Tailoring the dynamics of multisection lasers for 40 Gb/s direct modulation

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Abstract- We demonstrate theoretically how a proper tailoring of the longitudinal structure of multisection semiconductor laser help to achieve the required device performance when modulating current with 40 Gbit/s PRBS signal. For this reason we simulate and analyze the longitudinal dynamics with the software package `LDSL-tool`.

Introduction Recently direct modulated semiconductor lasers have become a great interest in laser applications for optical data transmission systems. Different laser configurations can be considered for this purpose. However, until now the speed of these lasers is limited by relaxation oscillation (RO) resonance frequency.

One of approaches to overcome these limitations is the optimization of the laser growth implying an increase of the RO resonance frequency. For example, a theoretical paper [1] suggests an enhancement of the RO frequency up to 30 GHz. This increase, however, is still not sufficient for our purposes, since we would like to deal with 40 Gb/s data streams.

Another approach allowing a growth of the main resonance frequency up to 50 GHz was discussed in [2]. Here, a master-slave laser system was considered. The resonance frequency of the slave (VCSEL) laser in this case was tuned according to the changed wavelength of the master laser.

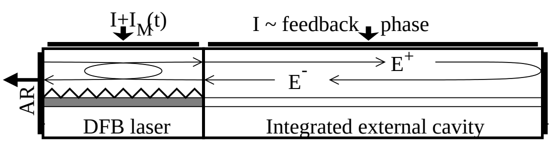

Figure 1: Scheme of the DFB laser with integrated external cavity.

In the present paper we do not try to optimize the transversal structure of a laser, but tailor its longitudinal design considering few monolithically integrated sections with sufficiently different field propagation properties. As it was noticed in [3, 4], multisection lasers can support the Photon-Photon (PP) resonance determined by the frequency separation of the two most important longitudinal optical modes. The simplest configuration of multisection laser admitting such PP resonance is the single-mode laser with a short external cavity (EC) [10] (see Fig. 1).

After finding the parameter regions where the PP resonance is dominant, we demonstrate the required device performance under direct current modulation with the random signal at 40 Gb/s rate.

Mathematical model and numerical tools To describe the dynamics of the multisection laser we use the Traveling Wave (TW) model [5]. It gives the spatio-temporal evolution of the slowly varying amplitudes of the counter-propagating optical fields which are nonlinearly coupled to the spatially averaged carrier density within active laser sections. The transverse properties of each laser section in this case are represented only by few parameters entering the TW model. However, as it was shown in, e.g., [6], our rather simple model is able perfectly to recover the qualitative dynamics of multisection lasers.

For simulations and analysis of the TW model the software package `LDSL-tool` (abbreviation for Longitudinal Dynamics in Semiconductor Lasers) [7] was used. Besides the straightforward integration of the model equations, this software package finds continuous wave (cw) states of the TW model, performs a mode analysis [8] and a bifurcation analysis of the reduced model properly describing the dynamics of the full TW model on the finite dimensional exponentially attracting invariant manifolds [9]. In the present paper we successfully apply all these different possibilities of `LDSL-tool`.

Finding the photon-photon resonance To have a dominant PP resonance at $\sim$ 40 GHz our laser device should satisfy a few requirements.

The required mode frequency separation can be realized if both the laser and the EC are not longer than few hundred microns. This condition can be fulfilled for the distributed feedback (DFB) laser with monolithically integrated passive EC section (see Fig. 1).

As it is known from [6, 9, 10], the PP resonance can be dominant if only the light feedback into the laser is large enough. To realize this requirement the EC should have a high reflecting outer edge and small field losses. To illustrate the importance of the feedback strength, we have treated it as a bifurcation parameter in Fig. 2. One can see here, that only for higher feedback the PP resonance can dominate.

Another important requirement is a possibility to change

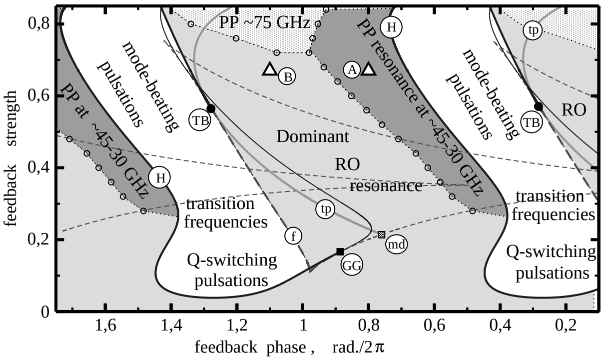

Figure 2: Two-parameter bifurcation diagram. Solid black lines: Hopf bifurcations. Dashed: fold bifurcations. Grey: a pair of cw states have the same threshold density (Tager-Petermann conditions [10]). Black box and bullet: codimension-two bifurcations. Grey box: mode degeneracy [9]. Different shaded areas: cw states with different dominant resonances. Empty triangles A and B: parameters of two cases considered below.

the field feedback phase. It was shown in, e.g., [6, 9] as well as by Fig. 2, that the tuning of this phase is implying switching on of the mode-beating pulsations with the PP resonance frequency. In the proposed devices the phase tuning can be realized by the changes of current in the passive EC section.

In our study we exploit the PP resonance in the vicinity of the Hopf bifurcation causing appearance of mode-beating pulsations. From the other hand, for direct modulation applications we still need to keep it damped, what implies the necessity to have a sufficiently large parameter regions with the dominant PP resonance.

Small and large signal analysis The dominance of the resonances at the different shaded areas of Fig. 2 were decided by inspection of the dominant eigenvalues of the TW model linearized at the stable cw states. To illustrate the validity of this approach we have also performed a small signal analysis at the parameters indicated here by triangles A and B.

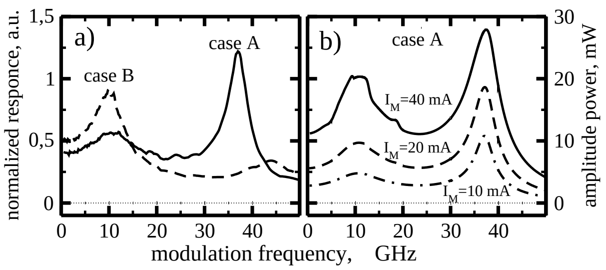

Figure 3: Small (a) and large (b) signal analysis. I_M in panel b) denotes amplitudes of current modulation.

The solid and the dashed lines in Fig. 3a) corresponding to the positions A and B clearly show the dominance of the PP resonance in the first case and its almost complete suppression in the second case.

In Fig. 3b) we have collected the performance of our device at the position A under periodic current modulation with different large amplitudes. Here, nonlinearity of our laser model imply the growth of the RO resonance.

Current modulation with 40 Gb/s PRBS Finally, we have set the parameters according to the position A shown in Fig. 2 and have performed the simulation of our laser with randomly modulated current at 40 Gb/s rate. The obtained results are collected in Fig. 4. The laser behavior demonstrated by this figure shows clearly opened eyes which meets minimum requirements for system applications.

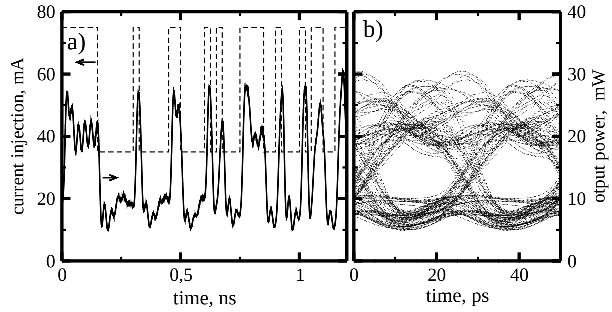

Figure 4: Simulated response of the device to a PRBS current modulation. a): injected current (dashed) and field output (solid). b): open eye diagram.

Conclusions We have demonstrated how the bifurcation analysis allows to find the parameter conditions at which the multisection laser can support the photon-photon resonance and at the same time suppress the usual relaxation oscillations. This PP resonance is exploited to achieve a satisfactory performance of the device under current modulation with 40 Gb/s PRBS signal.

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[1] M. N. Akram et al, *Semicond. Sci. Technol.*, **19**, p. 615, 2004

[2] L. Chrostowski et al, *Proc. Opt. Fiber Comm. Conf.*, March 6-11, p. OThM2, 2005

[3] G. Morthier, *IEEE PTL*, 16, p. 1616, 2004

[4] J.P. Reithmayer et al., *Proc. IPRM05*, May 8-12, p. 05CH37633C, 2005

[5] U. Bandelow et al, *IEEE JQE*, **37**, p. 270, 2001

[6] S. Bauer et al, *Phys. Rev. E*, **69**, 016206, 2004

[7] `LDSL-tool`: *www.wias-berlin.de/software/ldsl*

[8] M. Radziunas et al, *Chapter 5 in "Optoelectronic devices: advanced simulation and analysis" (ed. J. Piprek)*, Springer, p. 121, 2005

[9] J. Sieber, *SIAM J. Appl.Sys.*, **1**, p. 248, 2002

[10] A. Tager et al, *IEEE JQE*, **30**, p. 1553, 1994