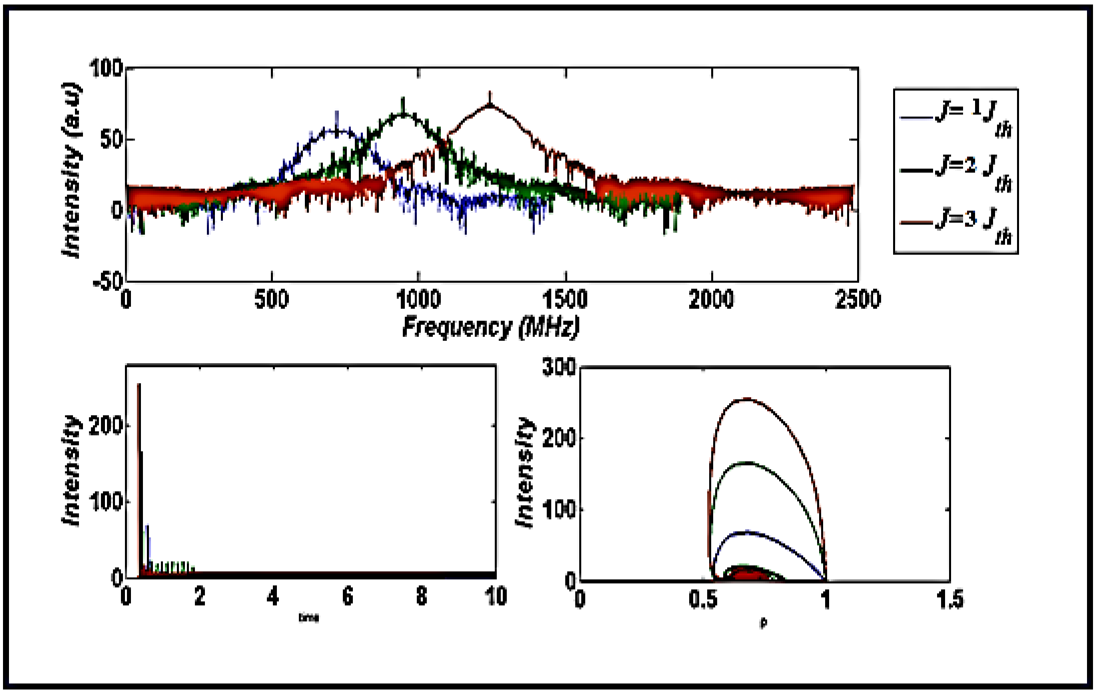

Fig. (3): Behaviors of laser and optical feedback for[(a) FFT, (b) Time behavior of intensity, (c) ρ and intensity attractor, with different values of injection current density.

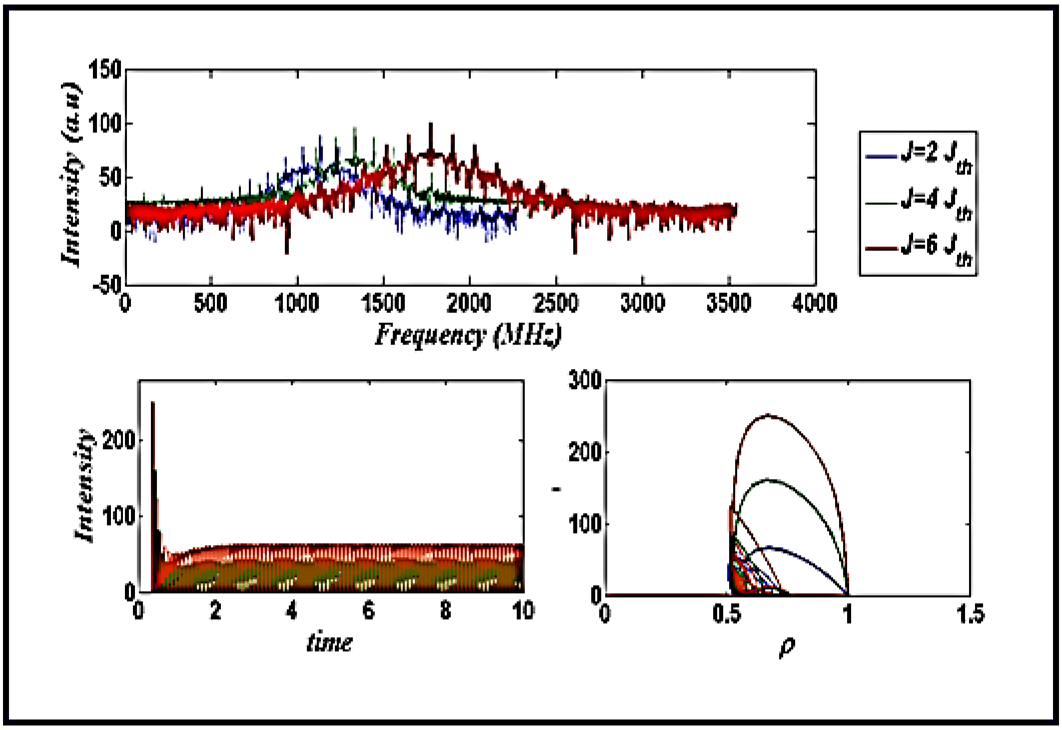

Fig. (4): Behaviors of laser and optical feedback for[(a) FFT, (b) Time behavior of intensity, (c) ρ and intensity attractor, with different values of injection current density.

4. Conclusion

A rate equation model using a delay differential equation (dde23) is given and solved numerically to estimate the behavior of different parameter values in a quantum dot laser. The change of injection current density and optical feedback strength of the quantum dot laser have important effects on the optical feedback. Nonlinear dynamics are observed in the output laser such as chaotic behavior and tested by fast Fourier transform.

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