CHARACTERIZATION OF COMPACT LATERALLY COUPLED LASER SOURCES FOR MICROWAVE SIGNAL GENERATION AND TRANSMISSION

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Abstract- Resonance of the lateral modes of two laterally coupled semiconductor lasers (beyond intrinsic relaxation oscillation frequency) is studied in terms of RIN and phase noise to demonstrate a new simple and compact microwave generation and data transmission device.

I. INTRODUCTION

The development of optical modulation techniques at frequencies of tens of Gigahertz is motivated to a large point by potential applications in microwave and millimetre-wave transmission in optical fiber, such as phased array antenna and mm-wave indoor personal communication systems [1,2]. In this sense various millimetre-wave techniques utilising semiconductor laser sources have been reported [3]. Schemes based on a single semiconductor laser (directly or externally modulated), two or more semiconductor laser sources (heterodyning) or dual-mode semiconductor lasers have been proposed [3].

In this framework it is important to note the efforts to obtain semiconductor laser sources with responses above the intrinsic relaxation oscillation frequency to extend the frequency of operation. In these kind of approaches the inconveniences of using two lasers for heterodyning or external modulation can be overcome with the obtaining of a more robust photonic microwave transmitter. In this sense, recent work in high frequency, narrow-band modulation of semiconductor diode lasers include direct modulation at the intermodal frequency in order to bypass the limitations imposed by the intrinsic semiconductor laser direct modulation bandwidth [4] [5].

The goal of this paper is to study and characterized a new device: a monolithic two laterally coupled diode laser source for microwave and millimeter signal generation and transmission. The intrinsic modulation bandwidth of a single semiconductor laser is extended to the frequency of the two lateral mode spacing of this device (above the intrinsic relaxation oscillation) as has been demonstrated [6]. These devices consist of two Fabry-Perot semiconductor laser emitters placed side by side in the wafer where each ridge mode overlaps with its neighbour and they combine to form a set of lateral modes for each longitudinal mode of the lasers with a frequency separation fixed through the separation of the ridges and other fabrication variables [7]. The appearance of these lateral modes in laterally coupled structures, suggested the possibility of actively phase-locked them to achieve high modulation bandwidths [8,9] and obtaining high speed devices with narrow-band resonant modulation frequencies beyond the intrinsic relaxation oscillation frequency.

In this work we describe the characterization of these two-laterally coupled lasers developed within the framework of European Project FALCON to applied them in microwave and millimeter wave generation and subcarrier data transmission. Issues like the small signal modulation response, RIN and phase noise of a microwave carrier transmitted in the resonance peak of the lateral mode beating are addressed. A simple data transmission experiment is also proposed and tested based on such devices where we demonstrate for the first time signal transmission using a compact laterally coupled semiconductor laser.

This paper is organized as follows: first a description of the two-laterally coupled diode laser (LCDL) is
presented. In Section III the device is experimentally characterized in the framework of microwave signal generation and data transmission. In Section IV a narrow-band high frequency data transmission experiment is described and we end with some conclusions.

II. DESCRIPTION OF THE TWO LATERALLY COUPLED MODE-LOCKED DIODE LASER (LCDL)

Several devices have been fabricated that consist of five AlGaInAs/InP quantum wells emitting at approximately 1.33 µm [10]. The two Fabry-Perot laser cavities are placed side by side in the wafer and mounted in a high frequency mount so current can be injected independently into twin ridges. In the experiments that follows we have used the device labelled K1, which has a geometry of 510-µm ridge length, 3.6 µm ridge width, and 2.76-µm ridge separation. The threshold for each independently biased ridge is 35 mA [10].

The mode-locked LCDL placed on the mount with a thermoelectric cooler is shown in Figure 1. As the two ridges can be independently biased with the aid of two different current sources, they can be characterized as independent laser emitters before the study of their coupled behaviour. In this Figure 1 the two SMA connectors to bias each ridge are shown.

III. EXPERIMENTAL CHARACTERIZATION OF THE DEVICE

A. Small Signal Modulation Response

The output light from the emitter under study is collected by a single mode fibre connected to a high speed InGaAs Schottky photodiode (New-Focus, model 1434) with a responsivity of 0.15 A/W for the LCDL output wavelength (λ=1.33 µm). The LCDL small signal frequency response is determined by measuring the S12 scattering parameter with a Hewlett Packard 8720ES (50MHz-20GHz) S-parameter network analyzer.

In Figure 2 we show the small signal modulation response of the LCDL when both ridges are biased above threshold. In this figure we see a dramatic change in the small signal modulation response of the LCDL when compared to the standard response of a single semiconductor laser. Due to the coupling between both emitters, a second peak at a frequency of 7.66 GHz of amplitude approximately equal to the low frequency value appears in the modulation response. This frequency corresponds closely to the separation of the lateral modes of this device of 7.7 GHz in agreement with the lateral mode-locked frequency appearing in the twin stripe diode laser [10].

It is important to note that this frequency response, and specifically the frequency of the second resonance peak, can be controlled through several fabrication parameters and, specifically, ridge separation [11]. In the framework of the FALCON project, laterally coupled semiconductor lasers with resonances up to 19 GHz have been fabricated and tested [11]. In this sense, these devices could find applications in distributing Ka-band signals in phase array antennas [12], as well as other applications where many high-frequency carriers have to be distributed.

![Fig.1. Picture of a LCDL. Note the two SMA connectors to independently bias both ridges.](image1.jpg)

![Fig 2. Small signal modulation response of the LCDL with the two ridges above threshold. I_{B1} = 36, I_{B2} = 36 mA.](image2.png)
B. Relative-Intensity Noise (RIN) in laterally coupled semiconductor lasers

In order to use the second resonance peak of the LCDL for subcarrier data transmission, a preliminary measurement of the relative intensity noise of the laser source has to be performed. In this sense in Table I we show the measured RIN at the resonance peak \( f = 7.66 \) GHz for several bias current when both ridges are equally biased \( (I_{B1} = I_{B2}) \). When compared those values to those obtained for the low frequency region \( (f<2 \) GHz), also shown in Table I, a maximum penalty of 14 DB is obtained.

<table>
<thead>
<tr>
<th>RIN (dB/Hz)</th>
<th>( I_{B1} = 37 ) mA</th>
<th>( I_{B1} = 39 ) mA</th>
<th>( I_{B1} = 41 ) mA</th>
<th>( I_{B1} = 43 ) mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta ) (dB)</td>
<td>8</td>
<td>11</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>

As we can see in this Table I, the penalty in RIN remains in a interval between 8 and 14 DB for all the bias currents. Preliminary data obtained indicates that the bias condition \( I_{B1} = I_{B2} \) (both ridges with the same current) seems to be the optimum case in terms of noise, and those are the results shown.

C. Single side-band (SSB) Phase noise in laterally coupled semiconductor lasers

One of the possible applications of these laterally coupled devices is optical control of phase arrays antennas where the carrier frequency is distributed in the second resonance peak and subcarrier data signals are sent in the low frequency part of the small signal response [12]. In this sense, it is important to evaluate the single side-band (SSB) residual phase noise of the microwave carrier signal sent in the second resonance peak.

In Figure 3 we show the evolution of the residual phase noise for a microwave carrier of 7.66 GHz introduced in the second resonance peak of the LCDL measured at 10 kHz offset frequency from the carrier. As in the experiment described before, the output light is collected by a single mode fibre connected to the high speed InGaAs Schottky photodiode and the phase noise is measured with a 22 GHz spectrum analyzer. In this figure 3, we can see that an improvement of 5 dB is obtained when working at high injection currents. The straight line in the figure shows the SSB phase noise floor of the CW generator used that is \(-84 \) dBC/Hz for the frequency of test \( (f = 7.66 \) GHz).

Two different cases have been studied. In the first case, the two currents where kept constant (cross). In the second case (circle), ridge 2 current \( (I_{B2}) \) is kept constant while ridge 1 current is varied. In both cases the evolution of the SSB phase noise is similar and recommend high injection currents to lower the effect of the phase noise.

IV. SUBCARRIER DATA MODULATION IN LATERALLY COUPLED SEMICONDUCTOR LASERS

The appearance of this second peak in the frequency response of the LCDL makes them a very attractive candidate for narrow-band high-frequency application like millimeter lightwave communication systems [13]. In this sense they represent an easy to fabricate, compact and low-cost solution for microwave and millimeter signal generation and transmission as they simply consist on two Fabry-Perot cavities place side by side on the same wafer.

![Subcarrier data modulation experiment](image)
To probe this, we show in Figure 4 a scheme that has been implemented for data transmission using the second resonance peak of the small signal response shown in Figure 1. On this experimental setup, a 30 MHz signal was introduced and recovered after filtering and amplification as shown in Figure 5. Current work includes the use of a 30 Mbps PRBS signal to test digital transmission using this second resonance peak.

V. CONCLUSIONS

In this paper we present a new concept of semiconductor laser sources for microwave and millimeter signal generation and transmission based on laterally coupled diode lasers (LCDL). These laser structures present a small signal modulation response with a second high frequency resonance peak beyond the intrinsic relaxation oscillation frequency. We have characterized this second peak in order to use these devices as microwave signal generators and transmitters through the study of the RIN and SSB phase noise. A transmission experiment has been implemented using a LCDL as a laser source demonstrating for the first time the possibility of data transmission using this second peak of a two-laterally coupled semiconductor lasers. In this sense we demonstrate the viability of this easy to fabricate and compact device for microwave and millimeter signal generation and transmission.

REFERENCES