Experimental Evidence of Slow Spiking Rate in a Semiconductor Laser by Electro-optical Feedback: Generation and Control

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Abstract

We report on experimental evidence of generation and control of low spiking events in a semiconductor laser. An experiment has been carried on a semiconductor laser with an electro-optic feedback, set in a parameter range where chaos occurs. The feedback is modulated by 1 kHz and 10 kHz, frequencies, 50mV amplitudes. The dependence of the injected current on the feedback fraction is observed.

Keywords: Chaos, Feedback, Control

1. Introduction

Chaos is an inherent feature of many nonlinear systems. In particular, the transition from order to disorder occurs with universality, irrespective of physical properties of the systems. Chaos occurs in optics, both in lasers and in nonlinear optical devices. Such systems, which are fundamentally simple both in construction and in the mathematics that describe them, provide excellent opportunities for investigating these nonlinear phenomena as well as for technological innovation.

Despite initial insights in the first half of the twentieth century, chaos theory became formalized as such only after mid-century, when it first became evident for some scientists that linear theory, the prevailing system theory at that time, simply could not explain the observed behavior of certain experiments like that of the logistic map. What had been beforehand excluded as measure imprecision and simple "noise" was considered by chaos theories as a full component of the studied systems.

An early pioneer of the theory was Edward Lorenz whose interest in chaos came about accidentally through his work on weather prediction in 1961[Lorenz, 1993].

The earlear observation of optical chaos in laser systems was realized by Arecchi et al. in a CO_2 laser cavity loss was modulated by an electro-optic modulator [Arecchi et al. 1987] and with saturable absorber. The semiconductor laser subjected to the feedback injection is suitable way to produce a chaotic dynamic. These chaotic systems using semiconductor lasers can be described by three dynamic rate equations [Al-Naimee et al. 2009] while the CO2 laser was described by six rate equations model given by [Arecchi et al. 2005].

In order to understand these complex dynamics, frequently observed in biological environments, and to provide controllable and reproducible experiments, considerable e_orts have been devoted to the search of analogous phenomena in nonlinear optical systems, and HC has been found in CO2 laser with feedback [Arecchi et al. 2005, Pisarchik 2001] and with a saturableabsorber [Hennequin et al.1988, Dangoisse et al. 1988].

The proposed research aims to build experimental setups to study the chaos generation conditions and the testing parameters through the observation of the time series and registration of the attractors and control.

However, in view of future experiments concerning synchronization in laser arrays, semiconductor lasers appear as ideal candidates since they allow the realization of a miniaturized chip of units optoelectronically coupled.

2. 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.

Different control parameters play crucial roles in generating a chaotic behavior of the laser output. These parameters are laser power, injection current of the laser diode and the amplifier gain. For all of these reasons, variable optical fiber attenuator, variable power supply, and variable gain amplifier are utilized. The received optical signal could be controlled thus the feedback photocurrent need to be attenuated in order to injected back to the transmitter. The detected signal is coupled with a fast response wave runner LeCroy 342 (digital wave analyzer). In order to modulate (control) the chaotic signal, sinusoidal wave with different amplitudes and different frequencies has been added to the chaotic signal.

The effect of the feedback injected photocurrent on the chaos generation is studied for laser diode source. The level of the injected photocurrent was varied as explained in chapter by two different control parameters, and the time series of the output has been recorded for a particular value of the feedback injected current as shown in the figure 2.

It was noticed during the experiments that when the feedback photocurrent of low level, the laser is oscillated periodically. When the level of the injected photocurrent (in the feedback part) is increased, the time series have mixed spectrum of strong peaks with broad high frequency contribution. The high frequency mainly generated due to bifurcation of the oscillating laser modes in the laser cavity when the feedback reach a certain value, which leads to the chaos mode, figure 2, a. The two control parameters (bias voltage and the amplifier gain of the feedback) are set so that the laser intensity displays a large spike above zero, followed by a fast damped train of a few oscillations and successive longer trains of chaotic bursts which in average appear as a growing oscillation. Damped and growing trains represent, respectively, the approach to and the escape from an unstable equilibrium point from where the trajectory rapidly returns to zero and then starts new orbit in the attractor of the signal, figure 2,b. The plot of attractors for the operating laser system is an important tool which is widely used for testing the chaos. It is clear that the attractor is indicating more than one visit to the saddle point and it contains two circles with different amplitudes. By this kind of attractors we can say, we have chaos. A suitable characterization of this regime can be provided by the return time of the main spike to threshold level.

To be sure that this regime is chaotic, many frequency components appeared in the power spectrum and the laser signal is unstable, figure 2, c. This situation is characterized by spectrum broadening leading to the splitting of the emission line resulting from rapid mode hopping. In the stable regime of operation, the minimum line width mode has the best phase stability while the mode with minimum line width is the dominant lasing mode. Above the certain threshold level of the feedback, there is a transition through series of bifurcation to dynamically unstable state (chaos).

As it is mentioned when the feedback is applied, fraction the chaotic regime is observed, but reaching the limit values of the control parameters leading to a sudden change from chaotic to periodic. In the same time it was noticed that the variation of the laser injection current as well lead to missing the chaotic behavior which need to play with the feedback current to find it again. This means that the coupling coefficient between the amplitude and the feedback current is stronger than the coupling with the population inversion

It was noticed during this work, at a certain value of feedback fraction, the system could be very sensitive and jumping fast between the chaotic (unstable regime) to the periodic (stable regime) and it was difficult to control it, above this limit of the feedback (1%) the system regained its stability or its regained its coherency and become insensitive to the perturbations. (It is in stable regime).

3. Chaos control

During this work the effect of modulation on the feedback is carried on. The feedback was modulated by 1 kHz and 10 kHz, 50mV amplitude each. A digital oscilloscope records the laser output with a sampling time of 5 µs. The average return interval value is 100ηs [8], it has been used to select an appropriate frequency range for the applied forcing or modulation. As our phenomena are relatively slow we can safely modulate the injection current of the laser. $P_o(1+m.\sin(2\pi ft))$.

For a given modulation period T_{mod}, the phase masking locking states are characterized by evaluating the quantity for different values of the modulation frequency. The existence of a (*p*:*q*) phase locking state obviously implies that *R*= (*p/q*) [Allaria et al. 2001]. Different locking regimes have been reported in figures 3-4 together with the sinusoidal forcing. The main phase synchronization domain is at 1:1 ratio. The behavior of R as a function of the modulation frequency is reported in figure 5. The suitable modulation frequency is when R value is 1. For shorter or longer forcing periods we observe 1:2, 1:3 or 2:1 etc locking ratios. For frequencies away from the natural value or its multiples the two chaotic systems looses perfect synchronization with the forcing signal, yielding extra spikes or missing spikes. If we normalize the power spectrum once can observe the occurrence of phase jumps, that we call phase slips. Figures show the experimental results of the modulation effect on the feedback at a given frequency, finally on the chaotic signal at different frequencies and amplitudes. This process initiated bursting conditions of the chaotic signals. It is clear that interbursting and intrabursting periods are changed by changing the modulation frequency.

4. Conclusions

In conclusion, we have experimentally studied the generation of chaos dynamics using semiconductor laser by means of opto-electronic feedback. The analysis of the chaos generation is presented showing the generation of mixed spectrum in the time series and the attractor. The dependence of the injected current on the feedback fraction is observed. The control of chaotic behavior can be achieved by applying a low level of perturbation signals.

Acknowledgments

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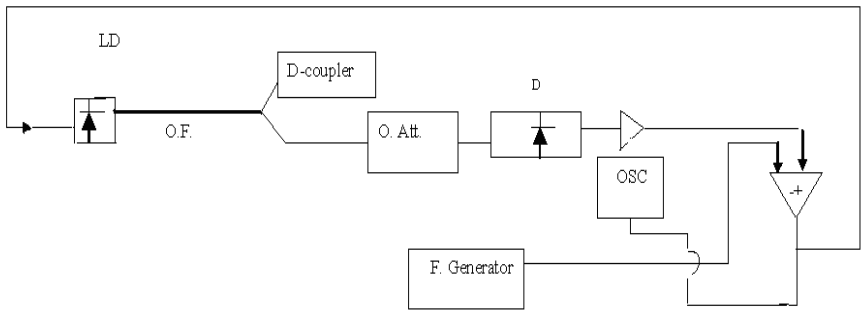
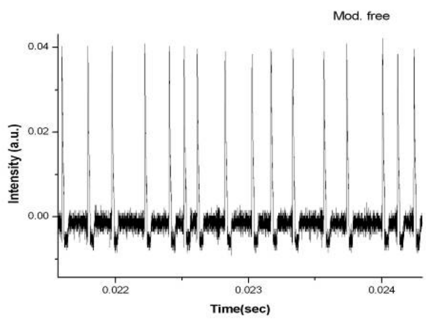
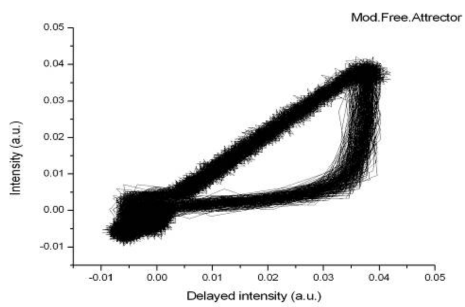


Figure 1. The experimental setup for chaos generating by an optoelectronic feedback. LD, laser diode, O.Att., optical attenuator, D, detector and OSC digital oscilloscope



a



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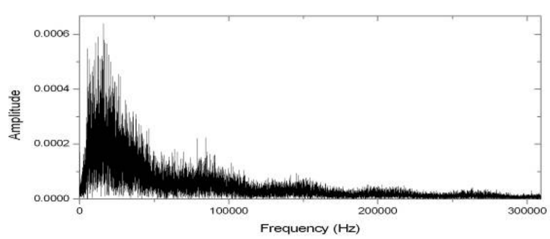


c

Figure 2. Time series of modulation free chaotic signal (a), the attractor of this signal (b), and its power spectrum (c)

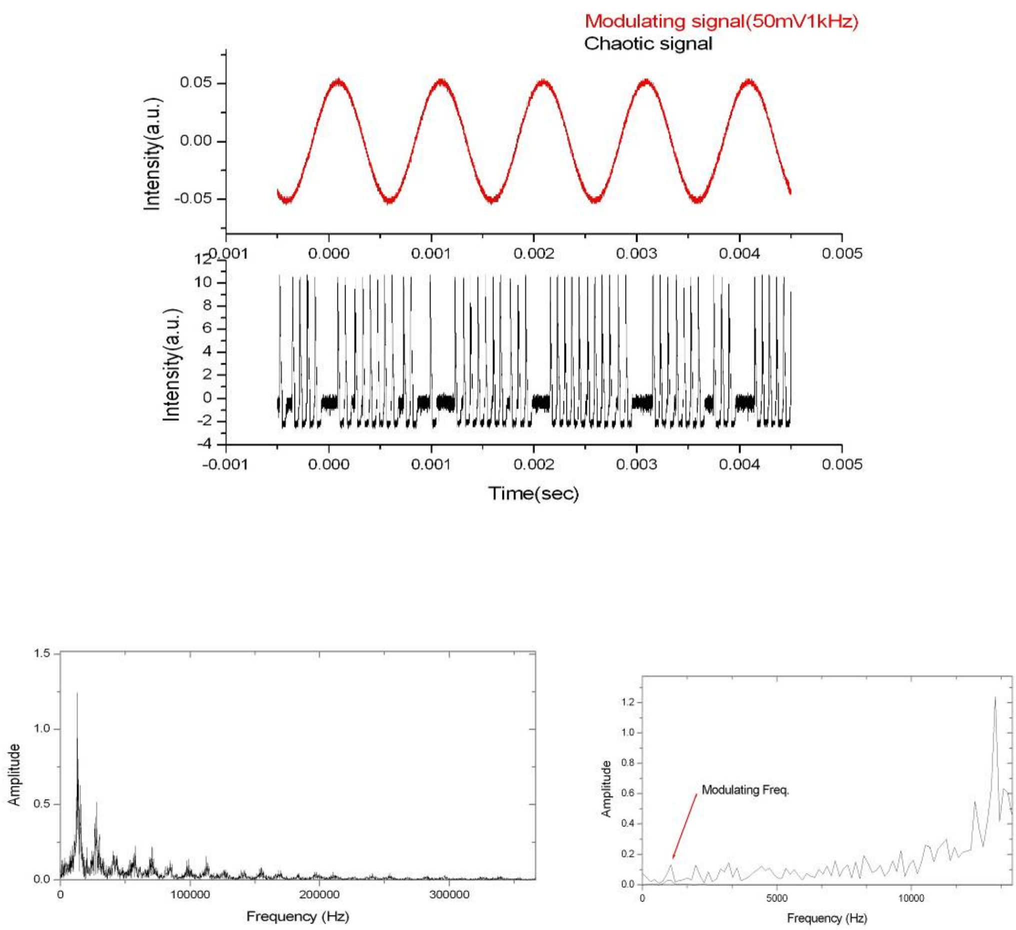
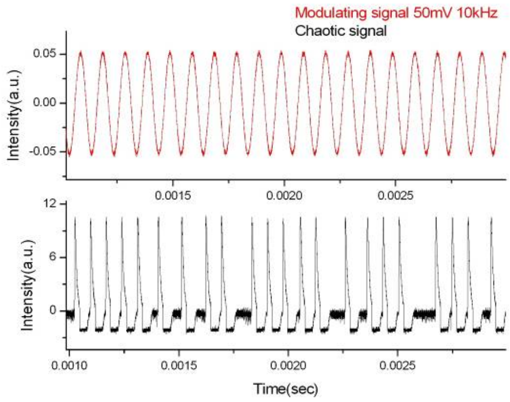


Figure 3. The chaos control using 1kHz, 50mV amplitude modulation signal, a) the modulated chaotic signal, b) the power(amplitude) spectrum of the chaotic signal



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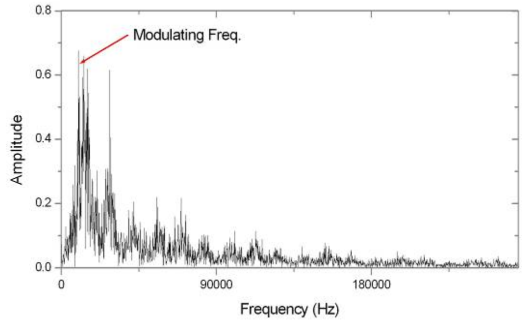

b

Figure 4. The chaos control using 10kHz, 50mV amplitude modulation signal, a) the modulated chaotic signal, b) the power (amplitude) spectrum of the chaotic signal

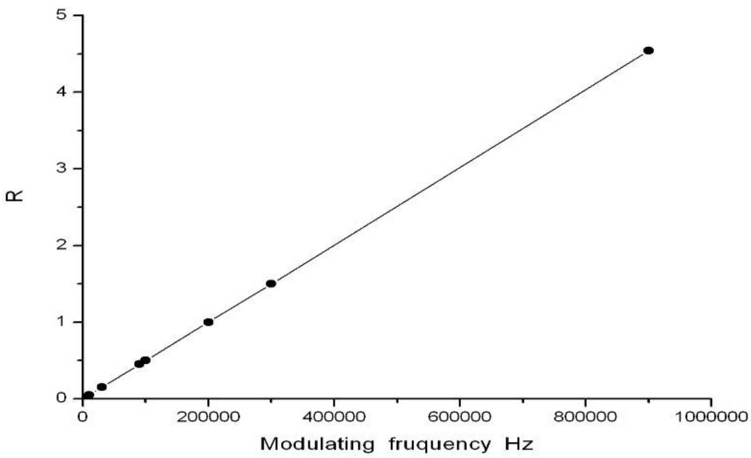

Figure 5. The R values with frequency, the optimum modulation frequency is at R equal to 1