

Direct Modulation of Widely Tunable Twin-Guide Lasers

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Abstract—The possibility to directly modulate widely tunable lasers up to several gigahertz is desirable in telecom applications. We discuss the dynamic properties of the recently proposed widely tunable twin-guide laser concept. It has promising prospects with a maximum theoretical bandwidth above 20 GHz and the 3-dB bandwidth at 250 mA indicates that an actual bandwidth of 12 GHz should be possible. The current lasers were not designed for high-speed modulation, so only 1-GHz modulation can be reached at the moment.

Index Terms—Modulation, semiconductor laser, tunable laser.

I. INTRODUCTION

WIDELY tunable semiconductor laser diodes with tuning ranges of several tens of nanometers are considered key components in optical telecommunication networks and sensor applications.

At present, several widely tunable laser concepts have been presented and many of them are distributed Bragg reflector laser diodes with one or two passive reflector sections [1]–[3]. However, also widely tunable distributed feedback lasers [4]–[6] have received attention in recent years. They only require two control currents, so they are easier to characterize and to control.

One of these devices is the sampled grating tunable twin-guide (SG-TTG) laser [4]. This new concept is based on the tunable twin-guide (TTG) laser concept [7] and uses the Vernier-effect to obtain a large tuning range. Electronic tuning over 40-nm wavelength range has recently been demonstrated for these devices [8].

In this letter, the dynamic properties of these SG-TTG lasers will be examined. The possibility to directly modulate the laser up to several or even 10 GHz is desirable for low-cost digital and analog optical telecommunication applications (e.g., in optical access networks).

We will first report on relative intensity noise (RIN) measurements that have been performed to obtain the intrinsic modulation bandwidths. A theoretical maximum modulation bandwidth has been extracted out of these measurements. In a second part,

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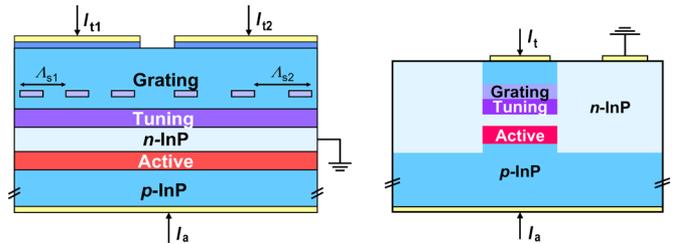


Fig. 1. Schematic drawing of a widely tunable twin guide laser with sampled gratings. (Color version available online at <http://ieeexplore.ieee.org>.)

we will briefly discuss the first experiments with directly modulated laser diodes.

II. DEVICE STRUCTURE

A widely TTTG laser [4] is a two section TTG laser [7], in which both sections contain a sampled grating or a superstructure grating with different superperiod. The device structure of a TTG laser (Fig. 1) consists of two p-n junctions with an n-separation layer in the middle that electronically decouples the active layer and tuning layer, so gain and filtering can be controlled independently.

Current injection into the tuning layer is used to change the effective refractive index and the Vernier effect creates tuning over a wide wavelength range (several tens of nanometers). Only two tuning currents are required to obtain full wavelength coverage, which makes the characterization substantially less time consuming. A high output power and a short device length are possible.

The SG-TTG laser has a competitive device performance. Recently [8], SG-TTG laser diodes with a tuning range of more than 40 nm and output powers higher than 10 mW were reported (Fig. 2). The slope is around 0,075 mW/mA and decreases due to leakage currents to 0.015 mW/mA around 250 mA.

For an untuned laser, the output frequency is 192.4 THz and the threshold is reached at an active region current of 27 mA, corresponding with a threshold current density of 1.7 kA/cm². Due to carrier-induced losses, this threshold current density goes up to 6 kA/cm².

III. NOISE MEASUREMENTS

The theoretical maximum modulation frequency under small signal modulation can be derived from the measurements of the RIN. The RIN describes the amplitude fluctuations in the optical field due to spontaneous emission.

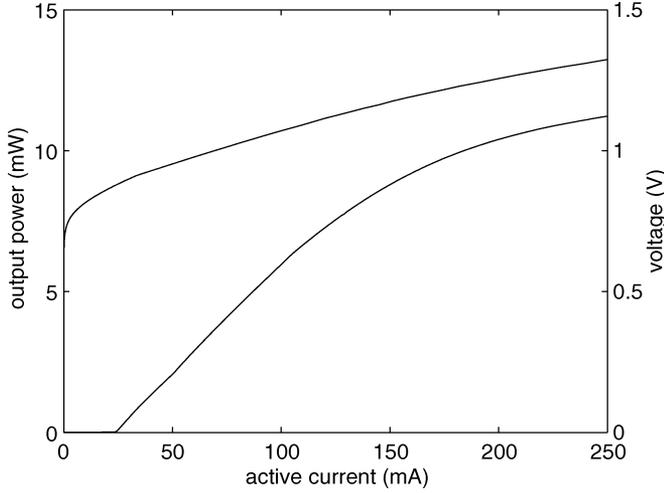


Fig. 2. Light output-current-voltage characteristic of a SG-TTG.

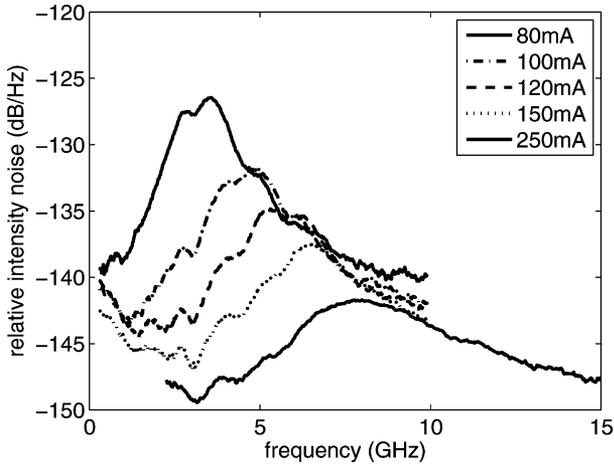


Fig. 3. RIN measurements of an SG-TTG laser for different active current values and tuning currents set to an output frequency of 195.1 THz.

The measured RIN results of an SG-TTG laser with a total length of 1200 μm for different values of the active current and zero tuning currents are shown in Fig. 3. These measurements can be fitted to the formula for the RIN to extract the resonance frequency f_r and the damping γ

$$\text{RIN}(f) = A \frac{f^2 + \left(\frac{\gamma}{2\pi}\right)^2}{(f_r^2 - f^2)^2 + \left(\frac{\gamma}{2\pi}\right)^2 f^2}. \quad (1)$$

Far above threshold, the resonance frequency f_r and the damping γ are connected by the K -factor [9]

$$\gamma = \gamma_0 + K f_r^2. \quad (2)$$

The K -factor is determined by the photon lifetime of the laser cavity and is inversely proportional to the maximum intrinsic modulation bandwidth [9]

$$f_{\text{max,damping}} = \frac{2\pi\sqrt{2}}{K}. \quad (3)$$

The extracted theoretical values for the maximum intrinsic modulation bandwidth are given for several ITU frequencies in

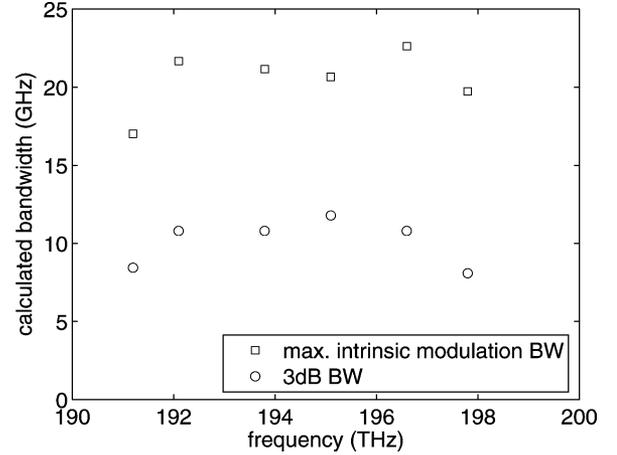


Fig. 4. Theoretical indication of actual bandwidth of an SG-TTG laser through modulation response formula.

Fig. 4. The variation of this theoretical bandwidth between 17 and 23 GHz is due to the wavelength dependence of the material and optical cavity parameters. These values for $f_{\text{max,damping}}$ are, however, the highest reported so far for tunable laser diodes. Only the Modulated Grating Y laser comes in the neighborhood [3] with a theoretical maximum intrinsic modulation bandwidth up to 20 GHz.

In practice, the performance of the device will be worse than predicted due to the presence of parasitics like stray capacitances parallel to the active region, the resistance of the semiconductor layers, the inductance of bond wires, etc.

The same parameters from the formula (1) are used in the small-signal modulation response formula

$$|M(f)|^2 = \frac{1}{1 + \left(\frac{f}{f_p}\right)^2} \frac{f_r^4}{(f_r^2 - f^2)^2 + \left(\frac{\gamma}{2\pi}\right)^2 f^2} \quad (4)$$

with f_p the parasitic cutoff frequency. An indication of the a more realistic theoretical 3-dB bandwidth (without parasitics) can be obtained by inserting the extracted parameters from our RIN fitting at an active current of 250 mA in this modulation response neglecting the parasitic factor. This leads to the 3-dB bandwidth values shown in Fig. 4. For all measured ITU frequencies, a bandwidth higher than 8 GHz and up to 12 GHz is obtained.

The extracted bandwidth is quite uniform over the whole tuning range, this is due to two counteracting effects. The tuning increases the threshold current considerably and this has a decreasing effect on the resonance frequency. On the other hand, the spectral variation of dg/dN (Fig. 5) compensates this because tuning is toward the high-frequency side where dg/dN is larger.

These two counteracting effects result in a more or less uniform bandwidth throughout most of the tuning range and, simultaneously explain for the decrease of the bandwidth at the edges of the tuning range where the $I - I_{\text{th}}$ decrease is the largest and the dg/dN variations are not strong enough anymore to compensate this. By adjusting the detuning of the gain peak and moving the grating center wavelength to lower frequencies, the average dg/dN value can be increased without

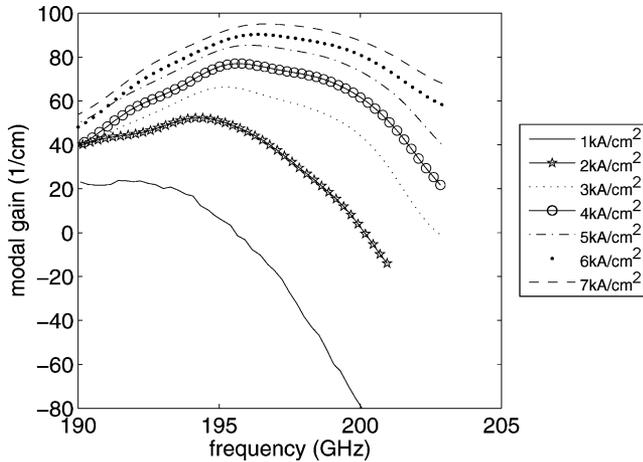


Fig. 5. Modal gain changes due to frequency and current density variations.

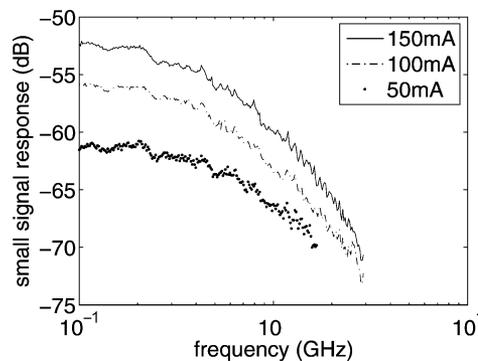


Fig. 6. Small-signal intensity modulation of a TTG laser at different active currents.

decreasing $I - I_{th}$ and, therefore, the bandwidth can on average be increased.

Additionally, modified concepts have been presented [10], [11] to increase the output power or the pumping efficiency of the TTG lasers considerably and, thereby, probably also the modulation bandwidth.

IV. SMALL-SIGNAL MODULATION

The SG-TTG laser sample has been probed with a Picoprobe 40 A, a high-frequency needle for small-signal modulation up to 40 GHz. A bias-T combines the dc and ac signal and isolates the sources from each other. The output signal is detected by a high-speed photodiode and processed by an HP71400 light wave signal analyzer to extract the amplitude of the optical power modulation.

The small-signal behavior for an SG-TTG laser at different active currents is shown in Fig. 6. A 3-dB cutoff frequency is reached around 1 GHz. The dynamic properties remain unchanged when the active current is increased (Fig. 6) or when the laser is tuned, indicating that presently the parasitic effects dominate the dynamic behavior.

The low modulation bandwidth is not a surprise because the present batch of devices was not designed for high frequency operation. Voltage–current measurements (Fig. 2) show that the parasitic series resistance is around 5Ω , so the parasitic capacitance is around 32 pF for a 1-GHz 3-dB cutoff frequency. The huge contact pad ($1200 \times 110 \mu\text{m}^2$) contributes to 8 pF of this 32-pF capacitance and can be almost completely eliminated simply by reducing its size and using a more suitable passivation like BCB. The remaining 24-pF capacity is most likely caused by the large p-n junction with a width of $25 \mu\text{m}$. To get close to the magical 10 GHz, a capacity of 3.2 pF is needed (assuming again a $5\text{-}\Omega$ series resistance). This can be obtained with a p-n junction of about $5\text{-}\mu\text{m}$ width. This is feasible with some design optimizations.

V. CONCLUSION

The widely TTG laser has promising prospects. It has a maximum theoretical bandwidth above 20 GHz and the 3-dB bandwidth at 250 mA indicates that an actual bandwidth of 12 GHz is possible when the parasitics can be minimized sufficiently. The current lasers were not designed for high-speed modulation, so only 1-GHz modulation can be reached at the moment.

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