RESEARCH PAPER

Experimental Study on the Generation of Optoelectronic Based Chaos Dynamics

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ABSTRACT:

In this paper, we present the experimental evidence of chaos generation, modulation by means of optoelectronic feedback of semiconductor laser. The output photocurrent of the pin photodiode is amplified and re-injected as a feedback to the semiconductor laser. The injected feedback photocurrent produce chaotic laser output, the chaos distribution depends on amplifying strength. In addition to the changing between different chaotic outputs, the jump between chaotic to periodic was observed depending on the amplifying strength of the feedback signal. The synchronization between two oscillators (chaos generators) has been achieved by uni-directionally coupling.

KEY WORDS: Chaos, Optoelectronic; feedback; Semiconductor; Synchronization.

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1. INTRODUCTION:

Lasers with highly accessible tuning parameters show variety of dynamical behavior [AREECHI et al. 1978]. In particular, chaos can be observed in laser with feedback loop in which cavity losses are modulated by signal proportional to the output intensity [MEUCCI et al.2002]. The Theoretical models was describe the chaos behavior are divided between the classical approach and quantum mechanical approach [HAKEN 1985, AREECHI et al. 1984]. The main theoretical or experimental works are concentrated on gas lasers such as CO2 lasers and Nd-Yag lasers [KHANSA et al. 2003]. The semiconductor laser has given externally interest in the recent years for the possibility of chaos generation in these lasers [AREECHI et al. 1986].

Most of the presented work (theoretical and experiments) are directed to the optical feedback. This can be attributed to the main goal of interest in studying the chaos dynamic in the laser medium, which was for understanding the role of communication between neurons [ANDERSON et al.1999]. Since the semiconductor laser working in 1330nm and 1550 nm it is consider as the key device in the optical communication. Excitability of period doubling sequence of small periodic and chaotic attractors was observed [AREECHI et al. 2005]. The existence of slow chaotic spiking sequences in the dynamics of a semiconductor laser with ac-coupled optoelectronic feedback was demonstrating [AL-NAIMME et al. 2010]. The experimental evidence of generation and control of slow spiking rate in a semiconductor laser by optoelectronic feedback was Applied [AL-NAIMME et al.2009].
2. METHODS OF CALCULATIONS

2.1 Chaos generation by optoelectronic feedback

The optoelectronic feedback is the way for obtaining incoherent feedback via the injection current of the laser and it is efficient technique to externally control the spectral characteristics of semiconductor lasers. The experimental setup is illustrated in figure 1. The emitted optical power by the laser diode is directed toward the photo receiver by means of single mode optical fiber combined with 50%/50% optical fiber D-coupler. The optical signal was attenuated more by using a variable optical fiber attenuator, then to the detector in order to convert the optical signal into the electrical signal. The detected signal is passed through the variable gain amplifier and differential amplifier to get the suitable signal level for generating the laser non-linear dynamics. The well attenuated (amplified) signal is reinjected into the laser after. The optoelectronic feedback drives the laser to chaos.

![Figure 1. The experimental setup for chaos generating by an optoelectronic feedback. Laser diode, LD, Optical attenuator, Detector, D, Digital oscilloscope, OSC.](image)

2.2 Study synchronization between two single mode semiconductor lasers.

Figure 2 shown the experimental setup synchronization between two single mode distribution feedback DFB semiconductor lasers with a wavelength of 1310 nm. The light is converted to a current by a high speed photodetector. By generation chaos by optoelectronic feedback and using two D-coupler to reduce the two signals. The optical output detected by the photodetector is observed with color digital oscilloscope. Photodetector type InGaAs / PIN Detector, Diameter 0.3 mm type New Focus 125MHz Low Noise Photoreceiver, 1811, The amplifier is composed of Le Croy Da 1855 Differential amplifier band width >100MHZ, color digital oscilloscope type Le Coty LT 342 DSO , band width is 500MHz, The optical attenuators type Anirus Optical Attenuator MN 924C designed for use with single mode optical fibers, wave length 1.3 and 1.55 µm , Return loss -40dB., are used in our experimental.

![Figure 2. Experimental setup of the two “distribution feedback DFB” Semiconductor laser synchronization.](image)

3. RESULTS AND DISCUSSION

The time series of output feedback power and the attractors register in this work, that the system at the beginning is stable figure (3, a and b). This is because the injected feedback photocurrent is very low-60dBm. The stability is decided from the attractor shape which is in the form of limit-cycle representing the periodic oscillation of the output laser power as mentioned before figure (4, a & b). When the feedback increases -55dB the attractor cycle is deformed indicating that the system goes toward the quasi-periodic (5, a & d b). After increasing the feedback fraction to about -50dBm figure the tours is forming and the system on the boundary of the chaos regime figure (6, a & b).
These figures show that the modulation of the feedback at low frequencies produced instability to the operating system, whereas the high frequency modulation force the system operating in chaos state to be operating in stable state.

It can be noticed from the analyzed figures 9 and 10 below that the system attend to be periodic for the high frequency modulation and this is clear from the attractor and the Fourier spectrum, when the attractor contains the clear loops without the internal vortex and the Fourier spectrum has its higher value in specific oscillation frequency. In case of low frequency, the main loop of the attractor contains high internal vortex and the Fourier spectrum looks like Boltzmann distribution and the highest amplitude is shifted from the specific value of frequency.

It can be noticed from the figures [3, 4, 5 and 6] the effect of modulation on the chaos regime are shown in figures 7 and 8.
Figure 9. a) Time series b) Attractor c) Fourier transformer spectrum, for modulating frequency 1MHz, 50mV signal

Figure 10. a) Time series b) Attractor c) Fourier transformer spectrum, for modulating frequency 10Hz, 50mV signal

The coupling strength is suitably adjusted, the jumps to the unstable orbits occur synchronously as shown in figures 11 and 12. A more detailed analysis reveals that the two lasers are nearly phase synchronized during the high amplitude chaotic regime while during the small amplitude regime, their dynamics are anticorrelated. When the amplitude of the control modulator is increased the synchronization between the master and slave lasers is improved.

Figure 11. Time series of master red color, slave blue color for modulating frequency 1KHz and 2V signal
The imperfect synchronization between the two lasers when the modulation frequency 1kHz and amplitude ranges between (10-80) mv are shown in figures 13 and 14.

When the amplitude is increased to over 150mv the synchronization between the two sources tends to be perfect synchronization as shown in figures 15 and 16 that is good agree with [ABDALA et al. 2010].
4. CONCLUSIONS

In conclusion, the chaos has been generated in low frequency regime (few hundred of KHz). The generated chaos by means of opto-electronic feedback in DF semiconductor laser is affected by depending on the amplifying feedback strength. The effect of feedback injection current on the attractor shape is demonstrated.

The control of chaotic behavior could be achieved by applying a low level perturbation signals. The effect of modulation on the chaos generation is clear when the modulation of the feedback at low frequencies produced instability to the operating system, whereas the high frequency modulation forces the system operating in chaos state to be operating in stable – state. The mixed spectrum can be identified by notice the attractor which selects the mode behavior inside laser cavity. The frequency synchronization of chaotic regime in two semiconductor lasers is achieved. We have shown the synchronization inside bursting events as a consequence of an inhibitory mechanism and transitions from synchronization to a synchronization at large coupling. The imperfect synchronization between the two lasers occurs when the modulation frequency is 1KHz and amplitude ranges between (10-80mV). The amplitude is increased to over 150mV the synchronization between the two sources tend to the perfect synchronization. Finally we are concluding the synchronization is clear for 1KHz modulation frequency whereas in 100KHz modulation frequency the synchronization is not perfect. This behavior may be explained the dependence the dynamic behavior on the natural frequency of the laser.

REFERENCES

AREECHI, F. T., and GRADOMSKI, W., 1987. Laser dynamics with competing in stability, Phys. Rev. Lett. 58, pp. 2205-2208.

MEUCCI, R., MCALLISTER, and R. Roy, 2002. Chaotic function generation: Complex dynamics and its control in a loss-modulated Nd-Yag laser, Phys. Rev. E 66, 026216.

HAKEN, H., 1985. Light Elsevier Science, New York.

AREECHI, F. T., LIPPI, G.L., G.P. PUCCIONI, and TREDICCE I. R., 1984. Deterministic Chaos in lasers with injected Signal, Optical Communication, Vol 5.1, p.308.

KHANSA  A. Al-TUMIMY, 2003. Analysis of the transverse Mode formation in three classes of lasers”, Ph.D. Thesis, Basrah University, Iraq.

AREECHI, F. T., MEUCCI R. and GRADOMSKI, W., 1986. Generation of Chaotic dynamics by feedback on a laser, Phys. Rev. A34, p.p.1617-1620.

LAWRENCE, J. S. 2000. Diode laser with optical – feedback, optical injunction, and phase – conjugate Feedback, Ph. D. Thesis, Macquarie University-Australia.

ASHWIN, P., TENY, J. R., THAMBURG , K.S, and ROY, R., 1998. Blowout bifurcation in a system of coupled chaotic lasers, Phys. Rev. E, 58, p.p.7186-7189.

COLLINS, P. and KRAUSKOPF, 2003. Chaotic lasers: Main folds, Bifurcations and Symbolic dynamics,

VANDER GRAAF, W. A. PESQUERA, L. and D. LENTSRA ,1998. Stability of a diode laser with phase conjugate feedback Opt. Lett. 23, p.p. 256-258.

ANDERSON, O.K., FISCHER, A. P., 1999. Experimental stability diagram of a diode laser subject to weak phase – conjugate feedback from rubidium Vapor Cel” IEEE J. Quantum Electronic., QE-35, p.p.577-582.

AREECHI, F. T., 2005. Feature binding as neuron Synchronization: quantum aspects” Braz. J. Phys. 35, p.p.1-16.

Al-NAIMME, K., MARINO, F., CISAK, M., ABDALA, S.F., MEUCCI , R., AREECHI, F. T., 2010. Excitability of periodic and chaotic attractors in semiconductor lasers with optoelectronic feedback", Eur. Phys. J. D 58, p.p.187-189.

Al-NAIMME, K., FRANCESCO MARINO, MARZENA CISAK, RECCARDO MEUCCI, F., AREECHI, F. T , 2009. Chaotic spiking and incomplete homoclinic scenarios in semiconductor lasers with optoelectronic feedback, New Journal of Physics 11.

ABDALA S.F, Al-NAIMME, K., MEUCCI , R Meucci, R., AL MUSLER, N., AREECHI, F. T , 2010. Experimental evidence of slow spiking rate in semiconductor laser by with opto-electronic feedback: generation and control”, Applied Physics Research Vol. 2, No. 2.