Excitability of Chaotic Transients in a Semiconductor Laser

O. V. Ushakov, H-J. Wünsche, and F. Henneberger
Humboldt Universität zu Berlin, Institut für Physik, Newtonstr.15, 12489 Berlin, Germany

M. Radziunas
Weierstraß-Institut für Angewandte Analysis und Stochastik, Mohrenstrasse 39, 10117 Berlin, Germany

A multi-section semiconductor laser is used to combine two fundamental phenomena observed so far only separately: excitability and chaotic transients [1]. Excitability means that the response of a system to external perturbations is "all" or "none" depending on whether the strength of the stimulus is above or below a critical threshold. Excitability is a paradigm in life sciences and fundamental for information processing in the brain. Excitable lasers could open new ways of information processing in optical networks. Chaotic transients, on the other hand, are long episodes of chaotic behavior which end eventually at an attractor that is usually not chaotic [1]. Lasers with such properties could be useful for chaotic communication. Semiconductor lasers with integrated optical feedback are excellent candidates to study such novel scenarios. The multi-section configuration enables us to tune feedback parameters in a wide range and to explore the phase space of the device in a systematic way [2].

The laser structure (Fig.1a) of the present study consists of a single-mode 1.55 μm distributed feedback laser, a phase section of higher band-gap material, and a 1.55 μm amplifier section (no Bragg grating), all with the same length dimension of a few 100 μm. While the current I_{DFB} pumps the laser above threshold, the extra injections I_{PH} and I_{A} serve to adjust phase and strength of the feedback as appropriate. When changing these control currents, the device undergoes a variety of generic bifurcations, where the mode of operation changes from continuous wave emission to chaotic oscillations and abruptly back to the continuous wave emission.

The generic phase-space portrait behind our observation consists in a boundary crisis of a chaotic attractor with a saddle born in a saddle-node bifurcation of continuous-wave states. The response to external stimuli of the device biased just beyond the crisis is studied by injecting short optical pulses into the DFB section. When plotting the height of the largest spike versus the energy of the stimulation pulse, an "all-or-none" response with a sharp threshold is found. Various facts clearly signify that the excitable dynamics of the system close to the boundary crisis is correlated with the former chaotic attractor. The transient spike trains subsequent to stimulation are highly irregular in frequency and amplitude. A striking finding from a practical point of view is that the device is capable of emitting hundreds of ns long pulse sequences (Fig. 1b), which is by two orders of magnitude longer than typical relaxation times of laser diodes. The measured duration τ of the chaotic transient decreases in a power law with the distance from the boundary crisis. Sufficiently far from the boundary crisis, the standard single-spike response of excitable systems is recovered.

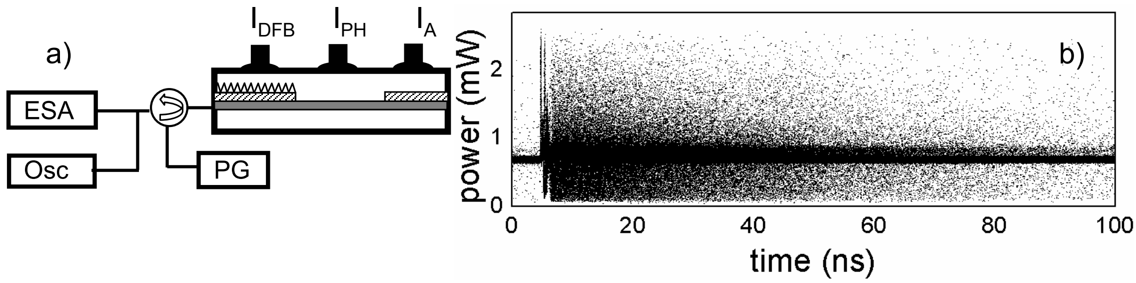

FIG. 1: a) Experimental setup: investigated laser, pulse generator (PG), electrical spectrum analyzer (ESA) to measure power spectra, and digitizing oscilloscope (Osc) to measure time dependent power. b) Excitable chaotic transients. The plot is a superposition of 500 repetitive scans with 500 data points each. Chaotic transients differ from each other after a time of the order of the largest inverse Lyapunov exponent. Consistently, a couple of quasi-deterministic spikes is seen at very early times. Later spikes are irregularly spaced and yield thus only a cloud of uncorrelated dots.

[1] A.L. Hodgkin, J. Physiol. 107, 165 (1948). C. Grebogi et al., Phys. Rev. Lett, 48, 1507 (1982).
[2] S. Bauer *et al.*, Phys. Rev. E. **69**, 016206 (2004).