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Modeling of devices for all-optical 3R-regeneration

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Abstract

Multisection DFB lasers for optical clock recovery and pulse reshaping are regarded. Understanding the complex dynamics within the devices leads to optimum conditions for different applications. New concepts towards very high bit rates are examined.

Introduction: The dramatic growth in internet traffic pushes the interest in high speed all-optical signal processing. One key function is 3R-regeneration (**r**eamplification, **r**etiming, **r**eshaping). A realization of this function at 40 GHz with using self-pulsating multisection DFB-lasers (Fig. 1) for clock extraction has been reported recently [1]. Here we briefly review the modeling that has accompanied the development of these devices and discuss results towards even higher frequencies. Furthermore, first investigations are outlined to use such compact devices as decision elements.

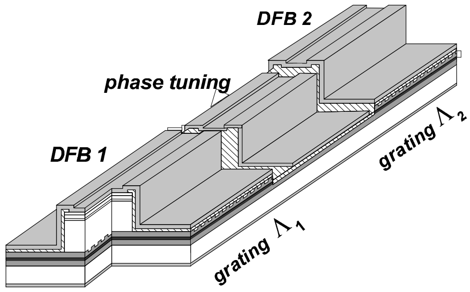

Figure 1: *View of a multisection (MS) DFB laser with detuned gratings.*

Model: We used mainly the simulation tool LDLS (longitudinal dynamics in semiconductor lasers) developed at HUB/WIAS to solve numerically the travelling wave equations for counter propagating optical fields combined with carrier rate equations. This tool offers several options to include effects as, e.g., gain dispersion, spatial hole burning, nonlinear gain saturation and spontaneous emission noise. It allows a detailed study of the dynamical processes within the devices. In particular, the provided mode analysis is essential to achieve an optimum mode control which is crucial for the functionality of the devices. LDSL together with the used parameter set has been evaluated by comparing to measurements with devices manufactured at HHI [2].

High speed optical clock: Multisection DFB lasers showing self-pulsations (SP) have opened a new field for the optical clock recovery at high bit rates. The basic effect was discovered in 1992 with 2-section devices [3] and interpreted in terms of dispersive self-Q switching [4]. Meanwhile this effect is well understood and successfully used in the 10 GHz regime of operation.

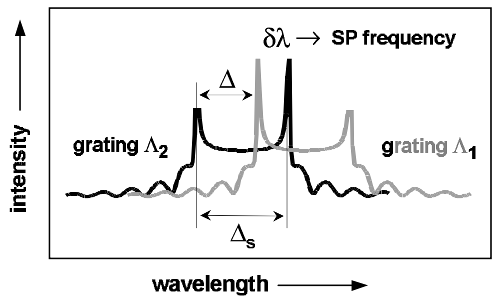

Figure 2: *Operation condition for two-mode self pulsations.*

To achieve much higher frequencies, we use two-mode SP [4]. Both DFB sections operate above threshold and have different grating periods. The estimated SP frequency $f_0 = c|\Delta - \Delta_s|/\lambda^2$ is governed by the difference between the detuning Δ of the two Bragg wavelengths and the width Δ_s of the stop band. Other theoretical investigations suggested to generate similar high-frequency beating pulsations in one-contact devices with chirped or pitch-modulated gratings [5].

However, to generate a self pulsation is not enough. It should have controllable properties. Therefore we have extended these ideas to more complex devices consisting of two DFB sections and one phase tuning section, each individually contacted (Fig. 1). In contrast to using only one or two contacts, this allows the independent control of different SP parameters by properly adjusting the three currents. The calculations yielded large areas of SP both for detunings smaller and larger

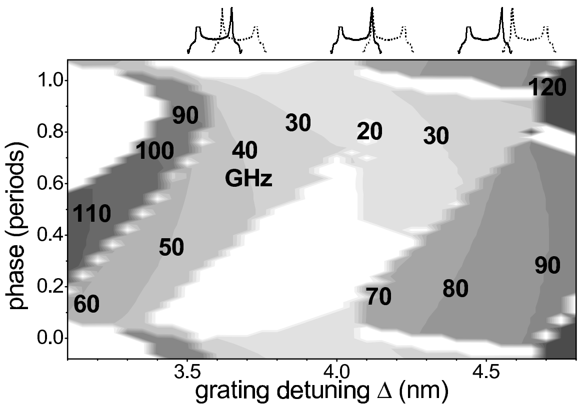

Figure 3: *Calculated frequencies of two-mode self-pulsations in dependence on phase shift and detuning* Δ *of the stop bands. White area: stationary single mode, SP with extinction ratio below 20% or chaos.*

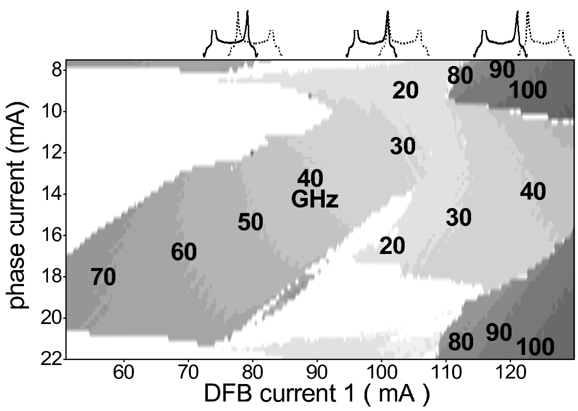

Figure 4: *Measured SP frequencies, notation as in Fig. 3. DFB section 2 is biased at 80 mA. DFB section 1 shows a thermal redshift by 1.7 nm over the plotted range of current, comparable to Fig. 3.*

than the stop band width (Fig. 3). The frequencies range from 20 to more than 100 GHz. MS-DFB-lasers with detuned gratings fabricated at HHI exhibited the expected high speed SP (Fig. 4). Other parameters behave similar in theory and experiment, too, indicating that the wanted physical effect is realized.

Optical clock recovery requires furthermore a good extinction ratio of the SP, synchronization to the tact of an injected data stream and a low jitter. With appropriate design and operating conditions, these features have been demonstrated both in simulation and measurement. Typical

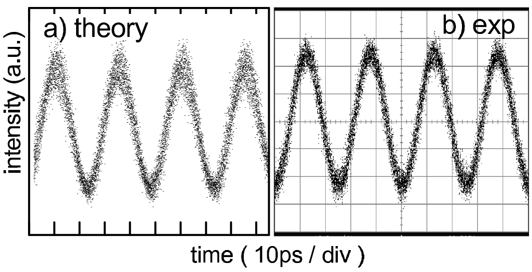

Figure 5: *Comparison of calculated and measured eye diagrams of a locked 40 GHz self-pulsation.*

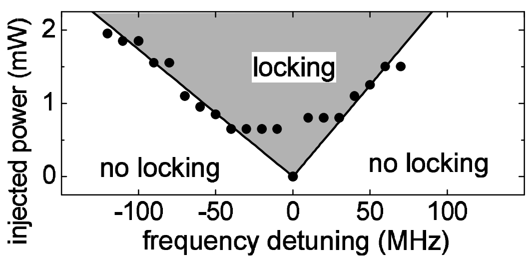

Figure 6: *Calculated locking range at 40 GHz.*

locking ranges are in the order of 100 MHz. Summarizing so far, the two-mode SP in MS-DFB-lasers are well suited for clock recovery at very high frequencies because they are not limited by the relaxation frequency. Several hundred GHz have been achieved in our simulation calculations with appropriately designed gratings.

Decision element: Today the best technique to perform the decision function in all-optical 3R regenerators are monolithically integrated interferometers. These devices have relatively large dimensions. Laser based devices could become a more compact alternative if they offer steep all-optical transfer functions. We very briefly refer to two directions of investigation.

Use of Q-switched lasers: Multisection DFB laser can also be used for dispersive Q-switching when appropriately designing and biasing them. Modulating the index of refraction by an injected optical signal causes steep changes of the optical output in this case. Very recently, such devices have been successfully applied as decision element in a 10 Gb/s optical 3R regenerator [6]. Extension towards 40 GHz is under work.

Use of nonlinear gain saturation: Much higher bit rates require a mechanism free from limitations by the carrier life time. When investigating the propagation of two incident waves through a long semiconductor optical amplifier (SOA) we found an unusual manner to exploit the four-wave mixing by nonlinear gain saturation with a very large extinction ratio for these purposes. Under certain conditions, the power extracted by this process from both incident waves is identical and the weaker wave experiences a larger relative damping along the device. As a consequence, a transfer function is obtained that improves with increasing length L of the SOA. Fig. 7 gives a simulated example. The incident power of one wave (control) is kept at 5 mW wheras that of the second wave (signal) varies. In time dependent simulations we observed that this strongly nonlinear and very attractive transfer function with a tunable threshold remains nearly unchanged up to bit rates of several hundred Gb/s because its speed is limited only by the response time of the nonlinear gain saturation (some hundred fs).

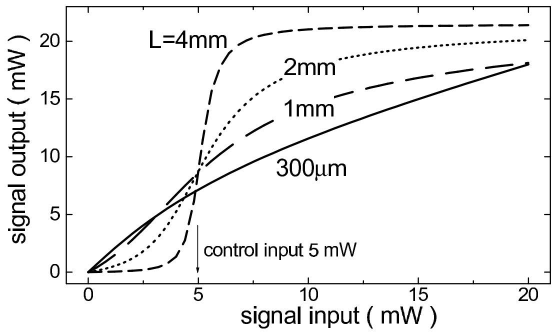

Figure 7: *Calculated stationary transfer function for different lengths L of a SOA under conditions described in the text.*

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