Monolithically Integrated Wavelength Tunable Dual Comb Source using Gain Switching

(Student Paper)

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ABSTRACT

A monolithically integrated dual output optical comb source is demonstrated by gain switching two separate injection locked Fabry Pérot lasers. The device consists of the two slave lasers and a master laser separated by a multi-mode interference coupler. Wavelength tunability has been demonstrated by varying the electrical bias of the master laser, which consists of three electrically isolated sections. Combs were generated and recorded for multiple wavelengths from each slave laser.

Keywords: optical frequency combs, photonic integrated circuit (PIC), pits mirror, injection locking, gain switching

1 INTRODUCTION

Optical frequency combs (OFCs) are very relevant in the fields of optical sensing, metrology and optical communications [1]. In telecommunications, optical combs provide a spectrally efficient means to generate multiple coherent channels which can facilitate highly spectrally efficient terabit per second (Tbps) communications systems [2]. Many methods exist for generating OFCs, one of which entails flexible OFC generation achieved by gain switching an injection locked laser diode [3]. With this approach, highly coherent and stable combs can be generated with the additional benefit of tunability.

Gain switching is a form of direct modulation wherein a high power radio frequency (RF) signal capable of switching the laser on and off is applied, causing the gain parameter of the laser to oscillate between positive and negative. The RF frequency applied directly relates to the spacing of the comb lines generated by this effect. Directly modulated lasers however suffer from added phase modulation known as chirp, which is measured as an increase in laser linewidth [4]. In this device such effects are mitigated through the on-chip injection locking of the gain switched laser. The use of injection locking from a single mode master laser into a simple Fabry Pérot (FP) slave laser has been previously shown to reduce linewidth and chirp in gain switched lasers [5].

In this paper we demonstrate a monolithically integrated dual optical comb source formed by a tunable master laser injecting into two FP slave lasers. Optical frequency combs are formed from the two injection locked slaves using a high power RF signal generator and the output of the slaves is analyzed (using an Ando AQ6317B with a resolution of 0.02 nm) in order to resolve the comb lines.

2 DEVICE DESIGN

The dual comb device consists of two slave lasers, referred to in Fig. 1 as slave 1 and slave 2, and a master laser composed of three electrically isolated sections labeled Pit 1, Pit 2, and Gain. Pit 1 and Pit 2 act as single mode reflectors for Gain; the gain section of the laser. To produce single mode lasing, Pit 1 and Pit 2 are populated with small circular perturbations etched through the waveguide as shown in the scanning electron microscope (SEM) image on the right in Fig. 1.

These etched "pits" provide additional optical feedback along the laser cavity in place of traditionally cleaved facet reflectors, which results in further wavelength selectivity and high side mode suppression ratio (SMSR) (>30 dB). This wavelength selectivity is dictated via the pit spacing [6]. Both pitted sections in the device consist of three clusters of three pits. In Pit 1 the clusters are 108 µm apart and the pits within these clusters are 9 µm apart. In Pit 2 the clusters are 96 µm apart and the pits within these clusters are 9 µm apart. Sections Pit 1 and Pit 2 are separated by the Gain section, an electrically isolated waveguide of length 550 µm. The master laser emission is then injected into the slave lasers via a 1x2 multi-mode interference coupler (MMI) of length 116 µm and width 10 µm. The FP slave lasers are approximately 500 µm in length. Both slave lasers have one cleaved facet and one deep etched facet, which also serves to isolate the slave lasers from the MMI section.

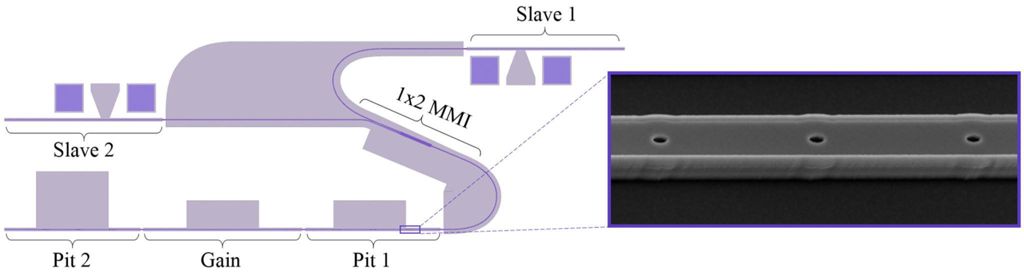
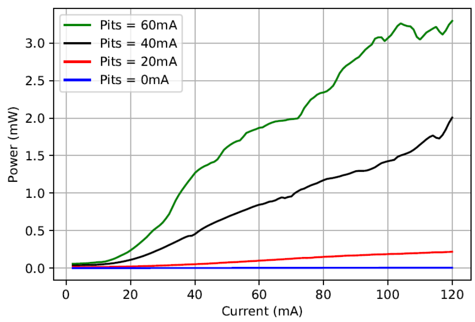


Figure 1: On the left, a schematic view of the device design showing labeled sections. Pit 1 and Pit 2 consist of clusters of three deeply etched pits as shown in the SEM image on the right.

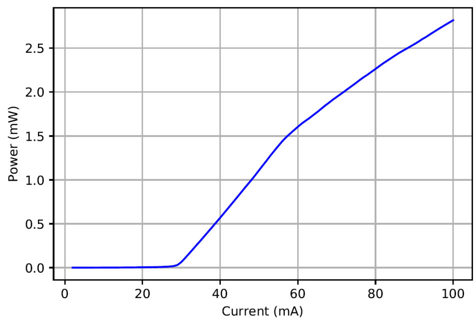
The device was fabricated on commercially available lasing material consisting of 5 compressively strained AlGaInAs quantum wells of width 6 nm, on an n-doped InP substrate. The upper p-doped cladding consists of a 0.2 µm InGaAs cap layer, followed by 0.05 µm of InGaAsP, lattice matched to 1.62 µm of InP. Standard lithographic techniques were used to define the ridge, with a ridge width of 2.5 µm, and height of 1.7 µm. Electrical isolation between different sections was achieved via narrow shallow etches, commonly referred to as slots with a width of 1 µm. These shallow ridge etches end above the quantum wells. A separate etch through the quantum wells was performed so as to provide access to the n region to form ground-signal (GS) contacts, to allow high-speed modulation of the slave section bias to facilitate gain switching.

3 DEVICE TESTING

3.1 DC Characterization



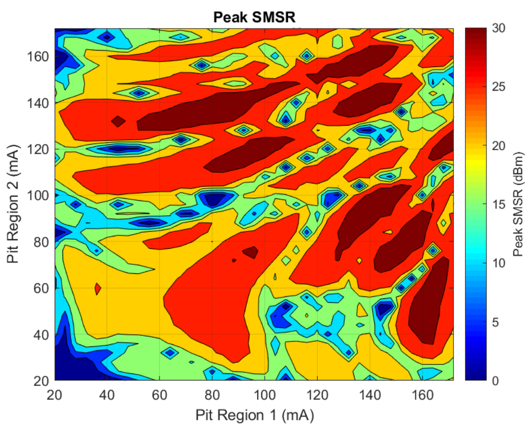
(a) LI curve of master laser with varying bias on sections Pit 1 and Pit 2.



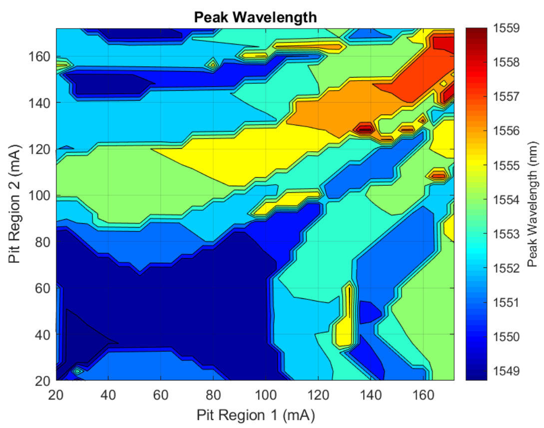
(b) LI curve of slave laser.

Figure 2: Light-current (LI) curves of component lasers of the device.

The DC characteristics of the device were first examined. The device was mounted on a temperature controlled chuck at 20 °C, and a lensed optical fiber was used to couple light from the device. To test the LI output of the master laser, the Gain section was swept while both surrounding Pit sections (1&2) were maintained at set currents. All other sections remained unbiased. To obtain the LI of the slave, only the current of the slave section was swept, all other sections remaining unbiased. The results are shown in Fig. 2.



(a) SMSR map of master laser.



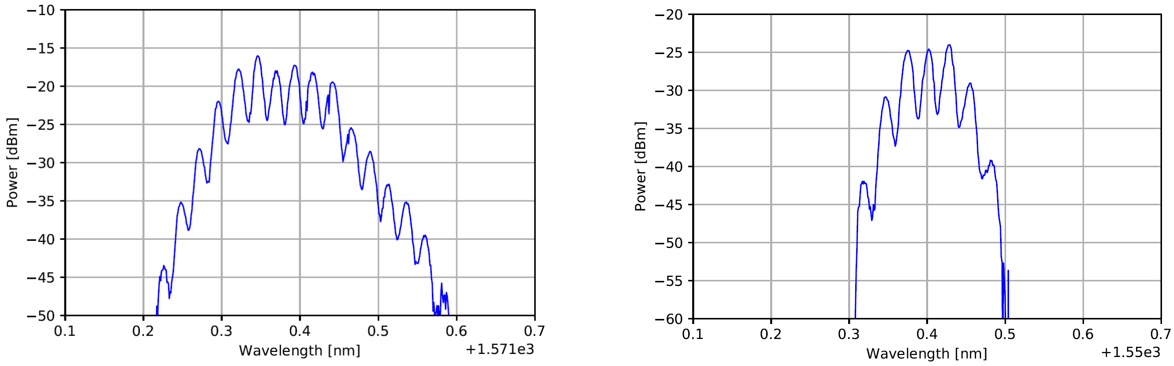
(b) Wavelength tuning map of master laser.

Figure 3: Tuning map of master laser under varying biases of sections Pit 1 and Pit 2. Gain was kept at 100 mA.

In order to suitably injection lock the slave lasers to the master laser, the light injected from the master laser was required to be single mode and sufficiently powerful. A tuning map of the peak wavelength and corresponding SMSR of the master laser was obtained by biasing the Gain section of the device with a current of $100\,\mathrm{mA}$ and sweeping the current through sections Pit 1 and Pit 2. Single mode behavior ($>30\,\mathrm{dB}$ SMSR) was observed for an approximate wavelength tuning range of $10\,\mathrm{nm}$ as shown in Fig. 3.

3.2 Comb Generation

To generate the optical combs, the slave section was biased just above threshold current. The master laser was then powered and injected into the slave via biasing the MMI section to passivation with a current of $120\,\mathrm{mA}$. The injection locked slave was then gain switched by applying a high power RF sinusoidal signal ($>20\,\mathrm{dB}$) at frequencies near $3\,\mathrm{GHz}$ from a signal generator to directly modulate the current. The slave laser DC bias was then tuned to obtain the best combs, which were recorded using an OSA. The master section was tuned so as to obtain the best combs over multiple wavelengths. The optical combs obtained from some of these configurations are shown in Fig. 4.



(a) Slave 1 is set at $36\,\mathrm{mA}$. Pit 1 and Pit 2 are set at $135\,\mathrm{mA}$ and $130\,\mathrm{mA}$ respectively. RF signal used was $2.905\,\mathrm{GHz}$.

(b) Slave 1 is set at $27\,\mathrm{mA}$. Pit 1 and Pit 2 are set at $50\,\mathrm{mA}$ and $97\,\mathrm{mA}$ respectively. RF signal used was $3.600\,\mathrm{GHz}$.

Figure 4: Sample combs generated from device. Gain was set at $100\,\mathrm{mA}$.

4 CONCLUSION

A dual output frequency comb has been demonstrated using the gain switching technique. Injection locking into two separate slave FP lasers was accomplished via a master laser, formed by pit-based sampled grating mirrors. This device has been shown to have a highly single mode output, suitable for gain switching. Multiple combs were obtained from each output ranging from $2.9\,\mathrm{GHz}$ - $3.6\,\mathrm{GHz}$.

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