Experimental measurements of the ridge spacing influence on the frequency response and optical spectrum of laterally coupled laser diodes.

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ABSTRACT

The objective of this work is to analyse the dependence of the frequency response of Laterally Coupled Diode Lasers (LCDL) focusing on the separation between the laser ridges. A detailed study of the integrated optical spectra and frequency response is presented for LCDLs with 300 µm cavity length and separation between the ridges of 2, 4, 6, 8 and 10 µm. This study is of major importance as it defines the range of frequency locking for each ridge spacing and also its dependence on the bias conditions applied.

1. INTRODUCTION

Semiconductor laser technology is facing a challenge in a way to achieve higher frequency bandwidths, which, so far, have been limited by the laser relaxation oscillation [1]. Proposals have been presented based on longitudinal mode locking [2], where locking frequencies of more than 100 GHz were predicted. More recently, as part of the FALCON TMR European project [3], analytical [4] [5] and experimental work based on lateral mode locking by means of Laterally Coupled Diode Lasers (LCDL) [6] was carried out, this lead to locking frequencies of 7.8 GHz beyond the relaxation oscillation frequency. In the LCDL devices there are two major structural characteristics of the device structure (see Fig 1) to consider, these are the separation between the ridges $d$, and the cavity length $L$.

As part of the FALCON TMR Project, several LCDL devices were fabricated [7] each having different cavity lengths and ridge separations. With knowledge of previously observed locking effects further investigation, presented in this paper, focuses on the high frequency dependence on the ridge separation applied to devices with 300 µm cavity lengths. Also included is a study on the bias condition effects, as these devices displayed frequency locking tuning phenomena.

The high frequency behaviour of LCDL is correlated with the optical spectrum, where the frequency of the second resonant peak (locking peak) observed in the frequency response matches with the observed frequency separation between the lateral optical modes. In section 2 the description of the device as well as their L-I characteristics is
presented, following, the explanation of the experimental setups used to measure the frequency response and the integrated optical spectra along with some significant results achieved, in section 3. This paper ends with section 4, where conclusions and final comments are presented.

2. L-I EXPERIMENTAL MEASUREMENT OF THE LCDL DEVICE

The LCDL FALCON Lasers consist of two AlGaInAs/InP Fabry-Perot cavities optical coupled laterally but electrically isolated, with stripe widths of 4 \( \mu \text{m} \), emitting at 1330 nm. The laser chip is mounted in a sub-mount with “K” connector for RF modulation (up to 40 GHz) and independent bias of each ridge. The results presented in this paper refers to LCDL with cavity lengths of 300 \( \mu \text{m} \), and ridges separations \( d \) of 2 \( \mu \text{m} \) (K2), 4 \( \mu \text{m} \) (K5), 6 \( \mu \text{m} \) (K6), 8 \( \mu \text{m} \) (K7), and 10 \( \mu \text{m} \) (K8). The L-I characteristics of these devices (Fig. 2) were measured independently for each ridge, i.e., while ridge 1 was measured, ridge 2 was turned off, and vice-versa.

![K2 L-I Characteristic](image)

(a) K2

![K5 L-I Characteristic](image)

(b) K5

![K6 L-I Characteristic](image)

(c) K6

![K7 L-I Characteristic](image)

(d) K7

![K8 L-I Characteristic](image)

(e) K8

Fig 2 – Current versus Power Characteristics of the LCDL. (a) K2 (2 \( \mu \text{m} \)), (b) K5 (4 \( \mu \text{m} \)), (c) K6 (6 \( \mu \text{m} \)), (d) K7 (8 \( \mu \text{m} \)), K8 (10 \( \mu \text{m} \)).

By analysing the L-I curves, these may be separated in two groups, the ones measured with the devices K2, K5 and K6, which are symmetric between each laser stripe presenting threshold currents for each ridge of 28 mA, 28 mA and 25 mA, respectively, with a small difference in the slope efficiency between each ridge individually characterized, and the second the ones with the devices K7 and K8 where their L-I characteristics are very asymmetric, from one ridge to the other, showing, respectively, a difference in the threshold current between ridges of 2 and 3 mA.
3. OPTICAL SPECTRUM AND HIGH FREQUENCY MODULATION ANALYSIS

The measurement of the optical spectrum of the LCDL was made according to the scheme shown in Fig 3. The use of the TRIAX 550 monochromator (and by positioning Ridge2 above Ridge1) allows the whole emission from the LCDL laser stripes enter into the instrument and the total optical spectrum of the device is measured. The measurements of the frequency response of the FALCON devices were performed using a HP8720ES network analyser, according to the setup described in references [8] and [9].

![Diagram of the setup used for the measurement of the optical spectrum.](image)

Making use of the possibility of bias each ridge of the FALCON devices independently, measurements of the optical spectrum and of the frequency response are presented. In the first set of results the device is tested biased with the same current in each ridge, while in the second set of measurements, different bias currents were applied to each ridge.

3.1 – Symmetric bias conditions

The behaviour of these LCDL devices when biased equally in both ridges (Fig 4) is in agreement with the previously observed results in ref. 6 concerning the matching between the frequency of the optical splitting and the locking frequency: 22 GHz for $K_2$, 17.7 GHz for $K_5$ and 17 GHz for $K_6$. We have to notice that, in this experiment, the Network Analyser used only allows measurements up to 20 GHz, but due to its modal characteristics one must to extrapolate that a locking frequency peak of $K_2$ exists at 22 GHz. In the devices $K_7$ (fig 4(d)) and $K_8$ (fig 4(e)) no locking frequency peak was found when the devices were biased symmetrically. This result is supported by the observation of the optical spectrum, where each ridge spectrum do not match with each other, which implies the inexistence of splitting between their optical modes. This phenomenon is not only due to the asymmetry between each individual LI characteristic, but mostly because of the high ridge spacing of these devices.
Fig 4 – Optical Spectrum (top) and frequency response (bottom) of LCDL when symmetric bias conditions are applied. Coupling effects are observed in Fig 4 (a), (b) and (c) in contrast with Fig 4 (d) and (e) where this effect is not observed.

3.2 – Asymmetric bias conditions
The bias conditions affects both dynamic and static behaviour of LCDL devices. As observed in Fig 5, the splitting between the optical modes changes when an asymmetric bias is applied to the device. The second peak observed in the frequency response matches with the observed splitting in the optical spectrum and descends to lower frequency values with the increasing ridge separation, as previously observed in section 3.1. In these measurements the bias conditions
were the same, with a difference between each ridge bias of 5 mA, for the devices K2, K5 and K6, while in the devices K7 and K8 higher bias condition differences (15 mA) between each ridge were applied for checking the existence of coupling in these LCDL’s.

Fig 5 – Optical Spectrum (top) and frequency response (bottom) of LCDL when asymmetric bias conditions are applied. Coupling effects are observed in Fig 5 (a), (b), (c), with locking frequencies smaller then the ones observed in fig 4 (a), (b), (c), as well as in Fig 5 (d). In contrast, in fig 5 (d) this effect is not observed.
The devices $K2$, $K5$ and $K6$ exhibit a decrease in the separation between the optical modes and consequent change in locking frequencies from the symmetric bias situation, where frequencies of 22 GHz, 17.7 GHz and 17 GHz, respectively, were observed, to the asymmetric bias conditions, where the locking frequency is of 19 GHz, 12 GHz and 10.5 GHz, respectively. With the devices $K7$ and $K8$ the locking phenomena was observed in $K7$, being the coupling very week, while with in $K8$ no locking behaviour was found (see figs. 5 (d) and 5(e)).

3. CONCLUSIONS

In this paper the locking phenomena was observed for devices with 300 $\mu$m cavity length where there was a matching between the splitting observed in the optical modes and the locking peak of the frequency response. It was measured that in devices with ridges separations smaller or equal to 6 $\mu$m, strong locking phenomena occurs and there is the possibility of tuning the locking frequency by changing the bias conditions of each ridge. In devices where the ridge spacing is higher then 6 $\mu$m, it was observed that the locking is very weak or inexistent. It was also observed that the locking frequency depends on the separation between ridges, since that $K2$ exhibits higher locking than $K5$ and higher than $K6$. These results shed light to a more clear understanding of LCDL devices and demonstrate the frequency locking tuning behaviour.

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5. REFERENCES

1. R. Olshansky, P. Hill, V. Lanzisera, W. Powazinik, “Frequency Response of 1.3 $\mu$m InGaAsP High Speed Semiconductor Lasers”, IEEE J. Quantum Electronics, vol. 23, no. 9, 1410- 1418, 1987;
2. K. Y. Lau, “Narrow-band modulation of semiconductor lasers at millimeter wave frequencies (>100 GHz) by mode locking”, IEEE Journal of Quantum Electronics, 26, pp250-261, (1990);
3. FALCON Web page: http://www.uc3m.es/falcon;