Mutually Coupled Semiconductor Lasers In Photonic Integrated Circuits

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Abstract

We report on the analysis of dynamics of mutually coupled semiconductor lasers in photonic integrated circuits. Slotted Fabry-Perot (SFP) lasers were integrated via waveguide sections of varying lengths to analyse the stability and properties of CW output, for use in advanced modulation formats.

1. Introduction

Mutually coupled lasers (MCLs) have proven a rich area of study as a system of coupled complex oscillators, exhibiting interesting phenomena in the view of nonlinear dynamical systems such as multi-stabilities and coupled chaos. One interesting dynamical regime in this system is when the lasers operate in CW with their frequency and phase mutually locked, [1]. This CW regime can be used to achieve advanced modulation formats, such as Orthogonal Frequency Division Multiplexing (OFDM) [2] and Quadrature Phase Shift Keying (QPSK) [3], on a photonic integrated circuit (PIC). Despite theoretical studies on the MCLs with small separations (assumed near zero delay) [1, 4]. There has been limited experimental investigations of MCLs on small separation scale [5]. In this work, we fabricate and experimentally study MCLs with small separation. We will also continue along the theoretical work carried out previously, [4].

2. Device Design

To experimentally analyse MCL dynamics, various arrangements were designed on a PIC using a standard quantum well InP based material, designed for emission around 1.55μm. The fabricated lasers were designed to be identical, however, the emission properties may change due to variation in process and fabrication parameters.

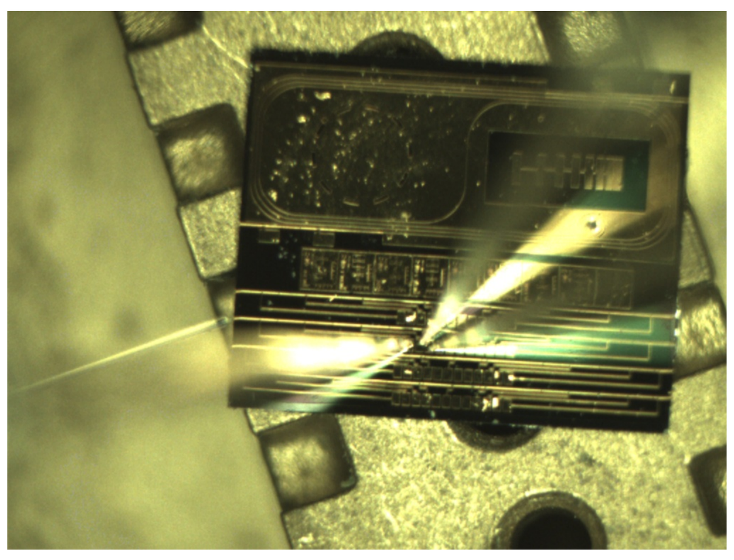


Fig. 1 PIC under testing

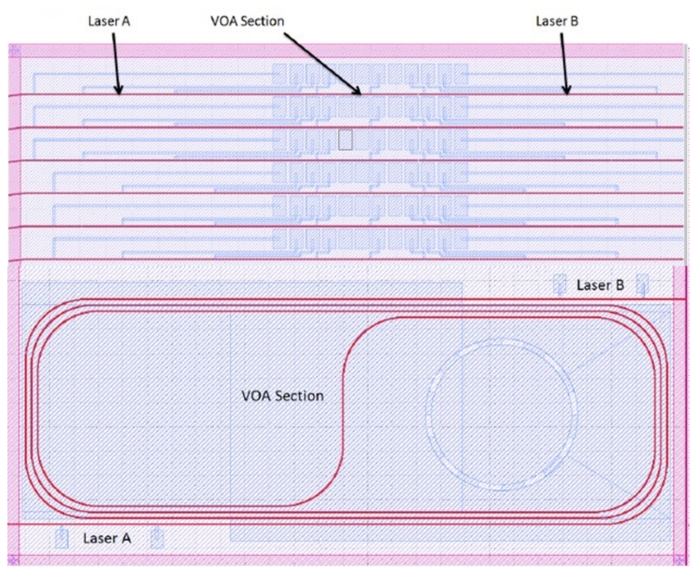


Fig. 2 Schematic of devices

The mutual pairs were separated by an active waveguide section which can be biased independently to control the attenuation acting as a Variable Optical Attenuator (VOA). The MCLs were fabricated with separations of 100μm, 700μm, 4500μm and 9000μm. To accommodate the larger separations a spiralling waveguide structure was used.

3. Device Characterisation

The facet-less SFP lasers on this chip have three sections per laser (one gain, two slotted mirror sections). By fixing the bias of the gain section and changing the mirror currents, single mode regimes on the optical spectrum could be found by measuring the SMSR, Fig. 3. The peak wavelength of these single mode regimes was also noted, Fig. 2, so the lasers can be tuned to have the same output wavelength.

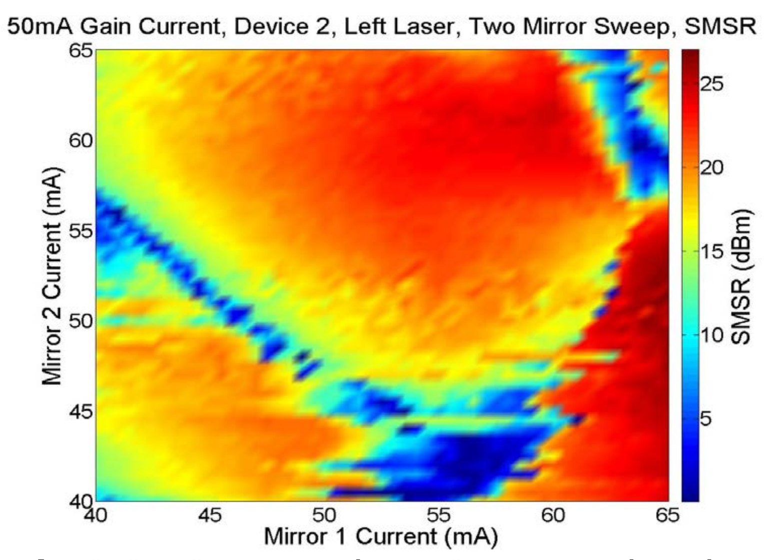


Fig.3 SMSR vs. Mirror Currents density plot

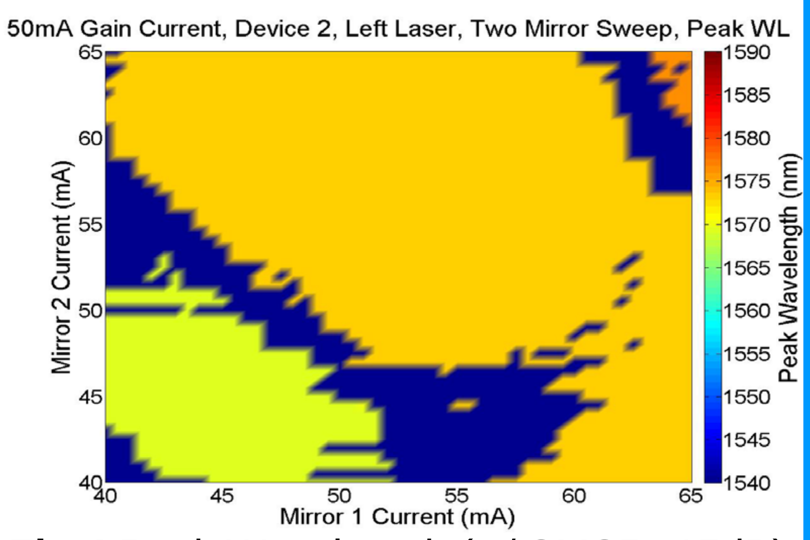


Fig 4 Peak Wavelength (w/ SMSR>15dB) vs. Mirror Currents density plot

4. VOA Transparency test

Coupling strength, the amount of optical power passing from one laser to the other is one of the important parameters in analysing the behavior of the system. The VOA can be made absorbing by reverse biasing it. The power being absorbed by the VOA as the reverse bias is varied can be calculated by measuring the photocurrent generated into the VOA section when one of the lasers is on.

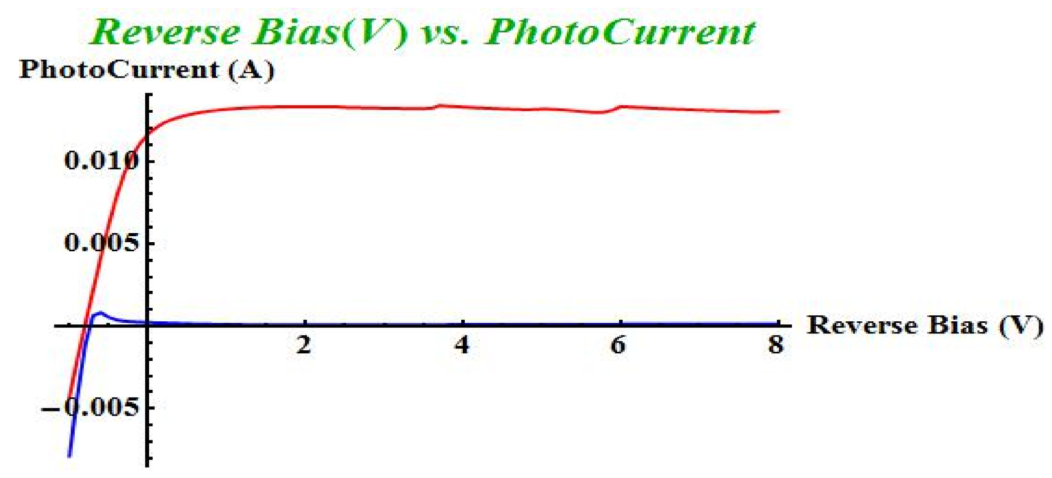


Fig 5. Reverse bias vs. Photocurrent, for a 700μm VOA section (Red) and the next section (Blue)

5. Experimental Setup

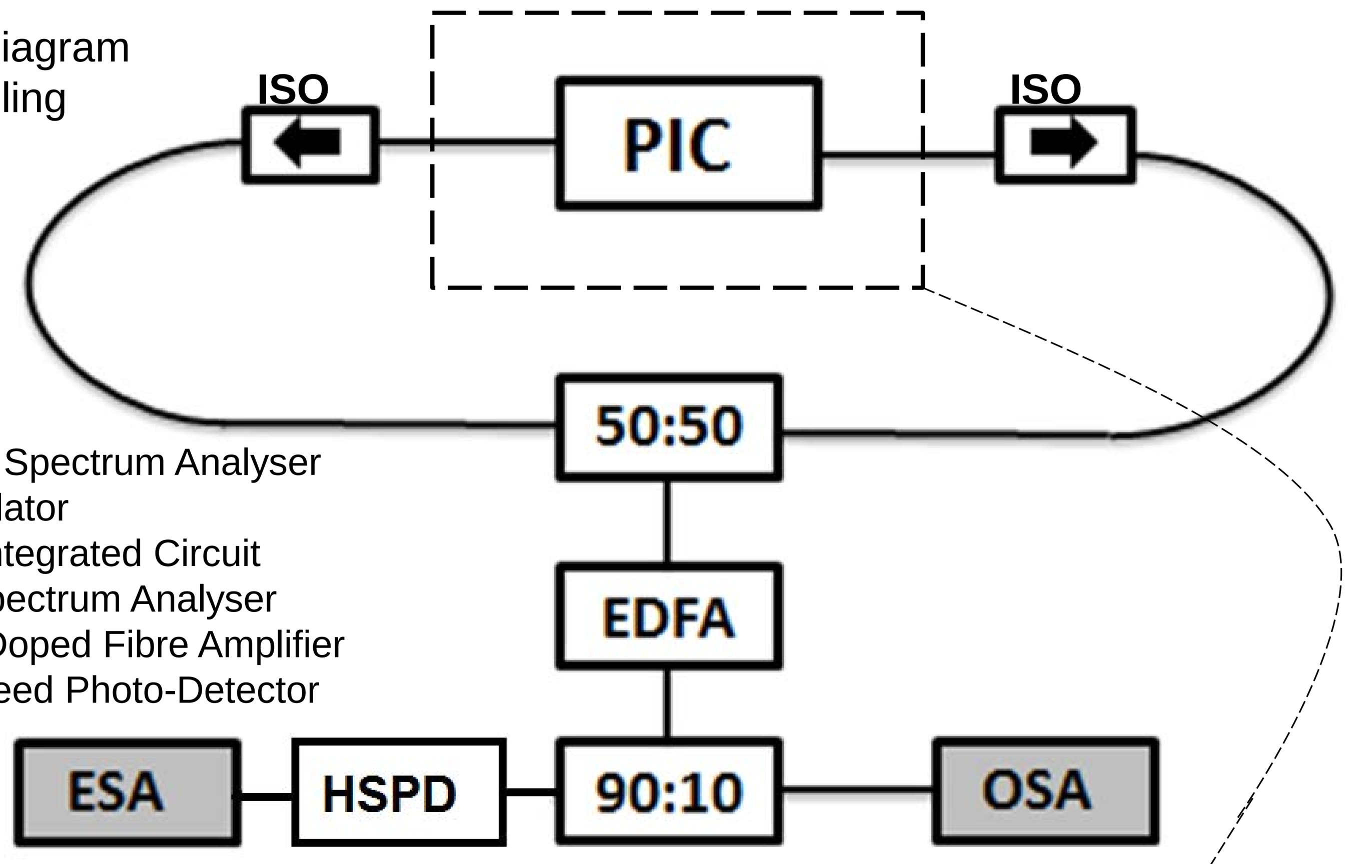


Fig. 6 Circuit diagram of mutual coupling experiment

ESA: Electronic Spectrum Analyser
ISO: Optical Isolator
PIC: Photonic Integrated Circuit
OSA: Optical Spectrum Analyser
EDFA: Erbium Doped Fibre Amplifier
HSPD: High Speed Photo-Detector

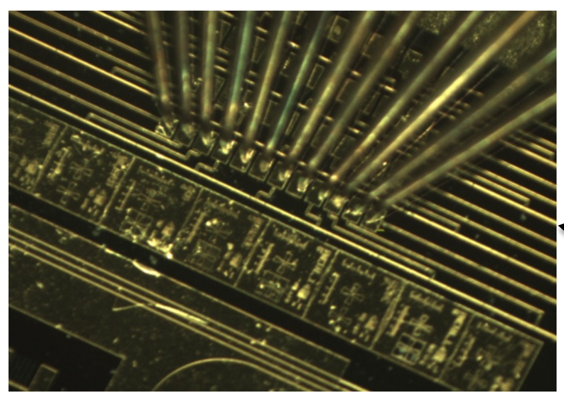


Fig. 8 Multi-contact probe on the device

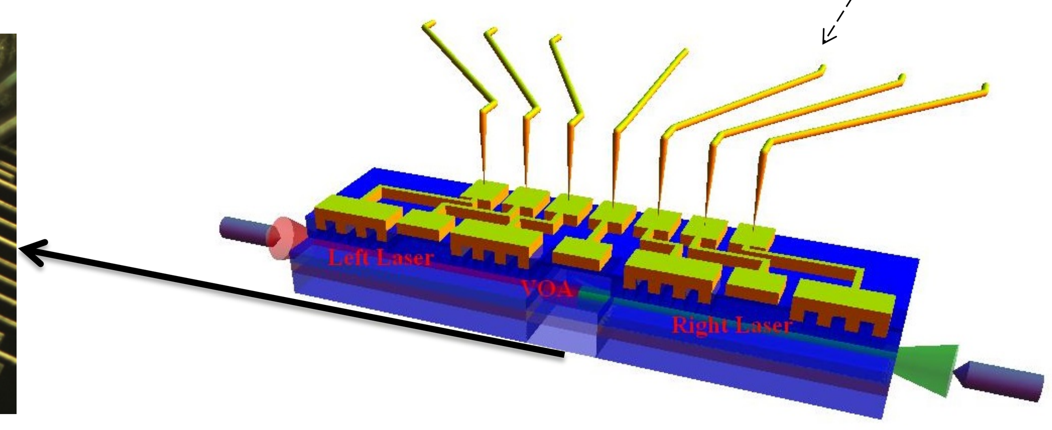


Fig. 7 3D model of device

For a single colour CW output one would see that each laser individually has a single predominant mode at identical wavelengths on the OSA, and a lack of any strong beat note on the ESA.

6. Preliminary Results

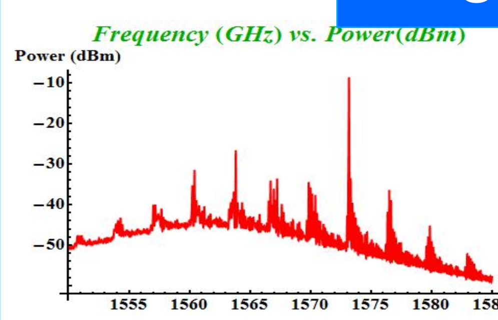
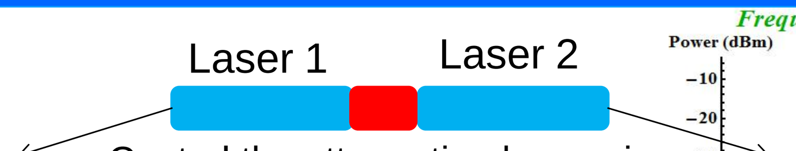


Fig. 9 Free running OSA Trace



Control the attenuation by varying the reverse bias on the VOA

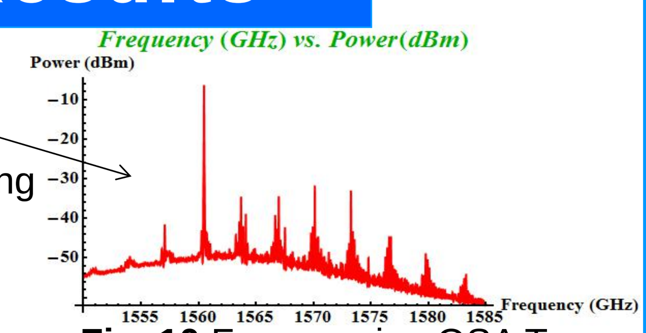


Fig. 10 Free running OSA Trace

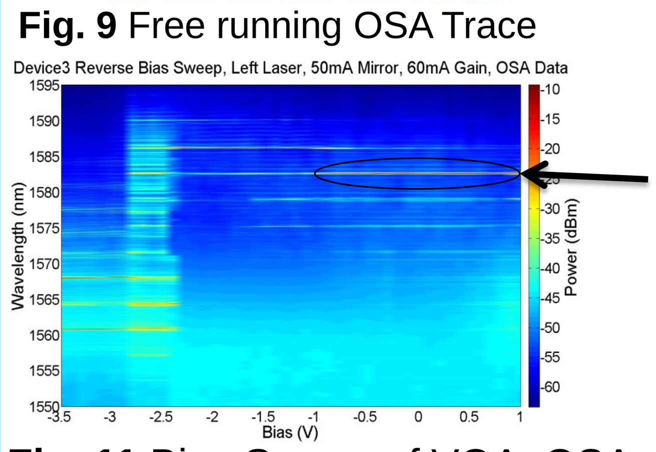


Fig. 11 Bias Sweep of VOA, OSA density plot

Wavelength matched, single mode behaviour.

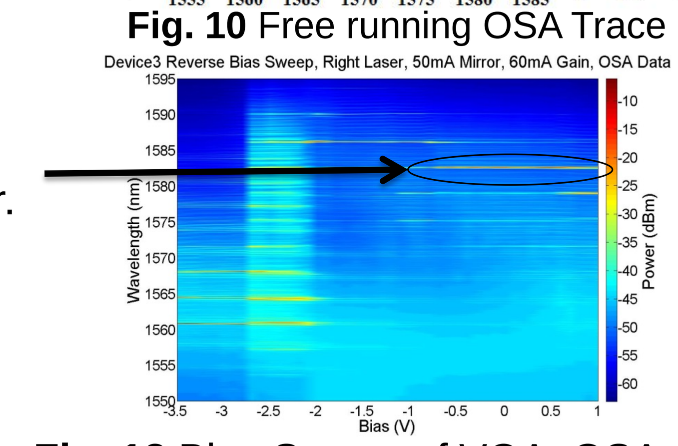


Fig. 12 Bias Sweep of VOA, OSA density plot

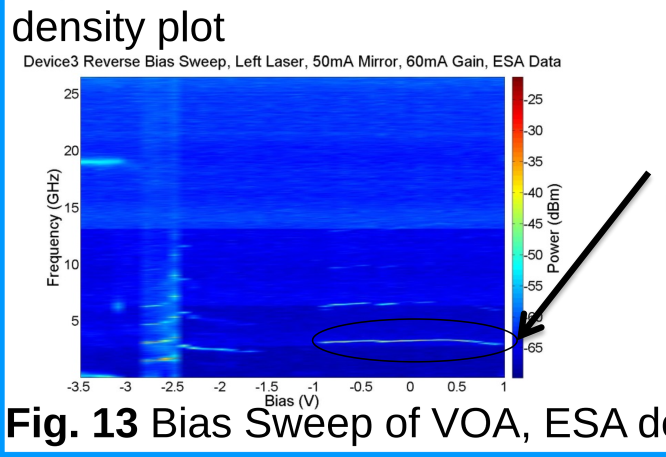


Fig. 13 Bias Sweep of VOA, ESA density plot

Feature suggests this is not CW.

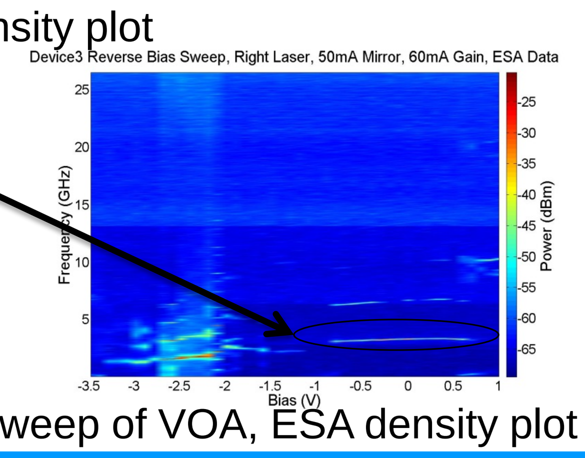


Fig. 14 Bias Sweep of VOA, ESA density plot

Conclusion

We demonstrated the system of MCLs with small separation in an integrated platform, PIC. The lasing characterization shows similar spectral and power from both lasers with good SMSR, desirable to study the system of mutually coupled single-mode lasers. The injection strength can be estimated by measuring the photo-current from the VOA section. The preliminary coupling measurements from optical and RF spectra suggests a frequency matched regime has been found, but it is not CW. Work is on-going to find a CW regime.

References

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