A $\lambda/4$-Shifted Sampled or Superstructure Grating Widely Tunable Twin-Guide Laser

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***Abstract*—A novel widely tunable laser diode that only requires two tuning currents is proposed. The laser structure is based on the tunable twin-guide laser with a $\lambda/4$-shifted sampled or superstructure grating. Numerical simulation results are given for the tuning characteristics.**

***Index Terms*—Optical communication, semiconductor lasers, tuning.**

I. Introduction

THE ADVANTAGES of tunable laser diodes, and in particular widely tunable laser diodes with a tuning range of several tens of nanometers, are known for many years. When used as spare lasers or backup lasers, they can be used to replace any fixed wavelength laser, and thus can bring significant savings in inventory costs. However, of even more importance is that they can be used for the introduction of new network concepts with added flexibility and functionality [1]. Recently, there is also some interest in the use of tunable lasers for packet switching purposes [2]. In all these applications they can either function as a transmitter or as a tunable pump in the equally important wavelength converters.

Widely tunable laser diodes have been investigated for many years [3]–[6]. Nevertheless, the existing concepts still seem to suffer from a number of important disadvantages. For example, a high output power only seems possible if all (passive) tuning sections are located on one side of the (active) gain section, which on the other side should have a cleaved or partly antireflection- (AR) coated facet. Of all edge-emitting widely tunable laser concepts, only the grating coupled sampled reflector (GCSR) laser is in this case. On the other hand, practice has shown that stabilization is easier when two tunable filters giving a series of narrow equally spaced peaks (such as sampled or superstructure gratings) are used. Operation points with high sidemode rejection then correspond with sharp optima in output power or active section voltage which lend themselves for feedback control [7]. This is the case for the super structure grating (SSG) or sampled grating (SG) distributed Bragg reflector (DBR) lasers, which are however less favorable from the point of view of achievable maximum power. In addition, almost all currently existing types of edge-emitting widely tunable lasers require at least three tuning currents (typically including one phase current to adjust the cavity mode location), and therefore, their characterization is time consuming. Some years ago, a new type of widely tunable laser, the so-called tunable distributed amplification DFB LD (TDA-DFB-LD) [6], with only two tuning currents has been proposed. However, the specific structure of this device (with short gain and tuning sections being alternated) requires complex growth and processing techniques.

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In this letter, we present another new widely tunable laser diode which combines the advantages of the GCSR and the (S)SG-DBR lasers. It also only requires two tuning currents, and hence its characterization is less time-consuming. In addition, the structure we propose has a less complex structure than the one introduced in [6]. The new laser structure is based on the tunable twin-guide (TTG) laser structure which has been introduced many years ago [8]. In Section II, we describe the structure and explain the operation principle of the widely tunable TTG laser. In Section III, we present simulation results obtained using a converted DFB-laser model, and we give some tuning characteristics. Conclusions will be drawn in Section IV.

II. Basic Structure

The schematic structure of the proposed widely tunable laser diode is shown in Fig. 1. The lateral/transverse cross section of the TTG-structure forms a single-mode waveguide in which carrier densities can be built-up in two different layers. The carrier density in the active layer causes a change in both the modal gain and the effective index of the waveguide, whereas the carrier density in the tuning layer only changes the effective waveguide index. Both carrier densities, and thus also modal gain and effective index, can be independently varied using the active current I_a and the tuning current I_t. A laser with a TTG-structure containing a diffraction grating, therefore acts as a DFB laser of which the Bragg wavelength can be tuned electronically.

Unlike in the ordinary TTG laser, the tuning layer in a widely tunable TTG laser is divided into two equally long parts with two different electrodes for separate current injection. The diffraction grating is replaced by two sampled or superstructure gratings, one in each tuning section, which are equal in grating period and amplitude, but different in sampling period. A phase shift of π ($\lambda/4$) is present in the grating at the boundary between both sections. The current density in the active waveguide is uniform. We also assume that the two laser facets are perfectly AR-coated.

To describe the tuning behavior of the laser diode, it has to be noticed that sampled or superstructure gratings with a basic grating period Λ and a sampling period L_{gi}, exhibit a number

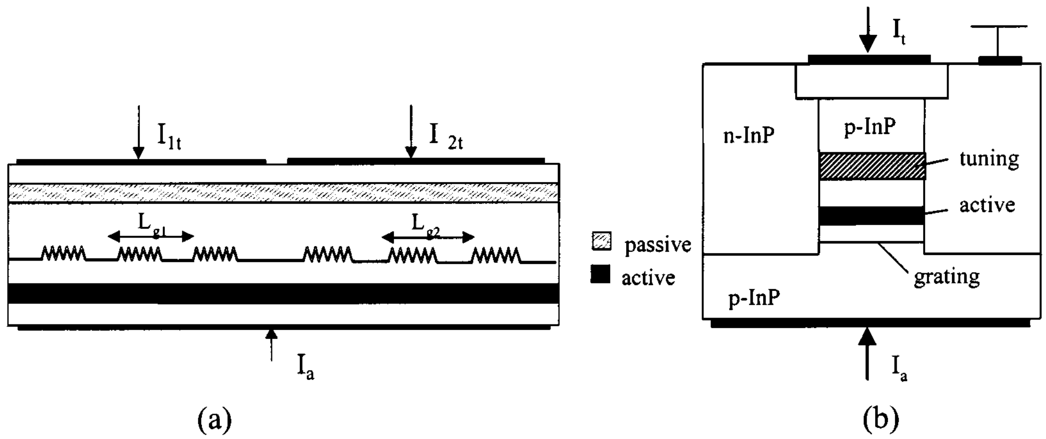

Fig. 1. Schematic structure of a $\lambda/4$-shifted (S)SG TTG laser. (a) Longitudinal/transverse cross section. (b) Lateral/transverse cross section.

of Bragg wavelengths $\lambda_{\mathrm{Bragg},k}$ (corresponding with a number of reflection peaks) located at

$$\frac{2\pi}{\lambda_{\mathrm{Bragg},\,k}} n_{\mathrm{eff},\,i} = \frac{\pi}{\Lambda} + k\frac{2\pi}{L_{gi}}$$

with $n_{\mathrm{eff},\,i}$ the effective index of the waveguide. For the structure of Fig. 1, with different sampling periods L_{g1} and L_{g2} in the left-hand side (LHS) and the right-hand side (RHS) section, one thus obtains a number of reflection peaks, but with different peak separation for both sections. However, if a peak of the LHS section overlaps with a peak from the same order k from the RHS section, the structure will, for that particular order k, behave as a $\lambda/4$-shifted laser due to the $\lambda/4$-shift in the grating. If the active section is pumped above threshold in that case, there will be a stable single-mode emission at the Bragg wavelength of order k. Since the reflection peaks of other orders ($\neq k$) will not overlap very well, there will only be significant feedback (and lasing) for the order k. This last statement is, of course, only true if the coupling coefficients are not too large and the reflection peaks are not too broad. Otherwise, a good overlap could exist for multiple orders k at the same time.

The principal advantage of the TTG structure is its operation as a $\lambda/4$-shifted DFB laser, which automatically ensures that the lasing cavity mode coincides with the appropriate filter peaks from both sampled gratings and which makes a phase section redundant. In addition, the Bragg wavelength of this $\lambda/4$-shifted DFB-laser can be varied by changing the effective index $n_{\mathrm{eff},\,i}$ of the waveguides using the tuning currents I_{it}. Obviously, continuous tuning of the order k emission can be obtained by changing $n_{\mathrm{eff},\,1}$ and $n_{\mathrm{eff},\,2}$, at the same time such that the overlap of the reflection peaks of order k remains, and such that the Bragg wavelength $\lambda_{\mathrm{Bragg},\,k}$ changes continuously. A larger shift in wavelength and a transition to another continuous-tuning curve can be obtained by changing $n_{\mathrm{eff},\,1}$ and $n_{\mathrm{eff},\,2}$ such that another pair of reflection peaks (from another order k') overlap.

III. Simulation Results

For the simulations we considered a sampled grating laser with two equally long sections of length 720-μm perfect AR-coatings on the facets and a π phase shift in the middle.

TABLE I
Device Parameters Used in the Numerical Simulation of the SG-TTG Laser

Parameter	Value
Thickness of active and tuning layer [μm]	0.15
Width of active and tuning layer [μm]	2.
Confinement factor of active and tuning layer	0.3
Monomolecular recombination coefficient [1/ns.]	0.2
Bimolecular recomb. coef. [cm^3/s]	10^{-10}
Auger recomb. coef. [cm^6/s]	$3.\ 10^{-29}$
Effective index without tuning current	3.283
dn/dN of the tuning layer [cm^3]	$1.69\ 10^{-20}$

The gratings in both sections have a coupling coefficient of 50 cm^{-1} and a grating duty cycle (or sampling fill factor) of 0.1. The grating period is 236.9 nm and the sampling period is taken as 72 μm for the LHS grating and 80 μm for the RHS grating. The other main parameters are given in Table I. The simulations have been performed using the longitudinal computer model CLADISS [9], which was slightly adapted for the simulation of SG-TTG lasers.

The wavelength as a function of the two tuning currents is shown in Fig. 2, while the corresponding values of the mode discrimination (in terms of the difference in normalized threshold gain between main and sidemode) are displayed in Fig. 3. On all the plateaus visible in Fig. 2, tuning curves can be drawn along, which a high $\Delta(\Gamma g_{\mathrm{th}}L)$ value (of 0.1 or more) and hence a stable single mode behavior is found. The main sidemode is always a distant cavity mode located on the (nonperfect) overlap of two other reflection peaks (and not an adjacent cavity mode). The sidemode suppression, therefore, could be enhanced even more by either using smaller coupling coefficients or taking the sampling periods in both sections even more different.

The threshold gain as a function of the two tuning currents for the laser is given in Fig. 4. One can see that the points of maximum threshold gain difference, and hence of maximum sidemode rejection correspond with points of minimum threshold gain. In fact, from Fig. 4, one can easily see that the tuning

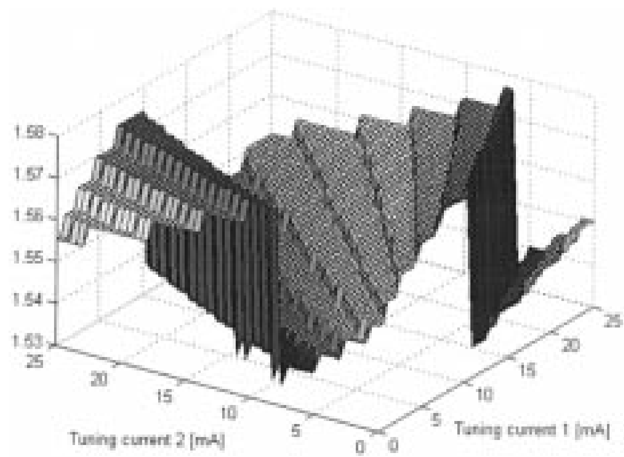

Fig. 2. Three-dimensional view of the wavelength (in μm) as a function of the two tuning currents.

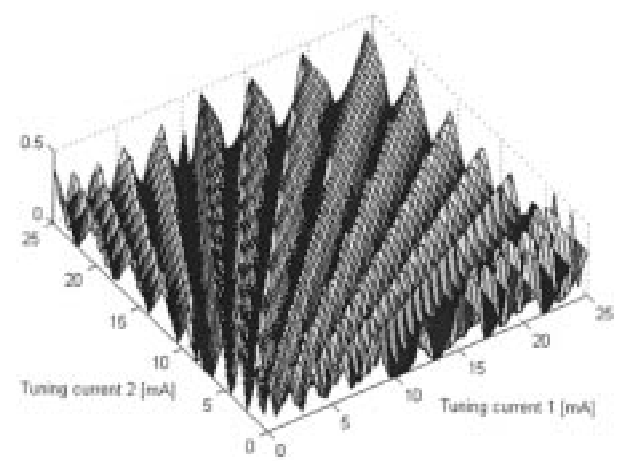

Fig. 3. Normalized threshold gain difference ($\Delta(\Gamma g_{\rm th}L)$) between main and sidemode as a function of the two tuning currents.

curves along, which a stable single-mode behavior is obtained, can be derived by varying the tuning currents along those directions for which a minimum gradient in threshold gain exists. The lines of minimum gradient are approximated in Fig. 4 by dashed lines. Considering that the minimum threshold gain corresponds with a minimum voltage over the active section, this implies that the characterization can be done very fast and that existing feedback control methods [7] can be used to stabilize the laser.

We also performed some simulations with a carrier density dependent loss in the tuning section. For a confinement factor 0.2 for both the active layer and the tuning layer and for a carrier density dependence of the loss in the tuning layer of eight 10^{-17} cm^2, we found that the threshold gain increased from 24 $^{-1}$to 33 cm^{-1} and the threshold current increased from 75 to 92.3 mA. The external efficiency decreased from 0.1 to 0.073 mW/mA (over the tuning range shown in Fig. 2).

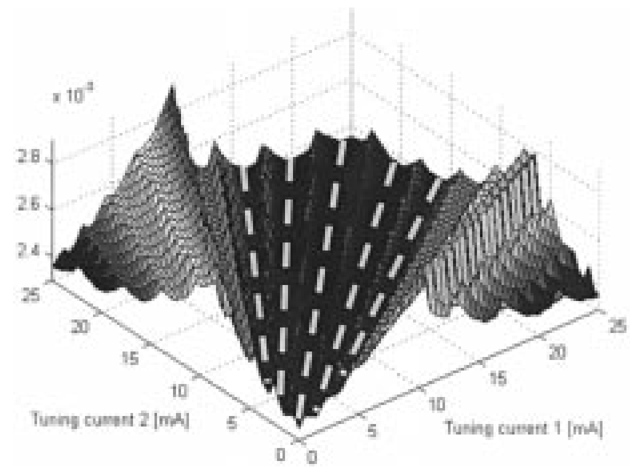

Fig. 4. Threshold gain (in μm^{-1}) as a function of the two tuning currents. The dashed lines indicate lines along which a minimum gradient in threshold gain is obtained.

IV. Conclusion

We have proposed a new widely tunable laser diode which only requires two tuning currents. The new structure, in addition, has the advantage of incorporating highly selective filtering, and thus is easy to stabilize. The behavior as a $\lambda/4$-shifted DFB laser, moreover, implies that the device should be capable of high power operation, while the presence of AR-coated facets will allow the integration with an amplifier or a modulator.

References

[1] E. Zouganeli, A. F. Mlonyeni, O.-P. Rostad, T. Olsen, and A. Sudbo, "Wavelength routed network using widely tunable laser transmitters," in *Proc. ECOC'2000*, vol. 4, Munich, Germany, Sept., pp. 51–52.

[2] J. Gripp, P. Bernasconi, C. Chan, K. L. Sherman, and M. Zirngibl, "Demonstration of a 1-Tb/s optical packet switch fabric (80*12.5 Gb/s), scalable to 128 Tb/s (6400*20 Gb/s)," in *Proc. ECOC'2000*, Munich, Germany, Sept., Postdeadline Paper 2.7.

[3] P.-J. Rigole, S. Nilsson, L. Backbom, B. Stalnacke, T. Klinga, E. Berglind, J.-P. Weber, and B. Stolz, "Quasi-continuous tuning range from 1560 to 1520 nm in a GCSR laser with high power and low tuning currents," *Electron. Lett.*, vol. 32, pp. 2352–2354, 1996.

[4] H. Ishii, H. Tanobe, F. Kano, Y. Tohmori, Y. Kondo, and Y. Yoshikuni, "Quasicontinuous wavelength tuning in super-structure-grating (SSG) DBR lasers," *IEEE J. Quantum Electron.*, vol. 32, pp. 433–440, Mar. 1996.

[5] V. Jayaraman, Z. M. Chuang, and L. A. Coldren, "Theory, design, and performance of extended tuning range semiconductor lasers with sampled gratings," *IEEE J. Quantum Electron.*, vol. 29, pp. 1824–1834, June 1993.

[6] H. Ishii, Y. Kondo, F. Kano, and Y. Yoshikuni, "A tunable distributed amplification DFB laser diode (TDA-DFB-LD)," *IEEE Photon. Technol. Lett.*, vol. 10, pp. 30–32, Jan. 1998.

[7] G. Sarlet, G. Morthier, and R. Baets, "Control of widely tunable SAG-DBR lasers for dense wavelength-division multiplexing," *J. Lightwave Technol.*, vol. 18, pp. 1128–1138, Aug. 2000.

[8] L. M.-C. Amann, S. Illek, and C. Schanen *et al.*, "Tunable twin-guide laser—A novel laser diode with improved tuning performance," *Appl. Phys. Lett.*, vol. 54, pp. 2532–2535, 1989.

[9] P. Vankwikelberge, G. Morthier, and R. Baets, "CLADISS—A longitudinal, multimode model for the analysis of the static, dynamic, and stochastic behavior of diode lasers with distributed feedback," *IEEE J. Quantum Electron.*, vol. 26, pp. 1728–1741, Oct. 1990.