Sampled grating tunable twin-guide laser diodes with wide tuning range (≥ 40 nm) and large output power (≥ 10 mW)

R. Todt[*1], **T. Jacke**[1], **R. Meyer**[1], **J. Adler**[2], **R. Laroy**[3], **G. Morthier**[3], and **M.-C. Amann**[1]

[1] Walter Schottky Institut, Technische Universität München, Am Coulombwall 3, D-85748 Garching, Germany
[2] Infineon Technologies Fiber Optics GmbH, Wernerwerkdamm 16, D-13629 Berlin, Germany
[3] Ghent University, Department of Information Technology, Sint-Pietersnieuwstraat 41, B-9000 Gent, Belgium

Received zzz, revised zzz, accepted zzz
Published online zzz

PACS 42.55.Px, 85.60.Bt, 07.57.Hm

The sampled grating tunable twin-guide (SG-TTG) laser diode is a DFB-like tunable laser that employs Vernier-effect tuning to achieve wide wavelength tuning. In contrast to most other monolithic widely tunable lasers (which are usually DBR-type lasers), a phase tuning section is not needed and, hence, the SG-TTG laser requires at least one tuning current less than comparable devices.
The devices provide full wavelength coverage over a 40 nm-broad tuning range that is centered at 1.54 µm. Its tuning behavior is quasi-continuous with up to 8.2 nm broad continuous tuning regions. High side-mode suppression (SMSR ≥ 35 dB) as well as large output power (P ≥ 10 mW) are obtained over the whole wavelength range from 1520.5 to 1561.5 nm.

Introduction

Wavelength tunable laser diodes with tuning ranges of several tens of nanometers have become valuable single-frequency light sources in the near infrared region and are being employed for fiber-optic telecommunications as well as for various sensing applications.

Commonly monolithically integrated devices based on the free carrier plasma effect are preferred over hybrid solutions, since the former ones have proven high reliability as well as fast switching times in the nanosecond regime. Several monolithically integrated devices have been presented to date (an overview can be found in Ref. [1],[2]). Practically all of them suffer, however, from the fact that they require at least three or even more tuning currents, thereby making device characterization and control time-consuming and expensive.

In the past the focus has been mainly on monolithically integrated DBR-type lasers. Only recently also DFB-like widely tunable lasers gained increasing interest [3]-[6]. While DBR-type lasers require a phase tuning section to adjust the cavity mode location, this is not necessary in DFB-like devices. Therefore, they offer potential to facilitate device characterization and control by a reduction of the number of tuning currents, which is of course desirable as long as the device performance is not impaired.

Despite this apparent advantage of the DFB-based device concepts, only two electronically widely tunable lasers were demonstrated so far [3],[5]. These suffered, however, from comparatively poor performance. This paper discusses characteristics of a DFB-like laser with competitive device performance. The so-called sampled grating tunable twin-guide (SG-TTG) laser diodes achieve full wavelength coverage over a tuning range of more than 40 nm along with large output powers above 10 mW.

* Corresponding author: e-mail: todt@wsi.tum.de, Phone: +49-89-289 12767, Fax: +49-89-320 6620

Device structure and fabrication

The SG-TTG laser, as schematically depicted in Fig. 1a, is based on the DFB-TTG laser [8]. In the SG-TTG laser [5], the vertically integrated tuning layer is longitudinally split into two sections, that contain sampled gratings (SG's) instead of DFB gratings. The sampling periods (Λ_{S1} and Λ_{S2}) of the SG's in the front and rear tuning section are slightly different. Thus, the comb-like reflection spectra of the SG's possess a slightly different periodicity, which permits the use of Vernier-effect tuning [9] to achieve wide quasi-continuous wavelength coverage. Whereas continuous tuning is obtained by tuning both reflectors simultaneously, large wavelength jumps, so-called supermode hops, are obtained by tuning one reflector while leaving the other one unchanged. Due to the vertical integration of active and tuning section, the laser behaves in essence like a DFB laser. Therefore, a phase tuning section is not necessary and only two tuning currents are required.
The devices were realized in a buried heterostructure design using the GaInAsP/InP material system. All four epitaxial steps were carried out in an Aixtron AIX 200/4 metal-organic vapor phase epitaxy (MOVPE) system. The bandgap-wavelength diagram of TTG ridge structure is shown in Fig. 1b. The active region is formed by an asymmetric separate confinement heterostructure (SCH), containing a strained layer multi-quantum-well (SL-MQW) with eight compressively strained ($\Delta a/a \sim 0.8\,\%$) GaInAsP wells. The emission peak of the MQW was adjusted to a wavelength of 1.55 µm. The asymmetric design of the SCH was chosen to enhance the confinement of the optical mode within the QW's and the tuning layer. According to our model calculations, the confinement of the optical field is 7.5 and 46 % for the QW's and the tuning layer, respectively.
The SG's were fabricated by a combination of holograhpy and optical lithography. The gratings with a pitch of 236 nm were etched into the tuning layer. The effective coupling coefficient κ_{eff} is estimated to be $\sim 10\,\text{cm}^{-1}$. The SG's have been designed to obtain a reflection peak spacing of 5.0 and 5.5 nm in the front and rear reflector, respectively.
Since facet reflections would interfere with the SG reflection spectrum and cause distortions, the front and back facets were formed by a combination of anti-reflection (AR) coatings and window structures [10] in order to obtain a facet reflectivity of below 10^{-3}. The 1200 µm-long and 1.3 µm-broad buried mesa was terminated approximately 30 µm before the facet.

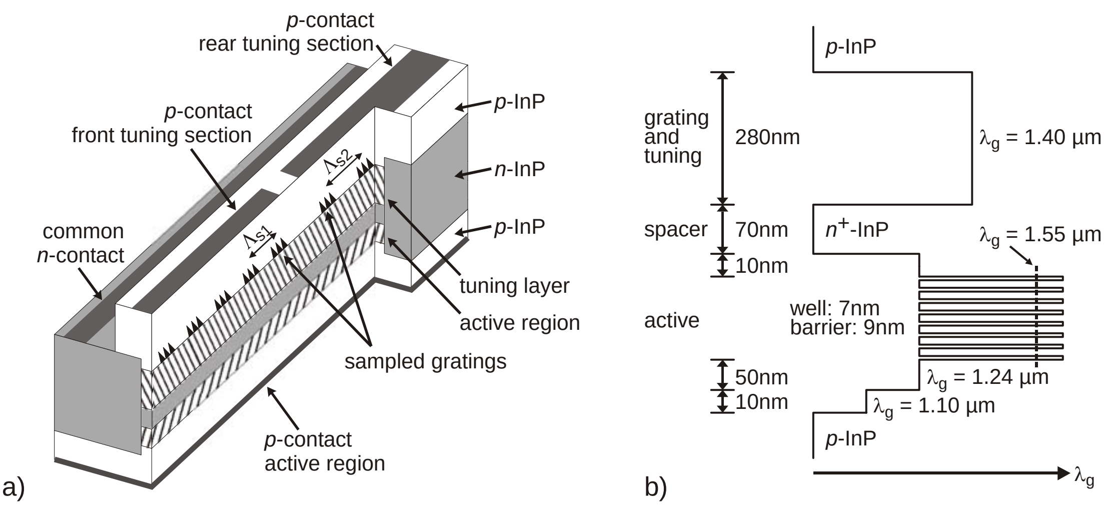

Fig. 1 a) Schematic drawing of a widely tunable twin-guide laser diode with sampled gratings. For the sake of the clarity, the window structures have not been included in the figure. b) Bandgap-wavelength diagram of the TTG ridge structure in the transverse direction.

Results and discussion

The characterization of the devices has been carried out at a heatsink temperature of 20 °C. Without applying any tuning currents, the lasing threshold is reached at an active region current of 27 mA, corresponding to a threshold current density of only 1.7 kA/cm^2.
The tuning characteristics of the SG-TTG laser diodes have been investigated by sweeping both tuning currents in a non-linear way up to a maximum current of 45 mA, while keeping the active region current constant at 250 mA. The resulting wavelength map of a typical device is shown in Fig. 2a. The map reveals the location of the various supermodes. These are separated by ~5 nm, in close agreement with the SG design. Within these supermodes, the emission wavelength can be continuously and mode-hop-free tuned by up to 8.2 nm.
The behavior of the side-mode suppression ratio (SMSR) and the output power during tuning along the exemplary tuning curve, indicated as dotted white line in Fig. 2a, is shown in Fig. 2b. At zero tuning current, the laser emits at 1551.7 nm. Exploiting the free carrier plasma effect for tuning, the emission wavelength decreases with increasing tuning current while tuning along the supermode. SMSR as well as output power decrease linearly and show only minor variations during tuning, thereby confirming the continuous tuning behavior.
The decrease of the output power during tuning is due to tuning induced losses and also contributes to some extent to the decrease of the SMSR. Most of the decrease in the SMSR is, however, caused by the rather strong spectral variation of the modal gain. Spectral gain measurements have shown that the slope of the gain curve strongly depends on the active region carrier density. While the spectral gain distribution is quite flat as long as the carrier density inside the active region is relatively low (corresponding to threshold current densities of < 2 kA/cm^2), the slope of the gain curve is quite pronounced for higher carrier densities (corresponding to threshold current densities of > 3 kA/cm^2). Such high threshold current densities are reached during tuning because the tuning induced losses need to be compensated. Furthermore, it should at this point be noted that the SMSR is limited by neighboring supermodes, which means that the variation of the modal gain over a distance of ~5 nm is the decisive figure of merit. In the worst case the spectral gain variation decreases the modal threshold gain difference by up to 4 – 5 cm^{-1} and, thereby, strongly impair the SMSR. Optimization of the spectral gain distribution provides, therefore, great potential for further improving the device performance.

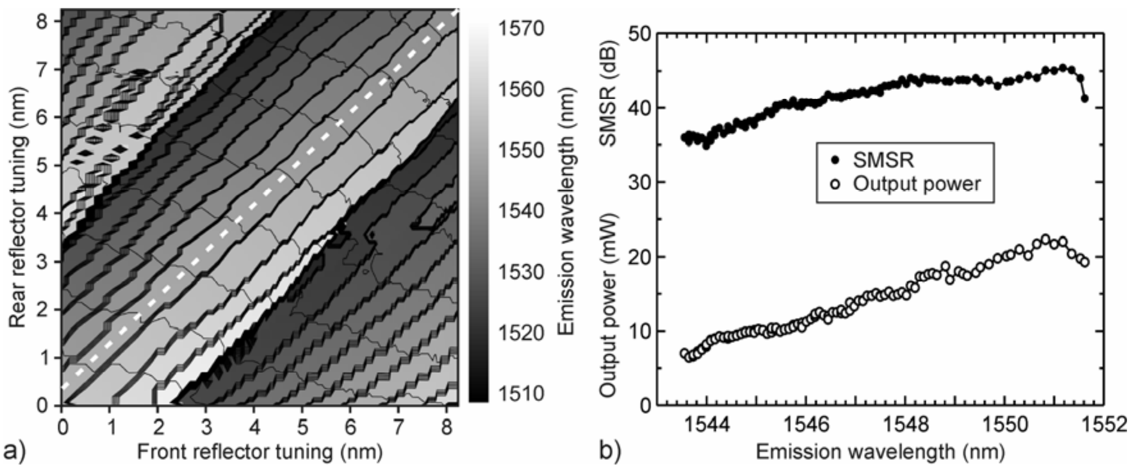

Fig. 2 a) Wavelength map of an SG-TTG laser diode. The various supermodes are enclosed by bold lines. Thin solid lines within the supermodes indicate iso-wavelength contours that are spaced in 1.0 nm intervals and are shown as a visual aid for determining the continuous tuning range of each supermode. b) Output power and side-mode suppression ratio along the exemplary tuning curve, which is indicated as dotted white line within the wavelength map. Within the supermode, continuous mode-hop free wavelength tuning of up to 8 nm is possible.

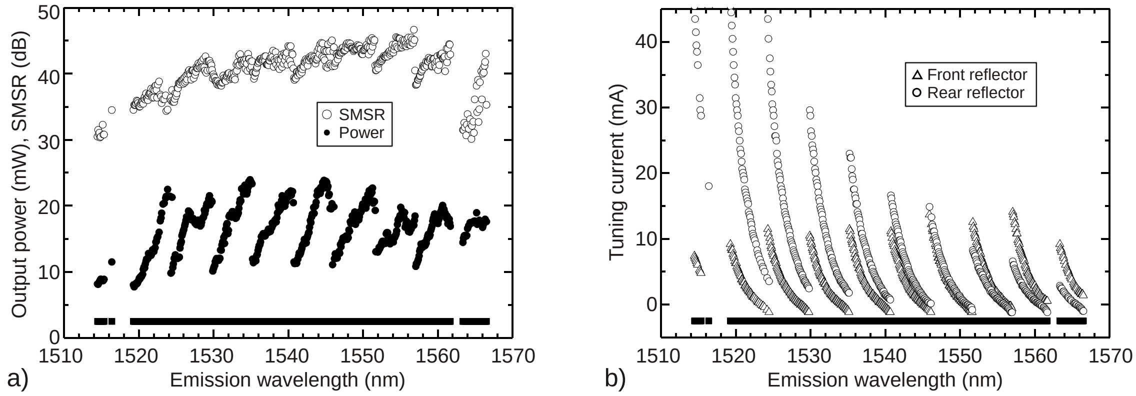

Fig. 3 Ex-facet output power and side-mode suppression ratio (a) as well as front and rear tuning current (b) versus emission wavelength. The bold horizontal line at the bottom of the graphs is shown as a visual guide to easily locate gaps within the tuning range.

Output power, SMSR, and tuning currents as function of the emission wavelength are shown in Fig. 3. Over a wavelength range of 41 nm (from 1520.5 to 1561.5 nm) the SMSR and output power remains above 35 dB and 10 mW, respectively. The absolutely regular behavior of the tuning currents (Fig. 3b) proves the regular tuning behavior of the SG-TTG.
Due to the high tuning efficiency of the TTG laser only small tuning currents are needed. For the present devices, a maximum tuning current of 45 mA is already sufficient to obtain tuning over a 40 – 50 nm wavelength range.

Conclusions

In conclusion, we realized widely tunable twin-guide laser diodes at 1.55 µm that are quasi-continuously tunable over a wavelength range of more than 40 nm and require only two tuning currents. Moreover, the lasers provide high spectral purity as well as large output power.

Acknowledgements We gratefully acknowledge the technical assistance of J. Grottenthaler, L. Mora, R. Heilmann, and E. Sckopke. Reinhard Laroy acknowledges the Institute for the Promotion of Innovation by Science and Technology in Flanders (IWT) for a specialisation grant. This work was supported by the European Union via the Information Society Technologies (IST) project IST-2000-28244 “NEWTON”.

References

[1] L. A. Coldren, G. A. Fish, Y. Akulova, J. S. Barton, and C. W. Coldren, J. Lightwave Technol. **22**, 193 (2004).
[2] J. Buus, M.-C. Amann, and D. J. Blumenthal, Tunable Laser Diodes and Related Optical Sources, 2nd edition (Wiley-IEEE Press, Piscataway, NJ, 2005).
[3] H. Ishii, Y. Kondo, F. Kano, and Y. Yoshikuni, IEEE Photon. Technol. Lett. **10**, 30 (1998).
[4] S. Kim, Y. Chung, S.-H. Oh, and M.-H. Park, IEEE Photon. Technol. Lett. **16**, 15 (2004).
[5] G. Morthier, B. Moeyersoon, and R. Baets, IEEE Photon. Technol. Lett. **13**, 1052 (2001).
[6] R. Todt, T. Jacke, R. Meyer, and M.-C. Amann, Appl. Phys. Lett. **87**, 021103 (2005).
[7] R. Todt, T. Jacke, R. Meyer, R. Laroy, G. Morthier, and M.-C. Amann, Electron. Lett. **40**, 1491, (2004).
[8] M.-C. Amann, S. Illek, C. Schanen, and W. Thulke, Appl. Phys. Lett. **54**, 2532, (1989).
[9] V. Jayaraman, Z.-M. Chuang, and L. A. Coldren, IEEE J. Quantum Electron. **29**, 1824 (1993).
[10] K. Utaka, S. Akiba, K. Sakai, and Y. Matsushima, IEEE J. Quantum Electron. **20**, 236 (1984).