Int. J. Pure Appl. Sci. Technol., 31(1) (2015), pp. 6-12

International Journal of Pure and Applied Sciences and Technology

ISSN 2229 - 6107

Available online at ***www.ijopaasat.in***

Research Paper

Chaos Generation of Modulated Optoelectronic Feedback in Semiconductor Laser

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(Received: 23-9-15; Accepted: 4-11-15)

Abstract: *Nonlinear dynamics of a delayed optoelectronic feed back with directly modulated semiconductor laser are studied numerically. The effects of changing the bias current of the delayed modulated optoelectronic feedback with small modulation factor producing chaotic outputs from lasers Diode with nonlinear gain reduction in its optimum value range is investigated. The beginning of transition from periodic state to the chaotic state when bias current (δ = 1.01402) was observed. The chaotic dynamics is completely determined by the variation of the injecting bias current.*

Keywords: Chaos, Delayed optoelectronic feedback, Directly modulation, Nonlinear dynamic.

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1. Introduction

Importance of chaotic dynamics of semiconductor lasers have receive more attention in the near past decades, due to the applicability of chaotic synchronization of such systems in the field of optical secure communication. This theory was proven by several research groups [1, 2, 3, 4, 5]. Semiconductor lasers are generally very stable systems when operated with only a dc bias current. By inclusion additional degrees of freedom to the system dynamic instabilities are induced. Involving external optical injection to the system produce different chaotic outputs [6, 7, 8, 9]. Producing optical feedback [10, 11], direct current modulation [12,13] and delayed optoelectronic feedback are the methods of generation chaotic optoelectronic feedback [14,15]. The conventional method of producing ultra-short pulses from positive delayed optoelectronic feedback [16] from semiconductor lasers. The dynamics of semiconductor lasers with direct current modulation widely studied [17].

It has already been proved that the effect of mode gain reduction occurring due to nonlinear processes is suppression of chaotic dynamics [18]. Producing chaotic dynamics by using bidirectional coupling configuration between two such lasers is also found [19]. A strong current modulation combined with positive delayed optoelectronic feedback is found to generate chaotic dynamics and bistability in semiconductor lasers [20]. The effect of such a combination in inducing chaotic dynamics through a quasi periodic route in quantum-well lasers also has been found [21]. The directly modulated semiconductor lasers with GHz modulation is the most preferred light source in the optical communication systems.

A widely investigated topic is Chaotic synchronization of two such lasers because of its applicability in optical secure communication [22, 23, 24]. The nonlinear gain reduction for in GaAsP lasers used in optical communication systems, is very strong and its direct consequence on the dynamics of such lasers is the suppression of chaotic outputs. A significant role in modeling semiconductor laser dynamics is the dynamic response of semiconductor laser strongly depends on the nonlinear gain [25, 26, 27]. Illustration the results of numerical investigations on the effect of a delayed optoelectronic feedback on the dynamics of lasers Diode [20]. The study was undertaken to find out the possibility of obtaining chaotic outputs Laser Diode under normal values of nonlinear gain reduction factor and small modulation window. The optoelectronic feedback scheme has the advantage of ease of implementation, as it is insensitive to the optical phase of the output intensity. Therefore the effects of negative delayed optoelectronic feedback schemes were investigated. The results reveal that in the range of normal estimates of nonlinear gain reduction factor for such lasers as suggested by Agrawal [17], only a strong negative delayed optoelectronic feedback is efficient in producing chaotic output. In this paper, the nonlinear dynamics of optoelectronic feedback semiconductor with directly modulated are studied numerically and the corresponding simulation model is established. In terms of dynamical time series, frequency spectrum and phase portraits, the influence of injection strength on the nonlinear behaviors of the considered system is investigated in detail.

2. Model Dynamics and Methods

The dynamics of the photon density S and carrier density N is described by the usual single-mode semiconductor laser rate equations [20] appropriately modified in order to include the AC-coupled feedback loop.

e is the electron charge, V is the active layer volume, g is the differential gain, (N_t) is the carrier density at transparency, γ_0 and γ_c are the photon damping and population relaxation rate, respectively, γ_f is the cutoff frequency of the high-pass filter and k is a coefficient proportional to the photo detector responsivity. Compared with optical feedback, optoelectronic feedback is reliable and robust because the system is insensitive to optical phase variations [28, 29, 30]. For this reason the phase dynamics of the optical field can be eliminated. A detailed physical model of the experimental system should include also a series of low-pass frequency filters arising from the limited bandwidth of the photo diode, the electrical connections to the laser [20]. For numerical and analytical purposes, it is useful to rewrite rate equations in dimensionless form.

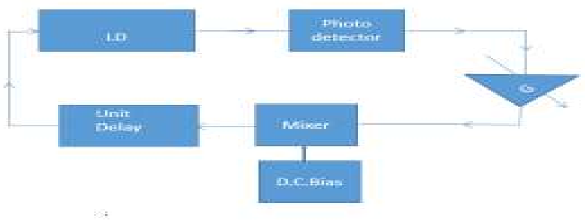


Fig. 1: Schematic diagram of directly modulated semiconductor lasers with a delayed optoelectronic feedback

$$dx/dt = x(y - 1) \tag{2.a}$$

$$dy/dt = (\gamma)((\delta 0) - y + f(z + x) - xy) \tag{2.b}$$

$$dz/dt = -\varepsilon(z + x) \tag{2.c}$$

Considering a closed-loop optical system, consisting of a LD with directly modulated AC-coupled nonlinear optoelectronic feedback (Fig.1). The output light is sent to a photo detector producing a current proportional to the optical intensity.

The corresponding signal is sent to a variable gain amplifier characterized by a nonlinear transfer function. $f(w + x) \equiv \alpha(z + x)/(1 + s(z + x))$ and then fed back to the injection current of the LD. The feedback strength is determined by the amplifier gain [20]. For a negative feedback it is deducted from the total input current comprising of the bias current and modulation term. Correspondingly the equation for the input current will be modified as follows.

$$dz/dt = -\varepsilon(z + x) - h*x \tag{3.c}$$

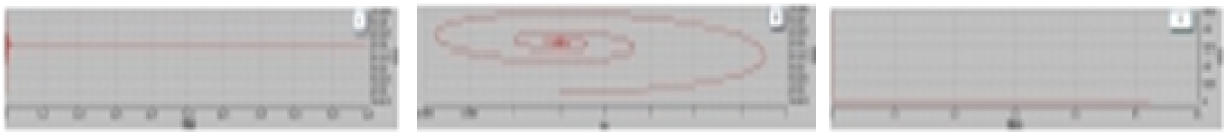
where h is the factor of modulation [31].

Table 1: Represent the parameters which we used in the model

serial	Parameters	Values
1	Saturation of nonlinear amplifier (S)	11
2	Ratio of population relaxation rate to photon damping (γ)	0.001
3	Feedback strength (ε)	$2*10^{-5}$
4	Amplifier gain factor (α)	1
5	Modulation factor (h)	0.001

3. Results and Discussion

Fig. 2 display the simulation results for different values of (δ), where the dynamical time series (first column), attractor (second column) and Fourier frequency transform (third column) corresponding to the different nonlinear regions are plotted. Among which Fig. 2 (1.a)-(3.a) represent steady state where a constant output in the time-domain, a spiral fixed point in the phase portrait and a close-zero intensity in the frequency-domain can be observed easily. Fig.2 (1.b)-(3.b) correspond to the periodic state, small amplitude was observed, and transition from steady state to periodic state, the frequency appear like fixed frequency. Fig.2 (1.c)-(3.c) illustrate limit cycle process the low amplitude change to high amplitude. Fig. 2(1.d)-(3.e) reveal the periodic doubling state where two amplitudes are appear. Fig. 2(1.f)-(3.f) correspond to quasi chaotic where the beginning of the chaotic nature is observed. Fig. 2 (1.g)-(3.g) represent the chaotic attractor which is rather different from other attractors, it looks very complex (strange attractor). Fig.2 (1.h)-(3.i) represent periodic self oscillations or Mixed Mode Oscillations (MMOs). Generally from the simulation results shown in fig.2 it can be seen that with increasing δ, the laser dynamics transit from steady state to single-periodic oscillation state, then from limit cycle state when ($\delta < 1.008$) to periodic doubling process when($\delta < 1.012$). Observing that in the Fig.2 the laser show no apparent nonlinear phenomena when δ is smaller than (1.013) Beyond this value, the laser shows chaotic behaviors. Especially, when (δ) exceeds a critical value (1.014 for our parameters), the laser enters the chaotic region. Noticing that the system becomes periodic self oscillations or Mixed Mode Oscillations (MMOs) as the dc-pumping current increased to δ=1.01702. There are multi orbits of attractor in fig. 2(2.i) represents the low amplitude oscillation in time series while the high amplitude spikes have been represents as large orbits. Fig 2(3.i) shows the corresponding FFT for this state, where many distinguished frequencies could be seen.



(1.a) **(2.a)** **(3.a)**

(1.b) **(2.b)** **(3.b)**

(1.c) **(2.c)** **(3.c)**

(1.d) **(2.d)** **(3.d)**

(1.e) **(2.e)** **(3.e)**

(1.f) **(2.f)** **(3.f)**

(1.g) **(2.g)** **(3.g)**

(1.h) **(2.h)** **(3.h)**

(1.i) **(2.i)** **(3.i)**

Fig. 2: The y-axis represents photon density and x-axis represent, The dynamical time series of the model, phase portrait and Fourier frequency transform for different injection parameter: (a) 1.0022 (b) 1.00402(c) 1.00602 (d) 1.00802 (e) 1.001002 (f) 1.001202 (g) 1.001402 (h) 1.001602(i) 1.001702

4. Conclusions

A delayed optoelectronic feedback scheme is employed to study the possibilities of obtaining chaotic output from a directly modulated semiconductor laser under GHz modulation. The generating chaotic spike by using optoelectronic feedback in diode laser with small window of modulation factor was numerically studied. The results showed the effect of variation the bias current on the output dynamics When all other control parameters are kept constant at the chaotic operating Condition also the effects of the negative modulation factor was observed. The Optoelectronic delayed feedback laser diode can be controlled to work at a given nonlinear state, such as the single-periodic, limit cycle, periodic doubling, quasi Chaotic, Mixed Mode oscillation (MMO) by choosing (δ) properly.

To further identification these nonlinear dynamic states, the dynamical time series, phase Portraits (Attractor), and frequency spectrum (FFT) are needed to be investigated

Acknowledgements

The authors would like to thanks Department of Biomedical physics and Department of Solid State physic Alneelain University for their technical support.

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