Chaos Based Communication of Multi Section Semiconductor Lasers with an Air Gap

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***Abstract* – We report the results of the dynamical behavior of a novel integrated semiconductor laser subject to multiple optical feedback loops. The laser's structure consists of distributed feedback section coupled to multi section cavities. It is found that due to the multiple feedback loops and under certain operating conditions, the laser displays chaotic behaviors appropriate for chaos-based communications. The optimal conditions for chaos generation are identified. The synchronization of two unidirectional-coupled (master–slave) systems is also studied. Finally, examples of 5 GB/s message encoding and decoding are presented and discussed.**

***Keywords* – semiconductor lasers, chaos based communications.**

I. Introduction

During the last years, the dynamics of the semiconductor lasers became a field of study in order to predict the evolution of different behavior. Distributed feedback (DFB) lasers with multi sections are the key element for different dispositive used in systems of optical communication. It is well known that, in semiconductor laser (SL) applications the presence of an optical feedback (OF) is inevitable. The mirrors of the laser's resonator or the reflexing from other optical components of the system can create this feedback. Even small values of the OF created by a plane mirror can cause the system destabilization and instabilities appear. Thus, OF can highly influence the dynamic behavior of the semiconductor laser (for more details see [1]). Even simple reflections from the exterior mirrors, might cause different phenomena as coherent collapse, frequency fluctuations or auto pulsations (AP), chaos etc. The presence of periodical or chaotic oscillations represent a well-known fact in SL with OF. The chaotic behavior can be both useful in the based chaos communications systems and unwelcome and should rather be avoided or fixed in other applications.

In this paper we analyze the way for the laser to be destabilized by the external cavities and using the chaotic oscillations in the communicational systems based on chaos. The communication based on the chaos became more attractive because it allows a further security improvement of the optical systems of data transmission. The interest for this domain considerably increased after the practical prove of the optical communication based on chaos in the network of optical fibers of the Athens. In communication optical system based on chaos are used different OF semiconductor lasers - complete optical or electro-optical [2]. Typically, to generate chaos, delay time must be greater than several hundred picoseconds.

The purpose of this paper is to present results related to the chaos-based communication using semiconductor lasers with OF from multi cavities, one of which is air. We will determine the appropriate conditions for the chaotic evolution of the system due to the influence of this feedback. We will also study the phenomenon of synchronization of two such systems and determine the regions of synchronization for two identical lasers. Finally, the examples of message encoding and decoding will be presented in the chaotic modulation method.

II. Laser Model and Equations

We consider for investigations a device shown in Figure 1, consisting of an SL operating under the influence of a multiple OF from external cavity similar to that of [3]. For modeling the scheme shown in Fig. 1 we consider a single mode laser operating in CW regime.

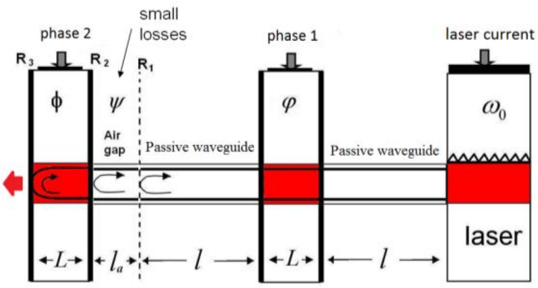

Fig. 1. Scheme of semiconductor laser with OF from multi section cavities. This device is used for synchronization of chaotic signal and for encoding and decoding of digital message.

The phase ψ of air cavity can be easily controlled by a piezoelectric element. We consider the approximation of a single loop. We note that we used this approximation just for simplifying of our numerical calculations.

The system dynamics is analyzed in the framework of the extended Lang-Kobayashi model [4] for the complex amplitude of the electric field E and density of the carriers N

$$\frac{dE_{t,r}}{dt} = (1+i\alpha)\left[\frac{g\left(N_{t,r}-N_0\right)}{1+\varepsilon\left|E_{t,r}\right|^2} - \frac{1}{\tau_{ph}}\right]\frac{E_{t,r}}{2} + \gamma_{t1,r1}e^{-i\varphi}E_{t,r}\left(t-\tau_1\right) \quad (1)$$
$$+\gamma_{t2,r2}e^{-i(\varphi+\psi)}E_{t,r}\left(t-\tau_2\right) + \gamma_{t3,r3}e^{-i(\varphi+\psi+\phi)}E_{t,r}\left(t-\tau_3\right) + k_r E_t,$$

$$\frac{dN_{t,r}}{dt}=\frac{I_{t,r}}{e}-\frac{1}{\tau_e}N_{t,r}-\frac{g\left(N_{t,r}-N_0\right)}{1+\varepsilon\left|E_{t,r}\right|^2}\left|E_{t,r}\right|^2. \qquad (2)$$

The subscripts *t* and *r* refer to transmitter and receiver lasers, respectively. The last term in (1) is present only in receiver laser and describes the unidirectional coupling between transmitter and receiver. Parameter k_r is the laser field intensity injected into the secondary laser. τ_1, τ_2, and τ_3 are the delays of the external cavities. $\gamma_{t1,r1}$, $\gamma_{t2,r2}$ and $\gamma_{t3,r3}$ are the feedback strengths governed by the reflectivity's R_1, R_2 and R_3, respectively. Other parameters have values: Henry factor α = 5, differential gain coefficient $g=1{,}5\cdot 10^{-8}\,\text{ps}^{-1}$, and saturation of the gain coefficient is $\varepsilon=5\cdot 10^{-7}$. The lifetime of photons and charge carriers are $\tau_{ph}=3$ ps and $\tau_e=2$ ns.

III. Numerical Result

For the relatively low OF signal intensity, laser emits in continuous wave mode or periodic oscillations. Chaotic regime appears only when the returned signal strength is high enough. Fig. 2 shows the time evolution (left) and power spectrum (right) of semiconductor laser under the influence of OF from multi cavity in the chaotic regime.

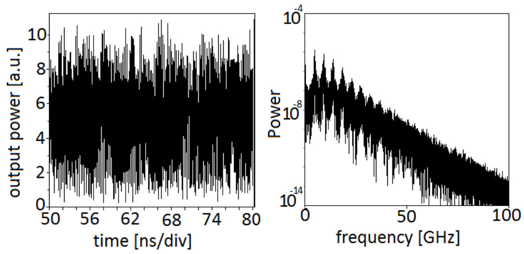

Fig. 2.Pulse trace of emerging power (left) and power spectrum.(right) of semiconductor laser under influence of OF.

Further on we l study the transmission - reception configuration and evaluate synchronization properties of two lasers. Thus, we examine the encrypting and decrypting of a digital message in the optical communication systems based on chaos. In the specialized literature where proposed various methods of chaotic encryption such as modulation chaos, chaotic switch of the key, chaotic masking etc. We analyze in detail only the case, when the informational message is included as a chaotic modulation amplitude - so called chaotic modulation.

Fig. 3 illustrates the process of transmission of a digital signal. Panel a) shows the shape of incident signal, i.e. the one that need to be sent. Panels b) and c) show the output power of the master laser without message and with it, respectively. Panel d) is the synchronization process, panel e) is the decoded message and panel f) is recovered message after filtering the information signal (solid line) and the incident signal (dotted line). As shown in this figure, for the ideal case when the parameters of both lasers coincide the message is fully recovered. Thus, we have shown theoretically that chaotic modulation method can be easily implemented in optical communication systems based on chaos.

IV. Conclusions

In the limits of Lang - Kobayashi equations the dynamics of a single mode semiconductor laser with optical feedback that comes from multi cavities was investigated. The presence of several sections results in a complication of system oscillations. An advantage of the proposed system compared with that of conventional optical feedback is that the chaotic behavior occurs for short lengths of cavities, which makes more compact device. On the other hand, under certain conditions two such laser systems could be synchronized when they operate under chaotic emitter-receiver configuration. For the parameter values, that the perfect synchronization is obtained, the possibility of encryption and decryption of the message by chaotic modulation method is demonstrated. The message can be adequately restored by the receiver, even at high speed information transmission.

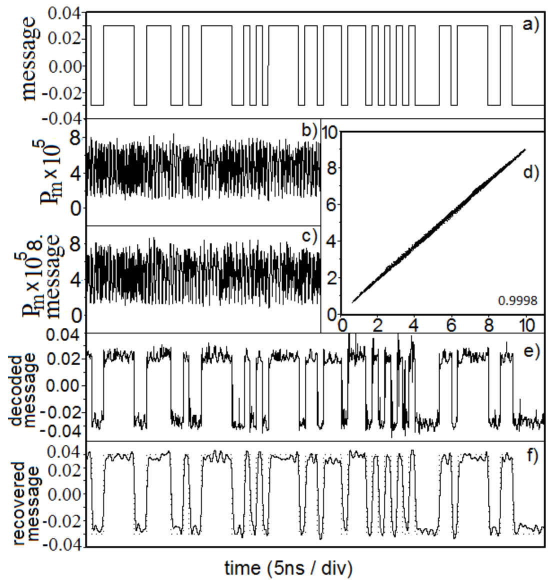

Fig. 3. Numerical results of a digital message encryption 5 Gbit/s, obtained with a chaotic lasers.

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References

[1] Krauskopf B. and Lenstra D. (Eds.) Fundamental Issues of Nonlinear Laser Dynamics, AIP Conference Proceedings. 2000, p. 548.

[2] Mirasso C.R., Colet P. and Garcia-Fernandez P. Synchronization of Chaotic Semiconductor Lasers, Application to Encoded Communications, IEEE Photon. Technol. Lett., 1996, vol. 8, p. 299-301.

[3] Tronciu V.Z., et al Chaos generation and synchronization using an integrated source with an air gap, IEEE J. Quantum Electronics., 2010, vol. 46, p. 1840-1846.

[4] Lang R. and Kobayashi K. External optical feedback effects on semiconductor injection laser properties, IEEE J. Quantum Electron., 1980, vol. 16, p. 347- 355.