Investigation of the Dynamical Behaviour of Mutually Coupled Lasers on a Photonic Integrated Circuit

(Student Paper)

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ABSTRACT

In this paper, we investigate the mutual injection locking properties of a photonic integrated circuit consisting of two slotted Fabry-Pérot lasers coupled together through a 1.1 mm variable optical attenuator/amplifier. The output of the lasers was observed on an electrical spectrum analyser, optical spectrum analyser and a high speed oscilloscope. Various types of dynamical behaviour were identified as a function of the coupling and the detuning between the lasers.

Keywords: Mutual injection locking, coupled lasers, photonic integration, laser dynamics.

1 INTRODUCTION

Optical injection locking of semiconductor lasers has been an area of great interest since the early 1980s [1]. The theoretical and experimental study of injection locked semiconductor lasers has resulted in many applications. For example, injection locking can be used to demultiplex an optical comb [2]. The comb lines can then be modulated individually before recombining the signal to create a coherent superchannel for coherent wavelength division multiplexing [3]. Injection locking can also be used to generate multiple phase locked coherent outputs [4], which are required for many modern day modulation formats [5].

Due to the ever increasing demand being put on optical communication networks, there is a significant move towards developing integrated devices to replace discrete optical components. Photonic integrated circuits (PICs) offer an effective solution for the advancement of system level functions at a compact scale. Integration vastly decreases the size of these systems and allows for lower power consumption and reduced cost. However, the implementation of injection locking in such a system is highly complex, due to mutual feedback between the lasers. Without feasible integrated isolators the injection locking system is no longer purely master-slave, but is now bidirectional, or mutual. In order to reliably enable applications that are based on injection locked lasers in a PIC, the limits of injection locking a system of integrated semiconductor lasers needs to be studied. In this paper we investigate the effect of the coupling and detuning between the lasers on the injection locking properties of two integrated slotted Fabry-Pérot lasers.

2 THE PHOTONIC INTEGRATED CIRCUIT

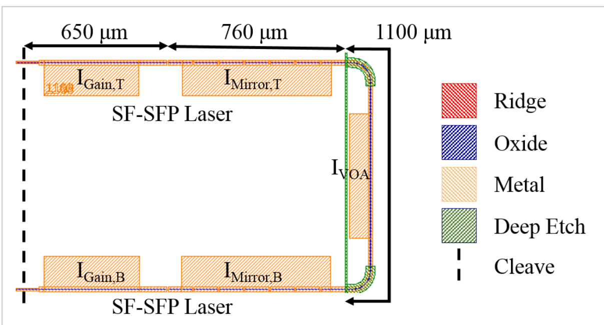

Figure 1. Schematic of the PIC with all variable parameters labelled. Two SF-SFP lasers are integrated together through a 1100 μm VOA section.

The PIC used to investigate mutual injection locking consisted of two identical single facet slotted Fabry-Pérot (SF-SFP) lasers [6] coupled together through a 1100 μm waveguide interconnect, referred to as the variable optical attenuator/amplifier section (VOA). A schematic of the full device, is shown in Fig. 1. The

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epitaxial structure used was commercially grown 1550 nm laser material on an InP substrate, with a total active region thickness of 0.4 mm, consisting of five compressively strained AlInGaAs quantum wells. The device was fabricated using standard processing techniques, similar to [7]. The SFPs were controlled by independently biasing their respective mirror, $I_{Mirror,}$ and gain, I_{Gain}, sections. Forward or reverse biasing the VOA section controlled the amplification or attenuation of the optical signal and hence varied the power coupled between the lasers.

3 MUTUAL INJECTION LOCKING

Both of these lasers were tunable over a 0.5 nm range while maintaining a side mode suppression ratio greater than 27 dB, therefore the effect of the detuning, Δ, (frequency difference between the lasers, set by their mirror and gain section biases) and the coupling (percentage power emitted by one laser that couples into the other laser, proportional to the VOA bias) between the lasers on the injection locking properties of the system were investigated. For this device, the VOA section was completely absorbing below 0.75 V, therefore the VOA bias was swept from 0.75 V to 2.00 V for various detunings between -18 GHz and 10 GHz. The output of the lasers was recorded on an electronic spectrum analyser (ESA), an optical spectrum analyser (OSA) and a high speed oscilloscope (HSO). The results for -7.4 GHz and 1.3 GHz detuning are plotted in Figs. 2-4.

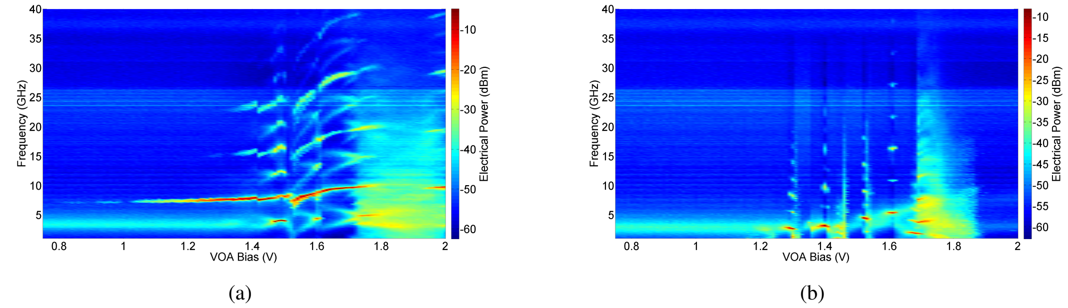

Figure 2. Colour intensity plots of the ESA traces from the top SFP for (a) -7.4 GHz, (b) 1.3 GHz detuning between the lasers.

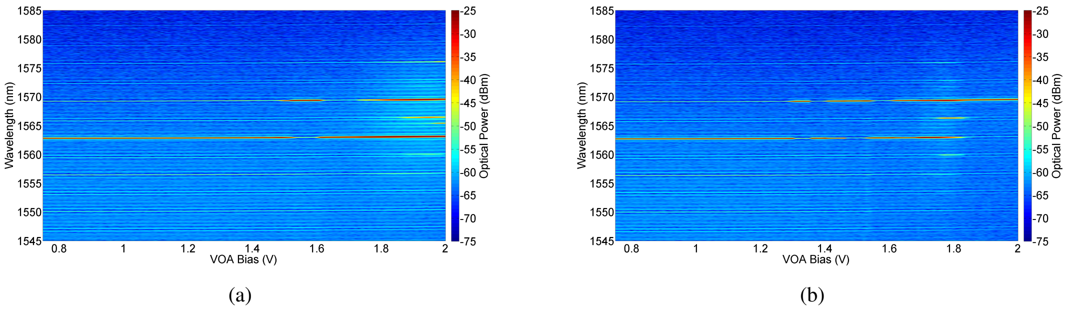

Figure 3. Colour intensity plots of the OSA traces from the top SFP for (a) -7.4 GHz, (b) 1.3 GHz detuning between the lasers.

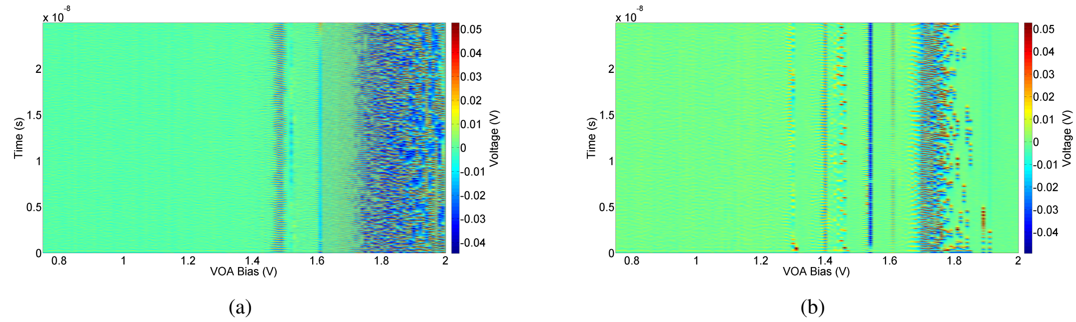

Figure 4. Colour intensity plots of the HSO traces from the top SFP for (a) -7.4 GHz, (b) 1.3 GHz detuning between the lasers.

These plots are only a small example of the full data set obtained. Various patterns and regions of dynamical behaviour can be seen in the colour intensity plots. The following types of behaviour were identified;

- Uncoupled - at low VOA biases, there is very little light coupling between the lasers, hence they are almost isolated and do not interact.

- Coupled - as the VOA bias increases the VOA begins to become transparent and sufficient light couples between the lasers so that they begin to interact, causing a beat note corresponding to the detuning between the lasers to appear in the electrical spectra.
- Quiet/Locked - for small detunings (-5 GHz $< \Delta <$ 5 GHz) regions of "quiet" were observed where only the relaxation oscillations (RO's) were visible on the ESA and noise on the HSO. The natural lasing wavelength for these lasers over this bias range was approximately 1563 nm. During these quiet regions the lasers either remained at their natural lasing wavelengths, $\sim$1563 nm or jumped to a higher lasing mode at $\sim$1569 nm. Since the RO's are not suppressed, the lasers are not completely injection locked but both lasers are lasing at the same wavelength.
- Chaotic - regions of multimode behaviour, where two or more lasing modes appeared in the optical spectra and wide peaks were observed in the electrical spectra.
- Period Doubling - regions where peaks at Δ and 0.5Δ and their harmonics are seen in the electrical spectra.

The detunings and VOA biases at which these types of behaviour occurred were found and the resulting bifurcation diagram is plotted in Fig. 5.

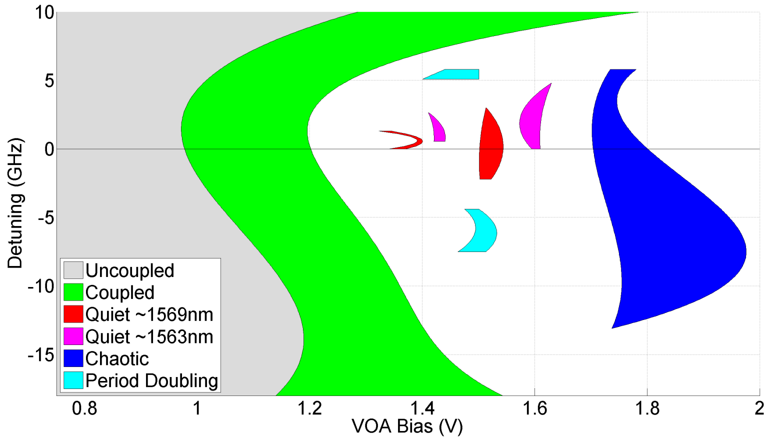

Figure 5. Bifurcation diagram showing the various types of laser dynamics as a function of the coupling and detuning between the lasers.

4 CONCLUSIONS & FUTURE WORK

We have begun to experimentally investigate the mutual injection locking properties of a PIC consisting of two integrated SFP lasers. The identification of these types of behaviour as a function of the coupling and detuning between the lasers will allow for a comparison with theoretical models. Further work will explore the repeatability of the work and also examine the dependence of the locking behaviour on the length of the delay between the lasers. It is hoped that this work will lead to a better understanding of the injection locking behaviour of lasers in next generation PICs.

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