*Optics and Photonics Journal*, 2013, 3, 162-164
doi:10.4236/opj.2013.32B039 Published Online June 2013 (http://www.scirp.org/journal/opj)

# Generation of Feedback-induced Chaos in a Semiconductor Ring Laser

**Xin Zhang, Guohui Yuan, Zhuoran Wang**
School of Optoelectronic Information, University of Electronic Science and Technology of China, Chengdu, Sichuan, China
Email: yuanguohui@uestc.edu.cn

Received 2013

## ABSTRACT

A scheme for chaotic signal generation in a semiconductor ring laser (SRL) with optical feedback is presented. Part of the output is returned to the SRL, resulting in chaotic oscillation.

**Keywords:** (140.1540) Chaos; (140.5960) Semiconductor Lasers; (140.0140) Lasers and Laser Optics; (060.0060) Fiber Optics and Optical Communications

## 1. Introduction

It is previously demonstrated that semiconductor lasers are widely used in the chaotic Optical communications as chaotic carrier source [1-2]. As a special case of semiconductor laser, semiconductor ring lasers (SRLs) can also be utilized to chaotic communication systems.

In this paper, we demonstrate the chaotic signal generation in a SRL with an optical feedback. Simulated results indicate the existence of chaotic oscillation in the SRL with appropriate disturbance.

## 2. Feedback-induced Chaos Scheme

The feedback-induced scheme for the generation of chaos is based on a SRL with a feedback waveguide as shown in **Figure 1**. Part of the output of the SRL is injected back to its cavity after a certain time delay, which induces chaotic oscillation in the SRL with appropriate feedback parameters. Simultaneously, the lasing direction of the drive SRL is set to the clockwise as a result of mode competition.

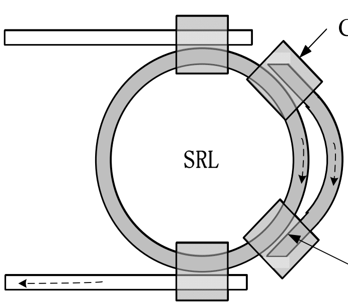



**Figure 1. Schematic illustration of a SRL with a feedback waveguide.**

The rate equations of the SRL with optical feedback are described here as [3]:

$$\frac{dE_1}{dt}=\frac{1}{2}\left(\Gamma v_g G(N-N_0)\left(1-\varepsilon_s E_1^2-\varepsilon_c E_2^2\right)-\frac{1}{\tau_P}\right)E_1 + \frac{K_f}{\tau_{in}}E_1(t-\tau)\cos\left(\omega_1\tau+\phi_1(t)-\phi_1(t-\tau)\right) \quad (1)$$

$$\frac{d\phi_1}{dt}=\frac{1}{2}\alpha\left(\Gamma v_g G(N-N_0)\left(1-\varepsilon_s E_1^2-\varepsilon_c E_2^2\right)-\frac{1}{\tau_P}\right) -(\omega_1-\varpi_{th})-\frac{K_f}{\tau_{in}}\frac{E_1(t-\tau)}{E_1}\sin\left(\omega_1\tau+\phi_1(t)-\phi_1(t-\tau)\right) \quad (2)$$

$$\frac{dE_2}{dt}=\frac{1}{2}\left(\Gamma v_g G(N-N_0)\left(1-\varepsilon_s E_2^2-\varepsilon_c E_1^2\right)-\frac{1}{\tau_P}\right)E_2 \quad (3)$$

$$\frac{d\phi_2}{dt}=\frac{1}{2}\alpha\left(\Gamma v_g G(N-N_0)\left(1-\varepsilon_s E_2^2-\varepsilon_c E_1^2\right)-\frac{1}{\tau_P}\right) -(\omega_2-\varpi_{th}) \quad (4)$$

$$\frac{dN}{dt}=\frac{\eta_i I}{eV}-\frac{N}{\tau_s}-v_g G(N-N_0) \times\left(\left(1-\varepsilon_s E_1^2-\varepsilon_c E_2^2\right)E_1^2+\left(1-\varepsilon_s E_2^2-\varepsilon_c E_1^2\right)E_2^2\right) \quad (5)$$

where $E$ is the electric field amplitude, $\Phi$ is the phase, and $N$ is the carrier density. The subscript *1* and *2* account for the clockwise and counter-clockwise directions of the SRL; $\tau$ is the delay time of the feedback light. $I$ is the injection current of SRL; $K_f$ is the feedback coefficient, the ratio of the feedback light to the light in SRL controlled by the bias current of the couplers. The detailed parameters of SRL are described in [3].

## 3. Simulation Results

The dynamics of the SRL with optical feedback depend on the adjustable system parameters including the delay time of the feedback light τ, and the bias injection current I of the SRL, the feedback coefficient Kf. In this paper, τ is set to 179 fs, which means that the feedback waveguide is about 15μm longer than that of the corresponding part of the resonant cavity of the SRL. We focus on the effect of the feedback coefficient and the bias injection current of the SRL on the nonlinear system.

It is well known that any system containing at least one positive lyapunov exponent is defined to be chaotic and the larger the magnitude of the positive lyapunov exponent is, the more chaotic the system is. The map of largest lyapunov exponent of the system is presented in **Figure 2** as a function of the feedback coefficient and the bias injection current of the SRL, which is approximately computed based on the classic Wolf's algorithm [4]. It is clear that the system is chaotic for the most part of the region in **Figure 2**. **Figure 3** shows that the chaotic output from the SRL when the feedback coefficient 0.25 and the bias current of the SRL is 110 mA, where the largest lyapunov exponent is about 0.14. **Figure 3(a)** is the Random-like time series and **Figure 3(b)** is the impulse-like autocorrelation, which also indicates a chaotic system.

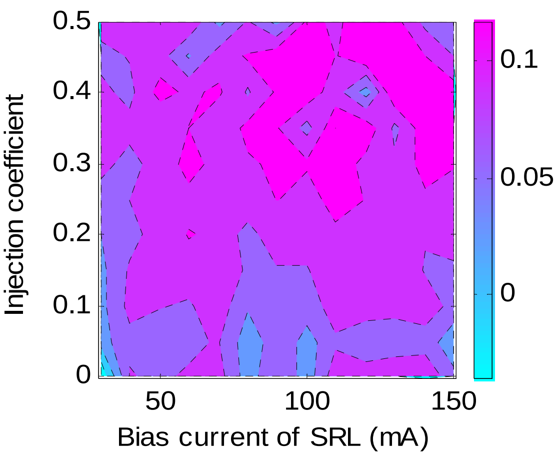
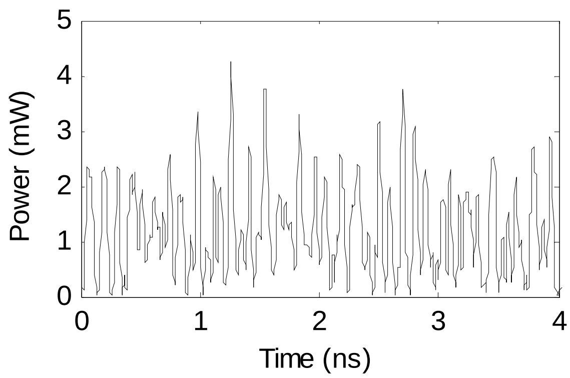
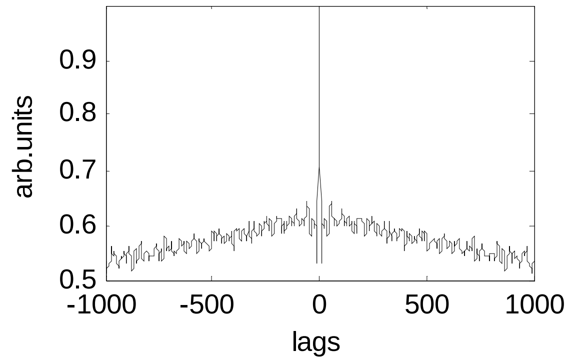



**Figure 2. Largest lyapunov exponent map as a function of the feedback coefficient and the bias current of the SRL.**




(a)




(b)

**Figure 3. Time series (a) and autocorrelation (b) of SRL when the feedback coefficients is 0.25 and the bias current of the SRL is 110mA.**

## 4. Conclusions

The generation of chaotic signal in a SRL with an optical feedback is proposed in this paper. The positive lyapunov exponent map, time series and autocorrelation of SRL indicate the occurring of chaotic oscillation in our nonlinear system with suitable system parameters, which paves the way for the utilization of SRLs in the chaotic Optical communication systems.

## 5. Acknowledgements

This work was sponsored in part by the National Natural Science Foundation of China under Grant 61107061, Grant 61107088, and Grant 61090393, Program for New Century Excellent Talents in University under Grant NCET-12-0092, Specialized Research Fund for the Doctoral Program of Higher Education (SRFDP) under Grant 20100185120016, Project of international sci-tech cooperation and exchange research of Sichuan Province under Grant 2012HH0001, the Scientific Research Foundation for the Returned Overseas Chinese Scholars of State Education Ministry 2012GJ002, the State Key Laboratory of Electronic Thin Films and Integrated Devices under Grant KFJJ201112, and State Key Laboratory on Integrated Optoelectronics under Grant 2011KFB008.

## REFERENCES

[1] N. Jiang, W. Pan, L. S. Yan, B. Luo, S. Y. Xiang, L. Yang, D. Zheng and N. Q. Li, "Chaos Synchronization and Communication in Multiple Time-Delayed Coupling Semiconductor Lasers Driven by a Third Laser," *IEEE Journal of Selected Topics in Quantum Electronics*, Vol. 17, 2011, pp. 1220-1227.

[2] J. M. Liu, H. F. Chen and S. Tang, "Optical- Communication Systems Based on Chaos in Semiconductor Lasers," *IEEE Transactions on Circuits and Systems,* Vol. 48, 2001, pp. 1475-1483.

[3] G. Yuan and S. Yu, "Bistability and Switching Properties of Semiconductor Ring Lasers With External Optical Injec- tion," *IEEE Journal of Quantum Electronics*, Vol. 44, 2008, pp. 41-48. doi:10.1109/JQE.2007.909523

[4] A. Wolf, J. B. Swift, H. L. Swinney and J. A. Vastano, "De-Termining Lyapunov Exponents from a Time Series," *Physica D.,*Vol. 16D, 1985, pp. 285-317. doi:10.1016/0167-2789(85)90011-9