

Detuned grating multi-section-RW-DFB-lasers for high speed optical signal processing

Martin Möhrle, Bernd Sartorius, Carsten Bornholdt, Stefan Bauer, Olaf Brox, Ariane Sigmund, Ralf Steingrüber, Mindaugas Radziunas, and Hans-Jürgen Wünsche

Abstract— We present a detailed description and a first theoretical study of an improved concept for high frequency self-pulsations (SP) in multi-section (MS)-DFB-lasers with an integrated phase tuning section. The DFB-wavelengths of the two DFB sections are spectrally detuned by nearly the stopband width using two gratings with different grating periods. If both DFB-sections are operated at lasing conditions and an appropriate phase is chosen, we obtain beating-type SP with a frequency given by the spectral distance of two lasing modes. Good agreement between theory and experiment is obtained with respect to the role of the detuning, the role of the phase section, as well as the synchronization to external injected signals. The modeling shows a strong nonlinear coupling of the two involved modes via the carrier densities. This effect is important for the mutual coherence and for the observed locking of the beating oscillations to external signals. From the results of the calculations we draw the conclusion that even higher SP frequencies can be obtained based on the new concept.

Keywords— semiconductor laser, distributed feedback, modelling, self-pulsations, high speed, all optical signal processing, synchronization

I. INTRODUCTION

The dramatic growth in internet traffic pushes the interest in high speed all-optical signal processing. Optical clock recovery is a key function, and self-pulsating (SP) DFB-lasers are promising candidates for this application. Polarisation independent optical clock recovery at 10 Gbit/s has already been shown successfully [1] and also bit-rate flexible operation from 5 GHz to 20 GHz has been demonstrated [2].

Theoretically, self-pulsations with frequencies up to 200 GHz were demonstrated already in '95 for two-section two-contact DFB lasers and qualified as beating of two coexisting modes [3], [4]. The main prerequisites of these SP were a static detuning of the two grating periods and operating both DFB sections above threshold. Other theoretical investigations suggested to generate such high-frequency beating pulsations in one-contact devices with either chirped gratings [5], [6] or pitch-modulated gratings [7].

Only very recently, a first practical realization of a device with detuned gratings for 40 GHz self-pulsations [8] and its successful system application [9] have been announced. In this paper we present a more detailed description and a

M. Möhrle, B. Sartorius, C. Bornholdt, S. Bauer, O. Brox, A. Sigmund, R. Steingrüber are with Heinrich-Hertz-Institut für Nachrichtentechnik Berlin GmbH, Einsteinufer 37, D-10587 Berlin, Germany.

M. Radziunas is with Humboldt-Universität zu Berlin (HU), Institut für Physik, Invalidenstr. 110, D-10115 Berlin, Germany and with Weierstraß-Institut für Angewandte Analysis und Stochastik (WIAS), Mohrenstr. 39, D-10117 Berlin, Germany.

H.-J. Wünsche is with HU.

first theoretical study of these devices. They comprise two DFB sections and a phase tuning section in between as sketched in Fig. 1. The DFB sections are identical except

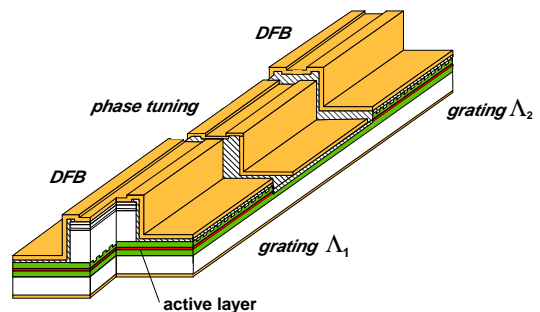


Fig. 1. Schematic cross section of MS-RW-DFB-devices

for different grating periods. Each of the three sections is individually contacted. In contrast to using only one or two contacts, this allows an independent control of output power as well as frequency and modulation depth of the SP by properly adjusting the three currents. This flexibility is important for optimum device operation in practical applications.

The paper is organized as follows. Sections II to IV give brief descriptions of the physical basis of the device concept, the technological realisation of the devices, and the scheme of the numerical simulation calculations, respectively. Results of measurements and calculations follow. Section V describes in detail how the effect of the grating detuning works, section VI shows the important function of the phase tuning sections, and Section VII demonstrates the locking to external signals. The paper closes with conclusions.

II. BASIC DEVICE CONCEPT

As suggested by theory [3], [4], the Bragg-wavelengths of the two DFB sections of our devices are spectrally detuned using two gratings with different grating periods, say $\Lambda_1 > \Lambda_2$. Both DFB-sections are operated at lasing conditions. It is useful to regard this situation as the face to face operation of two single section DFB lasers with detuned stop bands as sketched in Fig. 2. Each of the two lasers oscillates on that side of its stop band, which gets a large feedback from the stop band of the other laser. From this point of view, each DFB section plays a double role. It is the laser source of one mode and serves at the same time as a Bragg reflector for the other mode belonging to the op-

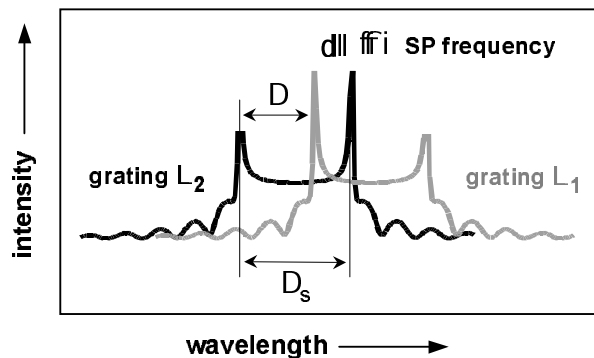


Fig. 2. Spectral situation for a detuning by nearly the stopband width.

posite laser. Both modes can coexist because they are fed independently by different sections each one pumped above threshold. The superposition of their amplitudes produces a beating-type SP with a frequency given by the spectral distance of the two lasing modes. Because this distance is governed by the difference between the detuning Δ of the two Bragg wavelengths and the width Δ_s of the stop band, the beating frequency can be estimated from

$$f_0 = \frac{c}{\lambda^2} |\Delta - \Delta_s|. \quad (1)$$

On this level of simplification, the relative detuning $\Delta - \Delta_s$ is the main parameter to control the pulsation frequency. In section V it will be investigated to which extent this remains valid in the real devices.

The simple linear superposition of two independent laser emissions with uncorrelated phase noises does not yield a useable beating. A nonlinear coupling of the two lasers is required to achieve their coherent operation as well as a locking of the beating oscillation to external signals. In our devices, the mutual optical injection leads to such a coupling of both laser fields via the interaction with the carrier densities. It is well known that the phase shift between the lasers plays a crucial role in such an optical-injection configuration. Therefore we have included a phase tuning section in our device concept. Its main function is to allow to adjust the phase shift with the help of a current. More details on its design are given in the subsequent section and its functionality is investigated in section VI.

III. DEVICE REALISATION

Based on the ridge-waveguide (RW)-structure MS-DFB-lasers comprising two DFB-sections with detuned gratings and an integrated phase tuning section have been fabricated (Fig. 1). For optical signal processing polarisation independence of the optical clock is of prime importance. Therefore we use an optimised InGaAsP-InP-bulk heterostructure as active layer which is grown by low-pressure MOVPE. It consists of a 1550 nm InGaAsP-layer which is embedded in an asymmetric 1180 nm/1300 nm-InGaAsP optical waveguide. Polarisation independence of the optical gain in the device is achieved by a suitable adjustment of the thickness of the layers and the strain of

the active layer. The detuned DFB-gratings are realised using electron beam lithography and reactive ion etching. The coupling coefficient of the gratings is typically adjusted to about 130 cm^{-1} . After the grating definition the active layer in the phase tuning section is removed and in a second MOVPE step the p-cladding layers are grown. The wafers are then processed into multi-section ridge-waveguide lasers. The length of the two DFB-sections and the phase tuning section are 0.25 mm, 0.25 mm and 0.4 mm, respectively. Both facets of the devices are anti-reflection coated.

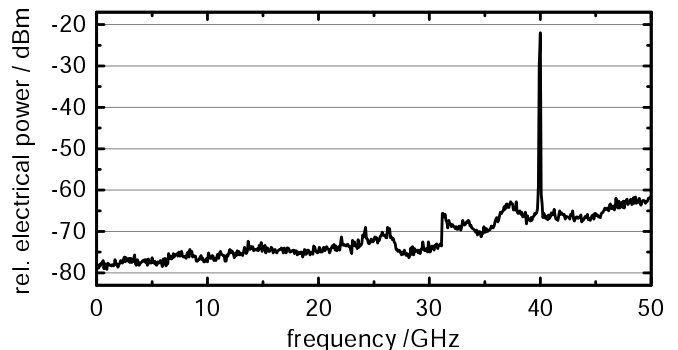


Fig. 3. A measured RF frequency spectrum indicating 40 GHz self-pulsation. Injection currents: $I_1 = 104 \text{ mA}$, $I_2 = 58 \text{ mA}$.

High-speed self-pulsations could be generated with the described devices by operating the two detuned DFB-sections at lasing conditions and adjusting the phase tuning current to SP conditions. As an example, a free-running SP at 40 GHz is indicated by the RF spectrum shown in Fig. 3. The optical spectrum in the same point of operation drawn in Fig. 4 a shows two distinct main peaks of similar height and with a separation just corresponding to the 40 GHz pulsation frequency. These results are a first confirmation of the basic concept of two-mode SP. Note also the pronounced suppression of all other modes by about 50 dB.

IV. NUMERICAL SIMULATIONS

A deeper understanding of the device operation beyond the simple noncoupled-laser picture of Section II requires a comprehensive modeling of the device. Very recently, some of us have reported on such a powerful and effective model of a three section laser with integrated phase tuning section [10]. Very good agreement between this model and experiment has been shown for the dispersive Q-switching self-pulsations in the 10 GHz band. This type of SP appears if one DFB section is kept passive by biasing it close to the transparency current. Now we apply the same numerical model to the devices with detuned gratings and with two active sections. We have carefully adapted its numerical performance to the expected much higher pulsation frequencies.

In the calculations to be presented we considered identical DFB sections (except the different grating periods) symmetrically pumped at $I_1 = I_2 = 70 \text{ mA}$. Most model pa-

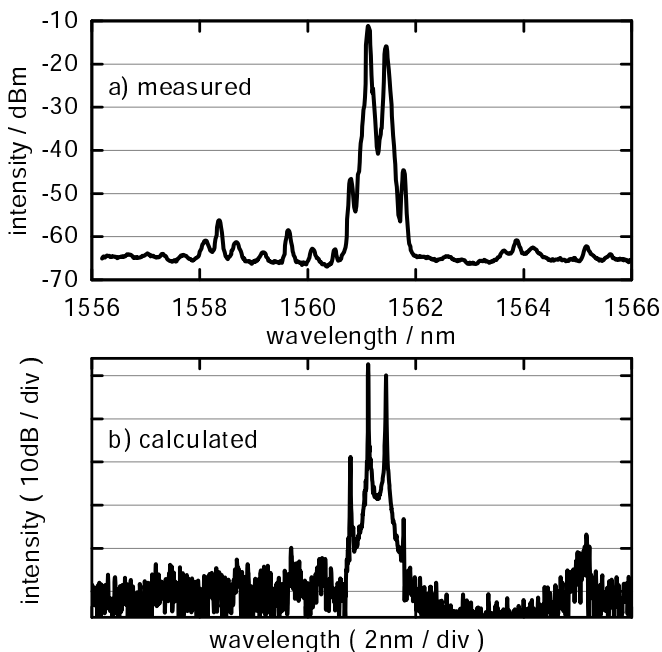


Fig. 4. Optical spectra of two-mode self-pulsations. a) measured for the 40GHz-pulsation of Fig. 3 and b) calculated for similar conditions.

parameters are taken from [10], only the differential gain and the Henry-factor are slightly changed to $g' = 2.3 \times 10^{-20} \text{m}^2$ and $\alpha_H = -4$. We have checked some different section lengths but did not find a dramatic influence within reasonable limits. Therefore the section lengths are fixed to those of the experimental device described in section III. As most important control parameters the detuning Δ and phase shift φ are varied. At every investigated point of operation the equations were solved in a 10ns time interval using the final state of the last point as initial state. The observed hysteresis effects were only marginal and are not drawn in the following figures for clarity. To characterise the dynamic behaviour of the device, the last 5ns of the calculated temporal evolution are used to calculate the power spectra, the optical spectra and to analyse the variations of carrier densities and output powers. Furthermore, we calculate the spectral positions and the dampings of the optical modes using the temporally averaged carrier densities.

To identify two-mode self-pulsations, we apply the following criteria:

- i) Periodic pulsations of the output power $P(t)$.
- ii) The optical spectrum has two distinct main peaks differing by not more than 10dB as in Fig. 4.
- iii) The spectral separation of the two peaks corresponds to the period of the pulses.
- iv) The two peak positions coincide with those of two different modes and all modes but these two are damped.

Applying these criteria, we detected two-mode SP in large parts of the investigated parameter space. In the next sections we shall present representative results in comparison with measured data.

V. EFFECT OF GRATING DETUNING

According to the basic concept of Section II, the detuning Δ between the two Bragg-wavelengths plays an outstanding role. In this section, we check this supposition and the simple formulae (1) by measurements and numerical simulations.

It is difficult to determine experimentally the dependencies on the grating periods because this would require to fabricate a series of devices with different grating periods but otherwise identical parameters. Fortunately, the required spectral shift of the stop band is also achievable with one and the same DFB section by changing its temperature. In particular, due to current induced heating, the stop band shifts to longer wavelengths with increasing pump current I [11]. In case of different pump currents, a corresponding thermal detuning Δ_{th} adds to the detuning Δ_{gr} that is caused by the different grating periods. We used this effect to change $\Delta = \Delta_{gr} + \Delta_{th}$ by varying the current I_2 in the shorter wavelength section and keeping the other currents constant. The measured frequencies in-

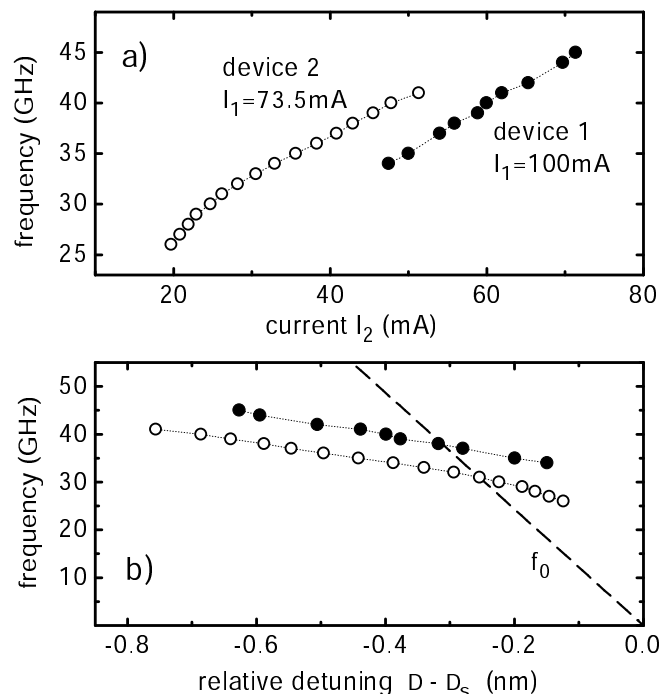


Fig. 5. Measured effects of grating detuning for the two different devices described in the text. a) SP-frequency versus pump current I_2 of the short wave DFB-section at fixed current I_1 of the long wave section. b) The same data plotted versus the relative detuning $\Delta - \Delta_s$ estimated as described in the text. Dashed: formula (1).

creased with I_2 as drawn in Fig. 5 a for two different devices with 40 GHz pulsations. This behaviour is expected for the spectral situation of Fig. 2, when the lasing mode of section 2 shifts red by the current induced heating, increasing the mode separation and, thus, the beating frequency.

In order to check this conclusion quantitatively and to compare with formula (1), we independently measured

the current induced thermal detuning of 250 μm long single DFB sections with the present device structure. The observed average red shift by 0.02 nm/mA is in good agreement with the 0.023 nm/mA redshift measured earlier with former device generations [11]. Together with the known values of grating detuning and stop band width (device 1: $\Delta_{gr} = 2.5$ nm, $\Delta_s = 3.7$ nm; device 2: $\Delta_{gr} = 4.5$ nm, $\Delta_s = 5.7$ nm), this allowed to replot the measured frequencies versus the relative detuning in part b of Fig. 5.

Both devices show a similar behaviour. The pulsation frequencies increase with $|\Delta - \Delta_s|$. However, the slope is much weaker than expected from the simple formula (1). The results of simulation calculations to be presented allow a natural explanation of this discrepancy as a consequence of the interaction between the two laser sections.

In the calculations, Δ is changed in the interval from 3 to 5 nm, centred at the estimated stop band width $\Delta_s \approx 4$ nm. Fig. 6 shows exemplary results for one fixed appropriate phase condition and equal pump currents $I_1 = I_2 = 70$ mA. Self-pulsations were obtained also for asymmetric pump currents as in the measurements. Their frequencies depended only on Δ but not on the currents as long as the pump asymmetry $|I_1 - I_2|/(I_1 + I_2)$ was below 50%. Thus, the dependencies on Δ calculated for $I_1 = I_2 = 70$ mA are representative and can be compared with Δ -dependencies measured with different currents.

For the particular value of the phase shift, self-pulsations are obtained not only for $\Delta < \Delta_s$ but within the whole investigated range of detuning. The corresponding optical spectra always show two main peaks of nearly the same height. The spectral position of each peak coincides with one of the modes and the mode spacing gives exactly the pulsation frequency. These features prove the two-mode regime of these self-pulsations in agreement with the basic concept.

The two active modes move with Δ similar to the corresponding resonances of the uncoupled lasers (dashed lines). Accordingly, the pulsation frequency f becomes minimum at $\Delta \approx \Delta_s$ and increases with $|\Delta - \Delta_s|$ up to about 120 GHz at the borders of the investigated detuning interval.

However, these variations are not continuous. Owing to the large coupling between the two active DFB sections, compound modes are formed. They vary with Δ much less than the uncoupled resonances. Mode jumps contribute to the large global shifts of the active wavelengths. At $\Delta - \Delta_s \approx -0.4$ nm, the short wave spectral peak jumps from mode -2 to mode -1, whereas both peaks jump to a next mode at $\Delta - \Delta_s \approx 0.6$ nm. Abrupt changes of the pulsation frequencies appear there. As a consequence, the variation of f in the continuous regions becomes weaker and not the whole frequency range can be addressed.

Another feature of coupled laser sections is that the compound modes do not cross each other. The separation of the active modes remains finite at $\Delta \approx \Delta_s$, resulting in a minimum frequency of the two-mode pulsations of about 25 GHz.

The calculated SP frequencies agree very well with the measured ones of Fig. 5 b. Both they vary with Δ much

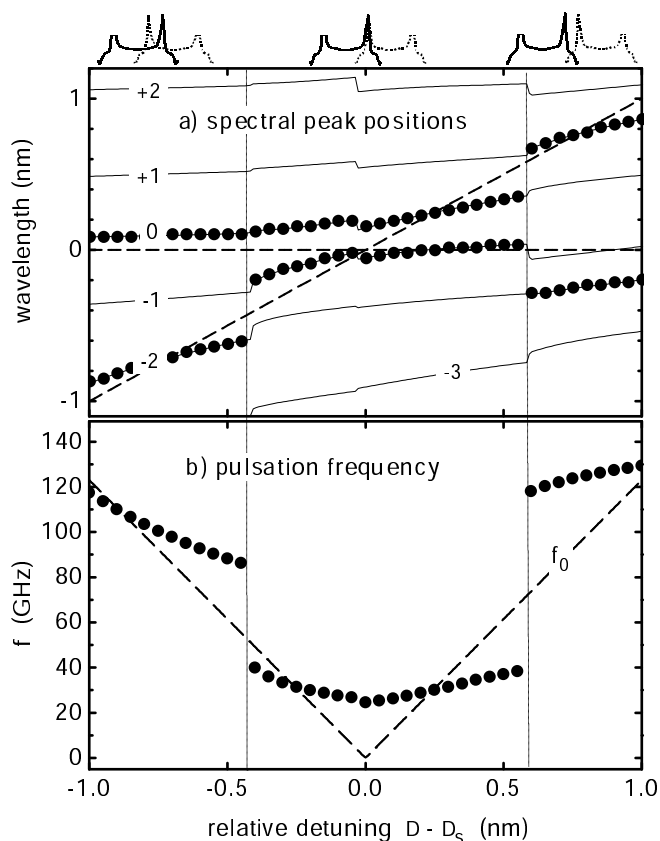


Fig. 6. Effects of grating detuning calculated for $I_1 = I_2 = 70$ mA and the fixed phase shift $\varphi/2\pi = 0.9$. a) Positions of all peaks of the optical spectrum within a 10dB margin (fat dots) compared to the mode wavelengths (thin lines). The zero of wavelength is arbitrary but fixed relative to section 2. The dashed lines illustrate the corresponding spectral shifts of uncoupled laser sections. b) SP frequency (fat dots) compared with the estimate from Equ. (1) for uncoupled lasers. The sketches above the figure illustrate the spectral correlations of the uncoupled laser sections in the corresponding range of detuning.

weaker than f_0 and do not tend to zero for $\Delta \rightarrow \Delta_s$ due to the coupling effects. The limited range of measurable frequencies did not allow an experimental check of the calculated mode jumps to higher frequencies. However, we believe in the modeling and are optimistic to achieve self-pulsations of this type in the 100 GHz range already in the near future.

Concluding this section, two-mode self-pulsations can be generated over large ranges of detuning. The measured SP frequencies are well explained by the numerical calculations. They are remarkably influenced by coupling effects that weaken their variation with detuning. The coupling is however important for the mutual coherence of the two lasers and for the ability to lock to external signals.

VI. EFFECT OF PHASE TUNING

Let us turn now to the role of the middle section of our device. Its most important function is to introduce a tunable phase shift φ between the two active DFB sections. Both in theory and experiment, the wanted generation of

two-mode self-pulsations requires to adjust to an appropriate phase.

Experimentally, phase tuning is possible via the injection current into this section. With increasing current, a cyclic appearance and disappearance of self-pulsations is observed. Fig. 7 shows a typical example for the first cycle covering about 7 mA. Note that the decreasing currents used as abscissa correspond to increasing phase shift. SP are found in about 65% of this period. Within this range, the frequency falls from 31 GHz down to 19 GHz. Thus, the phase tuning is not only essential for switching on the self-pulsations but moreover can be used for a fine tuning of the frequency.

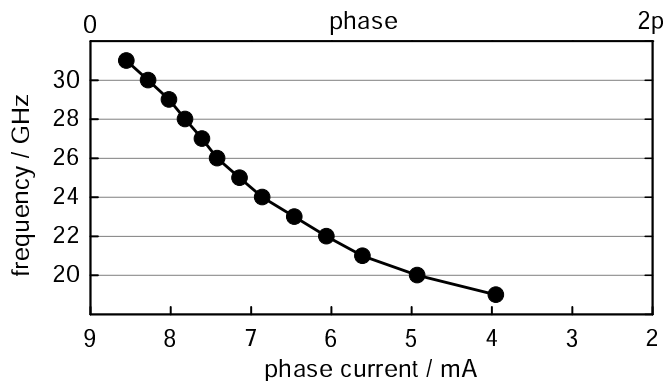


Fig. 7. Measured variation of the pulsation frequency with the phase tuning current. The depicted current interval of 7 mA is one phase period, decreasing current corresponds to increasing phase.

In the calculations, the phase φ is an independent parameter. Typical simulation results are drawn in Fig. 8 for a detuning belonging to the lower frequency band of Fig. 6. Three regions of qualitatively different dynamical behaviour can be seen, separated by the vertical lines labeled with capital letters. The two-mode SP appear in about 53% of a phase period. This compares well with the typical pulsation ranges known from the measurements. In the interval (A,B), only one mode carries noticeable power and a stable stationary output is observed. Other speaking, this is the region of mutual frequency locking of the two coupled lasers. An irregular chaotic output is generated in the phase interval (B,C). The optical output has irregular pulses and multiple peaks appear in a broad optical spectrum. Within the pulsation region, the calculated frequency varies by about 15 GHz. This is comparable with the widths of the frequency bands shown in Fig. 6 b and also with the typical measured ranges of frequencies (cf. Fig. 7).

The carrier densities in the two DFB sections are different and depend on the phase condition (Fig. 8 c). On the first sight this appears surprising since both sections are operated at equal currents, and they are identical except the grating period. The dependence of carrier density on phase conditions turns out as one more signature of the considerable coupling between both sections as discussed above.

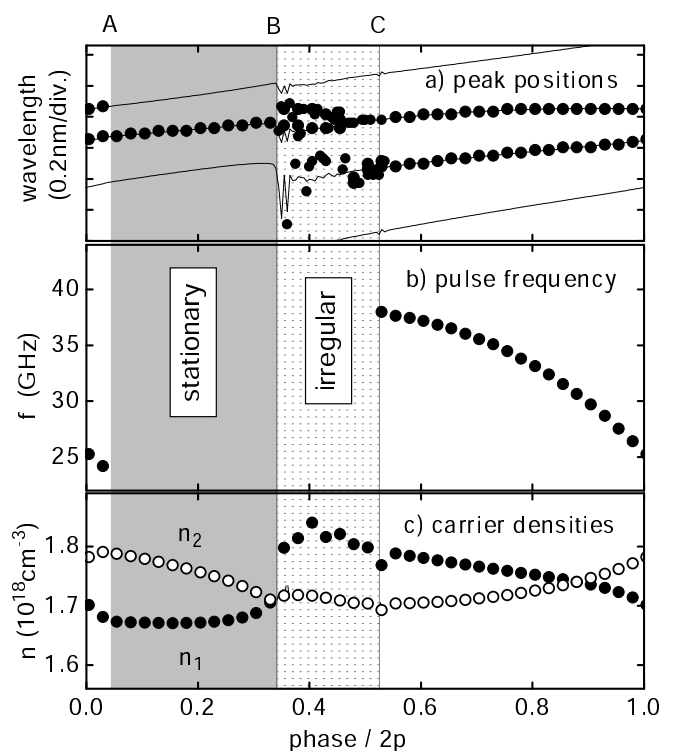


Fig. 8. Effects of phase tuning calculated for $\Delta - \Delta_s \approx -0.2$ nm. Notations in parts a and b as in Fig. 6. Part c shows the temporal average of the carrier densities in the two DFB sections.

VII. LOCKING

Optical clock recovery bases on the synchronization of the self-pulsation to the tact of a data stream optically injected into the device. In the present section we demonstrate and discuss this phenomenon for a device with 40 GHz two-mode self-pulsations both by simulation and measurement.

The emission of a self-pulsating laser has two characteristic frequencies, the optical frequency (about 200 THz) and the pulsation frequency of 40 GHz. Additionally, this nonlinear system has a damped resonance at the frequency of the relaxation oscillations (few GHz). All frequencies could lock to an according period of the injected data stream. In the following we confine ourselves to the case of nonresonant locking, i.e., the synchronization of the optical frequencies is prevented. To this purpose the wavelength of the injected light is chosen about 10 nm shorter than that of the laser. This is far from the stop bands but still in the gain regions of the DFB sections. Accordingly, the injected light is slightly amplified and causes an additional stimulated recombination of the carriers in both DFB sections. The resulting modulation of the carrier densities in the tact of the injected signal modifies the mode frequencies and in turn the pulsation frequency. A locking of the pulsation frequency to the tact of the signal may be the consequence. Details of the underlying mechanisms are not the subject of this paper and will be presented elsewhere.

Experimentally, the locking behaviour is investigated by

injecting a 40Gb/s RZ PRBS signal into the module. If the free running SP locks to the incoming signal, the peak of the RF-frequency spectrum shifts to the external frequency and narrows drastically. An example for a frequency detuning by -50 MHz is shown in Fig. 9 a. In the locked state, also the temporal pulse shapes can be measured by sampling techniques. The example depicted in Fig. 9 b indicates a high quality of the extracted clock signal. The polarisation dependence of the locking function is only about 0.5dB.

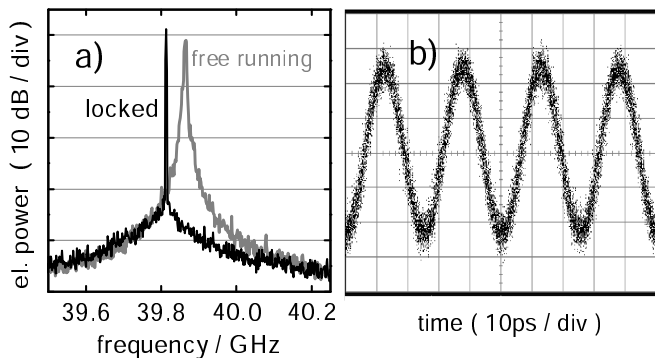


Fig. 9. Experimental demonstration of locking of a self-pulsation at 39.91 GHz to an injected pulse stream with 39.86 GHz tact frequency. a) Shift and narrowing of the RF frequency spectrum. b) Eye diagram of the locked self-pulsation.

In the simulation we confine ourselves to injected optical signals with a harmonic modulation with frequency f . Synchronization to the external frequency can be expected only for a sufficiently small detuning from the frequency f_0 of the self-pulsation. Typical locking ranges are of the order of some ten MHz. This is only an extremely small fraction of the pulsation frequency itself. Thus, f_0 has to be determined very accurately and f must be chosen very close to it.

For a given point of operation, we started the locking calculations always with a nonmodulated optical input with constant power $p_0 = 1$ mW. Already this constant input changes the carrier densities and causes a small shift of the pulsation frequency. We determine this shifted frequency f_0 very accurately from the mean period of a sequence of some thousand pulses. In the following steps we apply an amplitude modulation of the injected light according to $p_0 + \delta p \sin(2\pi ft)$ with a slightly detuned frequency f . Note that the mean power of this type of signal is independent on the modulation depth δp . This suppresses to a large extend a shift of the mean carrier densities and the resulting shift of f_0 . For a given modulation parameter δp , the optical output is sampled with the external frequency f over several thousand pulsation periods. The resulting eye diagrams allow a clear decision whether the pulsation is locked or not. Without locking a closed eye is obtained as in the left part of Fig. 10. A typical result for the case with locking is depicted in the right part of the same figure. Note that the calculated pulse shape as well as the jitter due to spontaneous emission noise agree well with the measurements in Fig. 9 b.

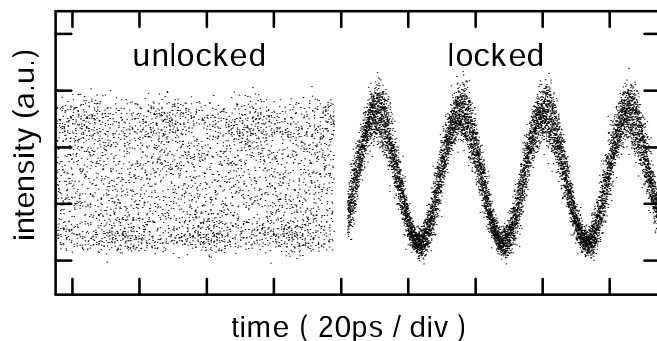


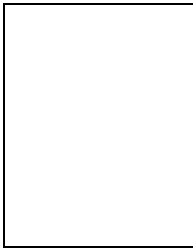
Fig. 10. Calculated locking of a 40 GHz two-mode self-pulsation. The detuning between the frequencies of the external signal and the free running SP is $f - f_0 = -80$ MHz. The modulation amplitude of the injected light is $\delta p = 0.5$ mW in the left part and 1 mW in the right part of the figure.

VIII. CONCLUSION

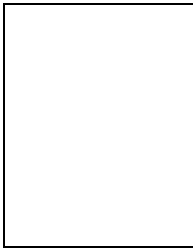
In summary, MS-DFB-lasers with detuned gratings have been fabricated and modelled. A good agreement between measurements and numerical simulations is obtained. The essential role of detuning and of the phase section are pointed out. Self-pulsation in the 40GHz range and the locking to data signals is demonstrated. The simulations indicate that even higher SP frequencies can be obtained based on the new concept.

REFERENCES

- [1] B. Sartorius, C. Bornholdt, O. Brox, H. J. Ehrke, D. Hoffmann, R. Ludwig and M. Möhrle, "All optical clock recovery module based on a self-pulsating DFB-laser," *Electron. Lett.*, vol. 34, pp.1664-1665, 1998.
- [2] B. Sartorius, C. Bornholdt, O. Brox, H. J. Ehrke, D. Hoffmann, R. Ludwig, and M. Möhrle: "Bit-rate flexible all-optical clock recovery", OFC99, San Diego, USA, paper FB1-1, Proc. Friday, pp. 24-26, 1999.
- [3] H.-J. Wünsche, U. Bandelow, H. Wenzel and D. Marcenac, "Self pulsations by mode degeneracy in two-section DFB lasers," *SPIE Proceedings Series*, vol. 2399, pp. 195-206, 1995.
- [4] H. Wenzel, U. Bandelow, H.J. Wünsche and J. Rehberg, "Mechanisms of fast self pulsations in two-section DFB lasers," *IEEE J. Quantum Electron.*, vol. 32, pp. 69-79, 1996.
- [5] Yuan-Hwang Liao and H. G. Winful, "Extremely high-frequency self-pulsations in chirped-grating distributed-feedback semiconductor lasers," *App. Phys. Letters*, vol. 69, pp. 2989-2991, 1996.
- [6] Kim A. Winick, "Longitudinal mode competition in chirped grating distributed feedback lasers," *IEEE Journal of Quantum Electronics*, vol. 35, pp. 1402-1411, 2000.
- [7] Thierry Fessant, "Large signal dynamics of distributed feedback lasers with spatial modulation of their coupling coefficient and grating pitch," *Appl. Phys. Lett.*, vol. 71, pp. 2880-2882, (1997).
- [8] C. Bornholdt, B. Sartorius, S. Schelhase, M. Möhrle, and S. Bauer, "Self-pulsating DFB-laser for all-optical clock recovery at 40 Gb/s," *Electronics Letters*, vol. 36, pp. 327-328, 2000.
- [9] B. Sartorius, C. Bornholdt, S. Bauer, M. Möhrle, P. Brindel and O. Leclerc, "System application of 40 GHz all-optical clock in a 40 Gbit/s optical 3R regenerator," OFC 2000, Baltimore, USA, post deadline paper PD 11, 2000.
- [10] M. Radziunas, H.-J. Wünsche, B. Sartorius, O. Brox, D. Hoffmann, K. Schneider, D. Marcenac, "Modelling Self-Pulsating DFB Lasers with Integrated Phase Tuning Section," *IEEE Journal of Quantum Electronics*, vol. 36, 1026-1034, 2000.
- [11] B.Sartorius, M. Möhrle, S. Reichenbacher, H. Prieler, H.-J. Wünsche, and U. Bandelow "Dispersive self Q-switching in self-pulsating DFB lasers", *IEEE Journ. of Quantum Electronics*, vol. 33, pp. 211-218, 1997.

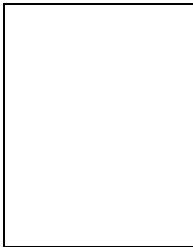


Martin Möhrle was born in Freudenstadt, Germany, in 1962. He received the Diploma degree in physics from the University of Stuttgart in 1988 and the Ph.D. degree from the Technical University of Berlin in 1992. In 1988 he joined the Heinrich-Hertz-Institut für Nachrichtentechnik Berlin, where he is responsible for research, development and fabrication of InGaAsP/InP and InGaAlAs/InP FP-, DFB- and Multi-Section-DFB-Lasers.

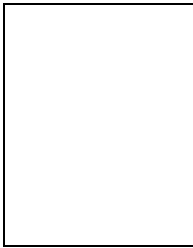


Bernd Sartorius studied Physics in Frankfurt and Berlin. He received his PhD from the Technical University of Berlin in 1982. He then joined the Heinrich-Hertz-Institute for Telecommunications, where he first worked on optical techniques for characterisation of semiconductors. In 1991 he became head of a technological project developing semiconductor optical amplifiers. He focussed the project work on devices for all-optical signal processing. Novel (patented) types of multi-section lasers and

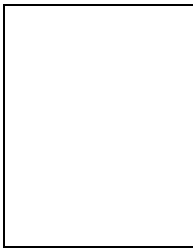
amplifiers were developed and applied especially for clock recovery and decision in all-optical 3R signal regenerators. Presently Dr. Sartorius is head of projects that cover the whole range from design and technology of devices up to system experiments on high speed all-optical signal processing.



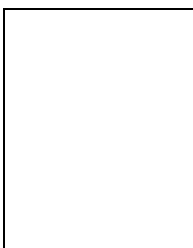
Carsten Bornholdt



Stefan Bauer

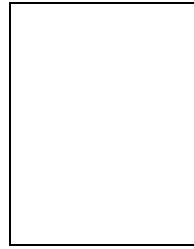


Olaf Brox was born in Jena, Germany, in 1969. He received the M.Sc. degree in physics in 1995 from the University of Essex, U.K., and the Dipl.-Phys. degree in 1997 from the University of Jena, Germany. From 1997 he has been with Heinrich-Hertz-Institut, Berlin, Germany where he is engaged in research work on switching phenomena in multi-section DFB lasers.



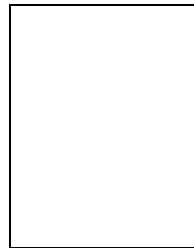
Ariane Sigmund was born in Berlin, Germany, in 1965. She received the Ing.grad. degree from the University of Applied Science Mittweida. She graduated in Microelectronics Technology. From 1992 she has worked in Heinrich-Hertz-Institut in the Department of

Micro Fabrication Technology. Since 1995 she is engaged in Laser Development Projects.

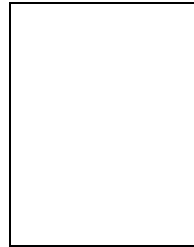


Ralf Steingrüber was born in Wilhelmshaven, Germany, in 1965. He received the diploma degree in precision engineering in 1991 from the Fachhochschule Wilhelmshaven and graduated from TFH Berlin in laser technology in 1992. Since 1992 he is with the Heinrich-Hertz-Institut Berlin where he is responsible for the electron-beam lithography technology. He is also engaged in CAD-work for data generation and preparation, and is co-responsible for the scanning electron microscopy technology. He

has authored and co-authored more than 40 papers and is inventor of several patents.



Mindaugas Radziunas was born in Vilnius, Lithuania in 1967. He received the Diploma in Mathematics in 1992 from Moscow State University, and the Ph.D. degree in 1996 from the Vilnius University, Lithuania, where he was specialised in numerical methods for nonlinear evolutionary type equations. Since 1997 he has worked with Weierstrass Institute and since 1999 with Humboldt University in Berlin as well. His current research interests concentrate on modelling of multi-section semiconductor lasers and numerical analysis of the model equations.



Hans-Jürgen Wünsche was born in Nossen, Germany, in 1948. He received the Diploma, the Dr. rer. nat, and the Dr. sc. nat. degrees in physics from Humboldt University, Berlin, in 1972, 1975, and 1983, respectively. He is still with the Humboldt University, has carried theoretical research on tunneling and high excitation phenomena in semiconductors. His current research interests concentrate on the theory of photonic materials and devices.