LDSL: a tool for simulation and analysis of longitudinal dynamics in multisection semiconductor lasers

Mindaugas Radziunas[†,‡] and Hans-Jürgen Wünsche[‡]

[†] Weierstraß-Institut für Angewandte Analysis und Stochastik, Mohrenstr. 39, 10117 Berlin, Germany.
[‡] Humboldt-Universität zu Berlin, Institut für Physik, Invalidenstr. 110, 10115 Berlin, Germany.

Motivation. Multisection semiconductor lasers are key elements in the optical data processing systems. For example, the lasers consisting of two highly pumped distributed feedback (DFB) sections with different Bragg gratings and passive phase section (see Fig. 1) are able to produce ∼40 GHz frequency self pulsations and have been successfully applied for all optical data processing [1, 2]. Nevertheless, a deeper study of the underlying nonlinear processes and an optimization of such lasers are still strongly required [3].

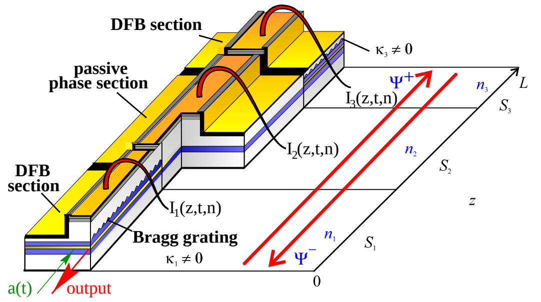

Figure 1: *An example of a 3 section DFB laser made at the Heinrich Hertz Institute, Berlin.*

Software tool LDSL. In order to simulate and to analyse nonlinear dynamics in multisection semiconductor lasers we have developed a software tool LDSL (abbreviation for Longitudinal Dynamics in Semiconductor Lasers, see [3, 4] and Fig. 2). LDSL-tool integrates models of different complexity, ranging from the systems of partial differential equations (traveling wave, or TW models (1)) to the reduced systems of ordinary differential equations (mode approximation, or MA systems (2)). Under certain assumptions our software allows to analyse the mode dynamics of TW model (Fig. 3), to compare the solutions (Fig. 3) and to do bifurcation analysis of TW and MA systems (Fig. 4).

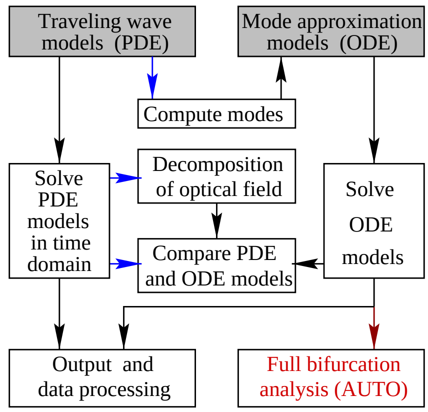

Figure 2: *A scheme of LDSL-tool.*

Traveling wave model. The nonlinear behaviour of multisection lasers can be described by the TW model, which takes into account the evolution of two counterpropagating optical fields $\psi = \psi^{\pm}(z,t)$, polarisation functions $p = p^{\pm}(z,t)$ within all laser device and carrier densities $n = n_j(z,t)$ within each laser section S_j (see also Fig. 1):

$$-i\partial_t \begin{pmatrix} \psi \\ p \end{pmatrix}(z,t) = H(\partial_z, \beta(n,|\psi|^2)) \begin{pmatrix} \psi \\ p \end{pmatrix}, \quad \frac{d}{dt} n(z,t) = J - R(n) - U(\Im m(\beta(n,|\psi|^2)), \psi, p). \quad (1)$$

Such a model contains a hyperbolic type system of partial differential equations of the first order governing evolution of optical fields ψ coupled with ordinary differential equations describing dynamics of functions p and n. More detailed description of operator H, propagation constant β, recombination and stimulation emission functions R and U can be found in [2, 4, 5].

Mode decomposition. A lot of useful information about the system (1) can be obtained by decomposing field/polarization functions at the actual values of $|\psi(z,t)|^2$ and $n(t)$ into eigenfunctions of operator $H(\beta)$:

$$\binom{\psi}{p}(t,z) = \sum_k f_k(t)\Theta(\beta(n,|\psi|^2),z), \qquad \text{where} \qquad H(\beta)\Theta(\beta,z) = \Omega(\beta)\Theta(\beta,z).$$

Analysing evolution of mode amplitude functions $f_k(t)$ we can better understand the profiles of computed laser output (upper part of Fig. 3) and detect all most important modes contributing to to the optical field at different time moments (lower part of Fig. 3).

Mode approximation systems and bifurcation analysis. Under the certain assumptions, we can approximate the TW model (1) by the mode approximation systems. For this purpose we substitute the field/polarization functions into (1) by their mode expansion and obtain the following system of ordinary differential equations describing dynamics of the mean sectional carrier densities $n_j(t)$ and modal amplitudes $f_k(t)$:

$$\dot{f}_k(t) = i\Omega_k(n)f_k + \sum_{m\neq k} D_m(\Omega,\Theta,\dot{n})f_m, \quad \dot{n}_j(t) = J - R(n) - \Re e\left(\sum_{m,k} U_{m,k}(\Omega,\Theta,n)f_m^* f_k\right). \quad (2)$$

If we select properly sufficient number of modes and have a good approximation of carrier dependent functions Ω_k, D_m and $U_{m,k}$, we can achieve a nice agreement between the solutions of TW and MA systems (see Fig. 3). Moreover, the analysis of the low dimensional MA system (2) with well developed path following tools can explain type of bifurcations observed in TW model (see Fig. 4 and [4]).

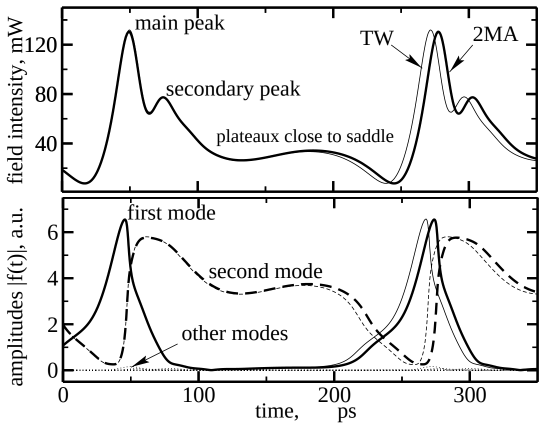

Figure 3: *Field intensity (above) and modal amplitudes $|f(t)|$ (below). Thin and thick lines indicate solution of TW model (or mode decomposition of the field) and solution of two mode approximation system, respectively.*

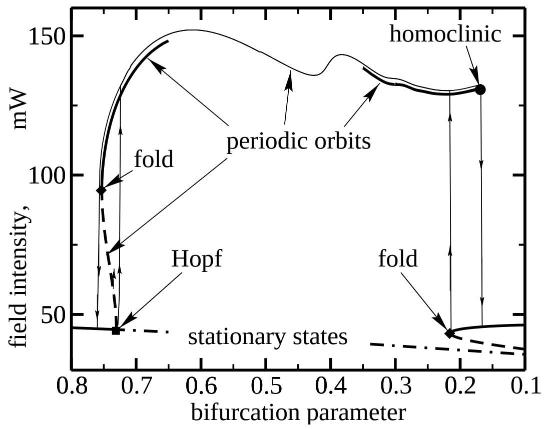

Figure 4: *Bifurcation diagram showing maximal field intensity of periodic solutions or stationary states in TW (thin) or two mode approximation (thick) systems. Dashed lines show unstable objects detected in 2MA case.*

Conclusion. In this summary we are briefly representing possibilities of LDSL tool simulating and analysing longitudinal dynamics of fields and carriers in the multisection semiconductor lasers. This tool was successfully used to investigate and to design lasers exhibiting various nonlinear effects such as self pulsations, chaos, hysteresis, mode switching, excitability, and synchronisation to an external signal frequency (see [3]).

[1] B. Sartorius et. all, *Electron. Lett.* **34**, pp. 1664, 1998.

[2] M. Möhrle et. all, *IEEE J. Selected Topics in Quantum Electron.* **7**, pp. 217-223, 2001.

[3] H.-J. Wünsche, *Invited talk at NUSOD-02*, ETH Zürich, Switzerland, September 25-27, 2002.

[4] M. Radziunas et. all, *WIAS – Preprint*, **713**, 2002. (available at "www.wias-berlin.de/publications/")

[5] U. Bandelow et. all, *IEEE J. Quantum Electron.* **Vol. 37 2**, pp. 183-189, 2001.