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Investigating the chaotic behaviour of multi-section semiconductor lasers using the transmission line laser model

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Abstract: A modified transmission line model was developed to investigate the chaotic dynamics of multi-section lasers: fast-tracking of the steady state and the Jacobian matrix analysis were used to improve its time efficiency.

1. Introduction

The chaotic behaviour of optically injected multi-section lasers, which consists of active and passive Fabry-Perot (FP) and DBR sections, has been of practical use for many applications [1]. Several numerical techniques for theoretical investigation of such dynamics are based on the rate-equation or FP method [2,3] and employ fast-tracking of the steady-state solution and subsequent Jacobian matrix analysis. However, they were developed only for simple one-section lasers and did not fully incorporate the spatial variation of the internal parameters [3]. On the other hand, the methods that take into account longitudinal non-uniformity of the laser cavity [4] are usually based on time-evolution techniques and require long computing time to accumulate data for laser dynamics analysis. In this study, we present the method that combines the advantages of the two approaches: it employs fast-tracking of the steady state point and the Jacobian matrix analysis and can handle a complex longitudinal structure with an arbitrary configuration.

2. Method, structure, and results

The governing equations describe the discrete-time evolution of a laser system. They are based on the transmission-line laser model, in which the cavity of a laser is divided into small subsections with piece-wise uniform longitudinal structures. The equations for the forward and backward propagating EM field are in the form of a scattering matrix that accounts for distributed feedback in DBR sections. The time-evolution formula for the carrier density is derived from the correspondent rate equation.

The setup consists of a master laser (ML) injecting light into a tuneable slave laser (SL) (Fig. 1). The dynamics of the SL is studied for different values of injection power and detuning between the ML frequency f_{ML} and the proper frequency of the solitary SL f_{SL}. In the first step, the steady-state of the SL under injection is fast-tracked using the transfer matrix approach and an iterative algorithm. The governing equations are then linearised with respect to a small perturbation to the steady state and the eigenvalues of the Jacobian matrix are calculated. The criterion for stability of a discrete time-evolution system is the magnitudes of all its eigenvalues must be less than one. The simulation results presented in Fig. 2 and 3 are (a) the spectrum, (b) the dynamics trajectories, and (c) the time series of the SL output signal for two values of the detuning (in the units of the relaxation oscillation frequency f_{RO}).

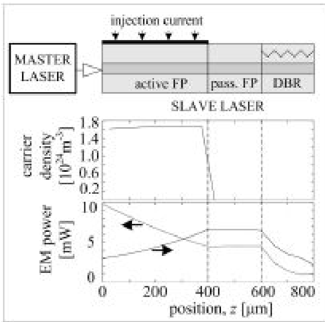

Fig. 1. General setup and structure.

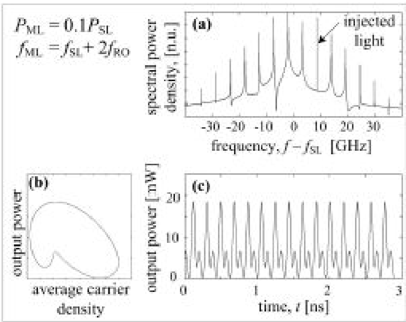

Fig. 2 Period-2 oscillation

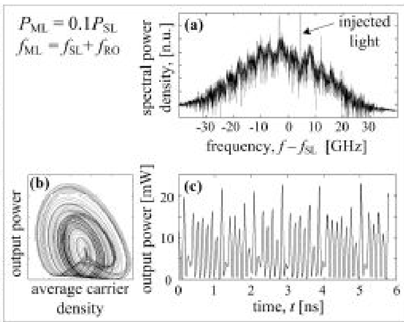

Fig. 3 Chaotic oscillation

3. Conclusion

A new approach has been proposed to investigate the chaotic behaviour of an arbitrary laser cavity. It combines two existing methods, the Jacobian-matrix analysis of the FP method and the spatio-temporal modelling of laser dynamics, in order to achieve the high computational efficiency of the former and retain the accuracy and versatility of the latter.

4. References

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