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Nonlinear dynamics of semiconductor lasers and optical resonator systems: Chaos, bifurcations and attractors

ALEXANDER A MASHKANTSEV[1], SERGEY V KIR'YANOV[1], ALEXANDER V GLUSHKOV[1], ANDREY A SVINARENKO[1], VASILY V BUYADZHI[1*]

1. Odessa State Environmental University, Mathematics Depr., L'vovskaya str. 15, 65009, Odessa
* Presenting Author

Abstract: An advanced chaos-geometric computational approach to analysis, modelling and prediction of the non-linear dynamics of semiconductor laser and optical resonator systems with elements of the deterministic chaos is briefly presented. The approach is based on using the nonlinear analysis and chaos theory techniques such as a wavelet analysis, multi-fractal formalism, mutual information approach, correlation integral analysis, false nearest neighbour algorithm, the Lyapunov's exponents analysis, surrogate data method, prediction models etc. There are listed the advanced numerical data on the topological and dynamical invariants (correlation, embedding, Kaplan-York dimensions, the Lyapunov's exponents, Kolmogorov's entropy etc) of chaotic dynamics for the semiconductor GaAs/GaAlAs laser with a retarded feedback and optical resonator systems.

Keywords: nonlinear dynamics, semiconductor laser and resonator systems

1. Introduction. Universal Chaos-Geometric Approach to Laser and Resonator Systems Dynamics

A quantitative study of the chaos phenomenon features in the quantum electronics systems and devices is of a great interest and importance for many scientific and technical applications [1-3]. Chaotic fluctuations in the laser diodes dynamics deserve much attention because of their potential for unprecedented application of the technologies, secure communication, the construction of chaotic lidars, optical reflectometers, true random number generators etc. It is known that a transition to chaos in dissipative regime of functioning of NMR-maser provides the construction based on a new type of detecting signals with unprecedented sensitivity especially when approaching control parameter to the point of doubling bifurcation. The numerical results of study (data on the topological and dynamic invariants) of chaos generation dynamics in some quantum generator and laser systems with a few controlling parameters have been presented in [1-3].

This paper goes on our work on studying and advancing an effective computational approach to analysis and prediction of the non-linear dynamics of semiconductor laser and optial resonator systems with elements of the deterministic chaos [2-4]. In particular, the are presented the results of analysis, modelling and processing the corresponding chaotic time series of thesemiconductor GaAs/GaAlAs laser with a retarded feedback and some optical resonator systems. The computational approach applied includes a combined set of non-linear analysis and chaos theory methods such as an autocorrelation function method, correlation integral approach, average mutual information, surrogate data, false nearest neighbours algorithms, the Lyapunov's exponents (LE) and Kolmogorov entropy analysis, spectral methods and nonlinear prediction (predicted trajectories, neural network etc) algorithms (in versions [2,3,5,6]).

2. Results and Discussion

As illustration in Table 1 our computational data on the Lyapunov's exponents, Kaplan-York attractor dimensions, the Kolmogorov entropy for the corresponding chaotic time series of the semiconductor GaAs/GaAlAs laser with a retarded feedback [(e.g. [1,3]) are listed. In the system an instability is generated by means of the retarded feedback during changing the control parameter such as the feedback strength μ (or in fact an injection current).

Table 1. The Lyapunov's exponents **(λ_i),** Kaplan-York dimension **(d_L),** Kolmogorov entropy K_{entr}

Regime	λ_1	λ_2	λ_3	d_L	K_{entr}
Chaos (I)	0.151	0.00001	-0.188	1.8	0.15
Hyperchaos (II)	0.517	0.192	-0.139	7.1	0.71

As the analysis shows there is appeared a multi-stability of different states with the modulation period: $T_n=2\tau/(2n+1)$, n=0, 1,2,… The state n = 0 is called as a ground one. With respect to the frequency modulation, other states are called as the 3rd, 5th harmonics and so on. A scenario of chaos generation is in converting initially periodic states into individual chaotic states with increasing the parameter μ through a sequence of the period doubling bifurcations. Further there is appeared a global chaotic attractor after merging an individual chaotic attractors according to a few complicated scenario (e.g. [1,3]. The analogous numerical analysis, modelling, forecasting procedure are realized for some optical resonator systems.

3. Concluding Remarks

There are presented the fundamentls of a chaos-geometric computational approach to analysis, modelling and prediction of the non-linear dynamics of semiconductor laser and optial resonator systems with elements of the deterministic chaos. There are listed the advanced numerical data on the topological and dynamical invariants (correlation, Kaplan-York dimensions, Lyapunov's exponents etc) of chaotic dynamics for the semiconductor laser and optical resonator systems.

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