Design of Multisection Semiconductor Laser for 40 Gb/s Direct Modulation

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Abstract *We consider theoretically a direct modulated distributed feedback laser with a very short integrated external cavity. We show how a proper selection of the field feedback strength and phase imply a required device performance for large signal modulation with 40 Gb/s NRZ signal.*

Introduction

Directly modulated semiconductor lasers are of great interest for low cost transmitter applications in short reach and very short reach optical data transmission systems. Mainly single section DFB laser modules are considered for this purpose. However, until now, the application of these lasers for data rates beyond 10 Gb/s per channel is limited by the modulation bandwidth, which is related to the relaxation oscillation (RO) resonance frequency.

At least three types of approaches are supposed to overcome this limitation. One concept optimises the laser stack, implying an increase of the differential gain and, in consequence, an increase of the RO resonance frequency. For example, in the theoretical paper [1] the enhancement of the RO frequency up to ~30 GHz is suggested.

Another approach is based on the injection of a holding beam [2]. It can allow an increase of the main resonance frequency up to 50 GHz in a master-slave laser system [3]. The resonance frequency of the slave (VCSEL) laser in this case was tuned according to the changed wavelength of the master laser.

A multisection laser concept has been stressed by several authors [4-6]. Experimentally, an increase of the 3 dB bandwidth up to about 40 Gb/s has been shown in small signal response analysis. The bandwidth improvement is attributed to photon-photon (PP) resonance.

In the present paper we theoretically investigate how to use the multisection concept in order to get both a high bandwidth for small signal modulation as well as a high performance in the large signal current modulation.

Concept

We design our multisection laser such that the dominating photon-photon (PP) resonance [4], determined by the frequency separation of the two most excited longitudinal optical modes could be located at ~40 GHz. At the same time the impact of the RO is suppressed.

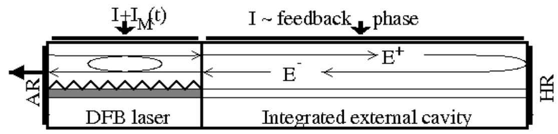

Fig 1. Scheme of the DFB laser with monolithically integrated ultra-short external cavity.

The simplest configuration of multisection lasers admitting such PP resonance is a single–mode laser with a short external cavity (EC) [7]. The required frequency separation is realized by a monolithically integrated passive EC section (see Fig. 1). Here, the distributed feedback (DFB) laser and the EC section are of a comparable length, and lead to a short roundtrip time in the compound cavity. The counter-propagating optical fields $E^{\pm}$ do not couple in the EC to the carriers or to each other, but undergo only some losses and a phase shift. It is highly important for our purposes that this phase can be tuned by changing the current injection into this section.

Optimum operation conditions

To simulate this considered laser we use the software package LDSL-tool [8] that integrates and analyses the traveling wave equations, describing the spatio-temporal evolution of the counter-propagating optical fields, and balance equations for the carrier density and the polarization.

In lasers with EC the PP resonance was already exploited to realize a high frequency mode-beating (mb) type pulsation of the optical field intensity [7,9]. These operation conditions are, however, not suited for our modulation purpose. In the present study we show, that similar lasers have cw states possessing a strong PP resonance before the onset of these pulsations, while RO resonance still can be kept strongly suppressed.

Fig. 2 shows a typical bifurcation diagram of the considered laser device depending on the feedback phase. Within the white area we have a stable cw state. At the phase A the RO resonance is dominant. At B both RO and PP resonances are equally pronounced. The PP resonance dominates at C, near to the Hopf bifurcation where mb pulsations appear.

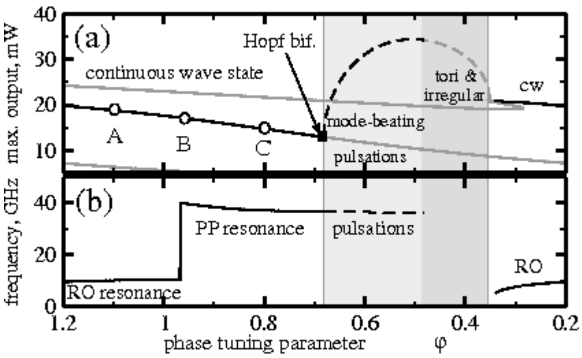

Fig. 2. Bifurcation diagram. 0utput power (a) and main resonance frequency (b). Solid and dashed: cw states and periodic orbits. Black/grey lines: stable/unstable branches. White: cw; grey: mb-pulsations, dynamics on tori and irregular dynamics.

Small and large signal analysis

At the phases A and C from Fig. 2 we have performed a small and a large signal analysis. Fig. 3a) compares the laser performance at these phases, showing the absence of the PP resonance at A and the dominating PP resonance at C. In Fig. 3b) we have collected the performance of our device at phase C under periodic current modulations with different amplitudes. Here, the intrinsic nonlinearity implies the growth of the RO resonance.

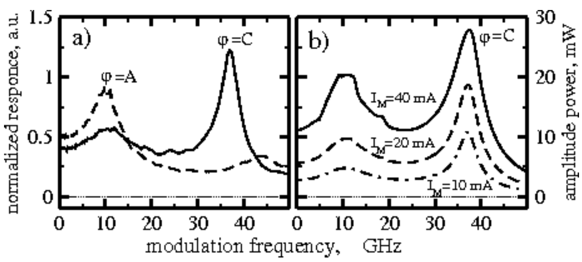

Fig. 3. Small (a) and large (b) signal analysis. I_M in panel b) denotes amplitudes of current modulation.

Current modulation with 40 Gb/s PRBS

Finally, we have set the feedback phase at C (see 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 behaviour demonstrated by this figure shows clearly opened eyes and a linear extinction of 3, which meats minimum requirements for system applications.

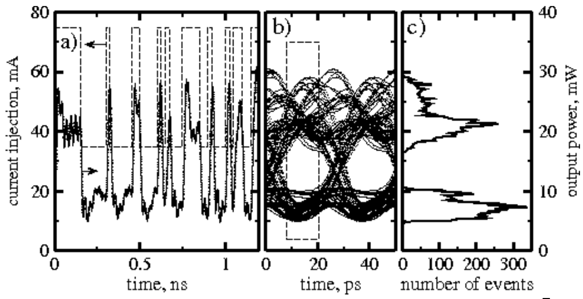

Fig 4. Simulated response of the device to a (2^7-1) PRBS current modulation (NRZ). a): injected current (dashed), field output (solid). b): open eye diagram. c): histogram of points within dashed box of panel b.

Further optimisation of the device

The frequency of the PP resonance can be optimised by a proper tailoring of the longitudinal structure. We could also exploit the PP resonance when simulating a three-section laser with an additional low pumped and suitably detuned DFB section at the right side of the EC. In this case the dispersive reflection implied by the broad stop band of this DFB section can play a similar role as the frequency independent reflectivity at the right facet of the EC. At the same time we have found that a higher differential gain and steeper P/I characteristics of the solitary DFB laser (which can be realized by an optimized transversal structure) can be also useful for enhancement of the device bandwidth and for the improvement of the quality of the device performance under current modulation.

Conclusions

We have demonstrated how properly prepared multisection lasers 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 NRZ signal.

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