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A Monolithically Integrated Tunable Comb Source and Filter

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Abstract *Modern optical networks employ hundreds of lasers that fill up the limited bandwidth. Each laser generates a channel and each channel is separated by a spectrally inefficient region of space called a guard band. Optical frequency comb sources (OFCS), can potentially reduce or eliminate the use of these guard bands by creating coherent superchannels with a precise and stable frequency. In this paper we demonstrate a monolithically integrated comb source which is integrated with a filter with the intent to be used as a de-multiplexer.*

Introduction

Optical frequency comb sources (OFCS) show significant promise in many modern day applications such as spectroscopy[1], spaced based instruments[2] and high speed telecommunications[3]. OFCS generate equally spaced spectral carriers with a known phase relation between adjacent carriers. Due to their precise and stable frequency and relative phases, they can be used in wavelength division multiplexing (WDM) communications to create coherent optical superchannels, where guardbands between neighbouring WDM signals are no longer required[4]. One method of generating a frequency comb in a PIC (which is the method described in this paper) is by injection locking a slave laser to a single mode master laser and gain switching the slave laser by applying a high power radio frequency (RF) signal.

A comb based coherent superchannel would require the optical source to be integrated with a de-multiplexer, which would filter out individual lines into separate waveguides with separate modulators before being recombined and transmitted. Monolithically integrated comb sources with frequency spacings of 4 - 9 GHz have been demonstrated with InP devices[5]. However, typical methods of de-multiplexing these narrow lines on a PIC have not been feasible[6], due to the difficulty of de-multiplexing the comb while retaining relative coherence between the optical carriers.

In this paper we focus on an injection locked ring laser as a tunable filter element that can be used as part as a full de-multiplexer, which is monolithically integrated with a tunable comb source. The comb source itself is demonstrated by injection locking a single mode master laser into a gain switched slave laser. Injection locking using an external master laser has been demonstrated to reduce phase noise and linewidth in gain switched lasers[7]. These two lasers are monolithically integrated in a strongly coupled master/slave configuration[5], whereby the slave laser is optically phase locked to the master laser. The single mode characteristics of the slave laser have been known to improve by on-chip optical phase locking, particularly with increasing the side mode suppression ratio (SMSR) of the slave[8]. The master laser is more heavily biased than the slave and so the two lasers are operating in an asymmetric bias regime. So while no isolator exists between the two lasers, the asymmetry of the operation has been shown to allow for injection locking[9]. The slave laser is then gain switched using a high power RF signal generator to generate the optical combs. The generated comb is injected into a monolithically integrated ring laser which acts as an integrated laser filter (ILF). Using current injection, this ILF filters out a single comb line. The output of the device is analysed by an ANDO AQ6317B optical spectrum analyser (OSA), which has a resolution of 0.02 nm, and so the comb lines and their spacings can be observed.

Device Design

The device was fabricated with commercially available material designed for the emission at 1550 nm, purchased from IQE. This lasing material consists of 5 compressively strained 6 nm wide AlGaInAs quantum wells on an n-doped InP substrate. The upper p-doped cladding consists of a 0.2 μm InGaAs cap layer, which is followed by 0.05 μm of InGaAsP, lattice matched to 1.62

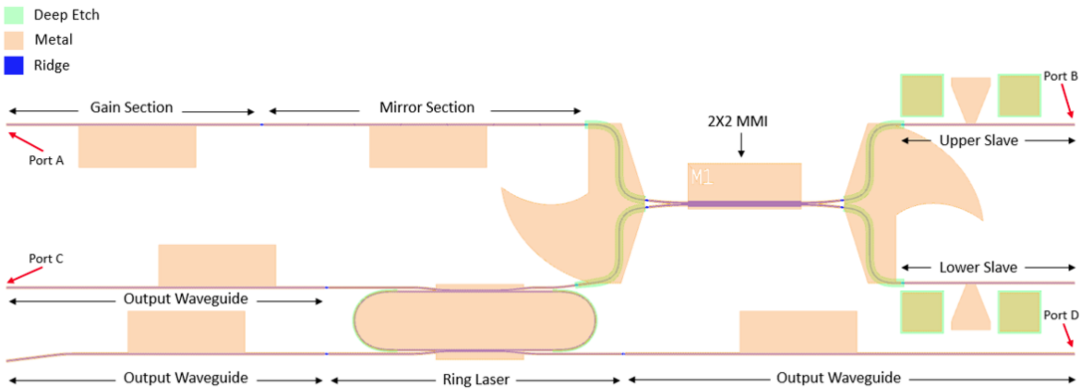

Fig. 1: Schematic of the PIC design

μm of InP. The ridge and slot features are defined using standard lithographic techniques, with a ridge width of 2.5 μm and a height of 1.7 μm, and a slot width of 1 μm, with the ridge etch stopping above the quantum wells. The slots were used as both optical reflection as well as electrical isolation between different sections of the PIC. A ground-signal-ground (GSG) contact was added to the slave section to allow for the gain switching of the device.

The master section of the device is made up of the gain section, 600 μm in length, and mirror section. The mirror section is made up of 8 slots etched into the ridge with an interslot separation of 108 μm. These slots act as reflective defects along the ridge by creating regions of lower effective refractive index, effectively creating a master section that is both single mode and tunable[5],[10]. This master laser is integrated with a 2$\times$2 multimode interferometer (MMI) which splits light equally into both slave lasers. At this point, either slave laser could be used to generate the comb. The upper slave is injection locked to the master and is gain switched, generating a comb while the lower slave is unused. This comb is reflected back into the 2$\times$2 MMI and is split equally into the master laser and into the lower waveguide coupling with the ring laser. The ring laser is used to filter a single line from the comb by injecting the comb into the ring[11]. The individual comb lines are filtered using current injection and are detected through Port D. The addition of multiple ring laser filters would facilitate the full de-multiplexing of the comb.

Results

The master laser was initially characterised by biasing the gain and mirror sections of the device independently, sweeping the current through both sections and measuring the spectra through Port A at each interval. The SMSR and lasing wavelength were recorded and plotted as shown in Fig. 2.

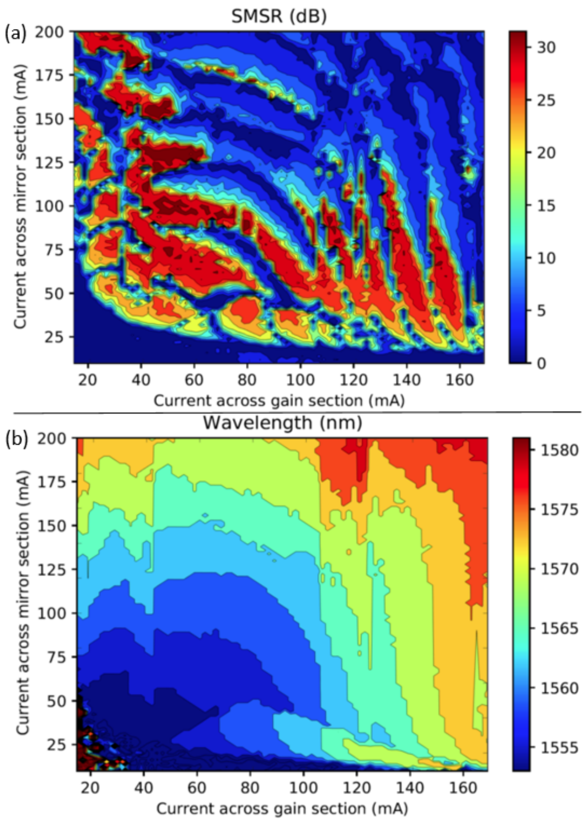

Fig. 2: (a) SMSR and (b) lasing wavelength of the Master Laser.

When the single mode nature of the master laser was determined, the MMI section was biased at 180 mA, the upper slave laser was biased just above threshold current and the spectra of slave laser was optically phase locked to that of the master. A strong RF signal was applied to the slave section to allow for gain switching to occur and a comb to be generated. Due to the design of the PIC, the generated comb was detected through Port A, B and C as shown in Fig 3.

Once this was achieved, the ring was biased and the resulting spectra was detected through

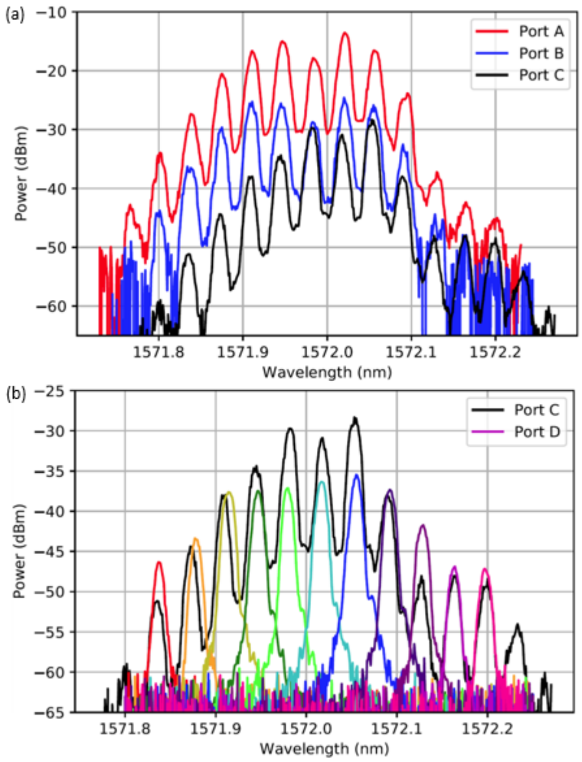

Fig. 3: (a) Generated comb detected through Port A, B and C and (b) the individual comb lines detected through Port D.

Port D. By varying the current through the ring laser, different peaks were attained, and plotting these against the comb detected through Port C (Fig. 3) it is clear that these peaks are a result of the different comb lines being filtered by the ring laser. The colour plot in Fig. 4 illustrates the growth and suppression of the individual comb lines as the current across the ring laser is varied.

Future Work

We have demonstrated a monolithically integrated PIC that can generate a frequency comb and filter out the individual comb lines using a ring laser as an ILF.

In a de-multiplexing system, the individual lines of the comb are filtered at once, and so further ring lasers are required. The next generation device shown in Fig. 5 depicts a smaller design with dimensions of 1700 μm $\times$ 500 μm, compared to the 2600 μm $\times$ 700 μm PIC focused on in this paper. An additional ring laser is also integrated with the PIC in order for for more than one comb line to be filtered at one time. Future designs would include a network of multiple ring lasers which would be used to de-multiplex the comb lines and separate them into different waveguides with separate modulators before being recombined and transmitted.

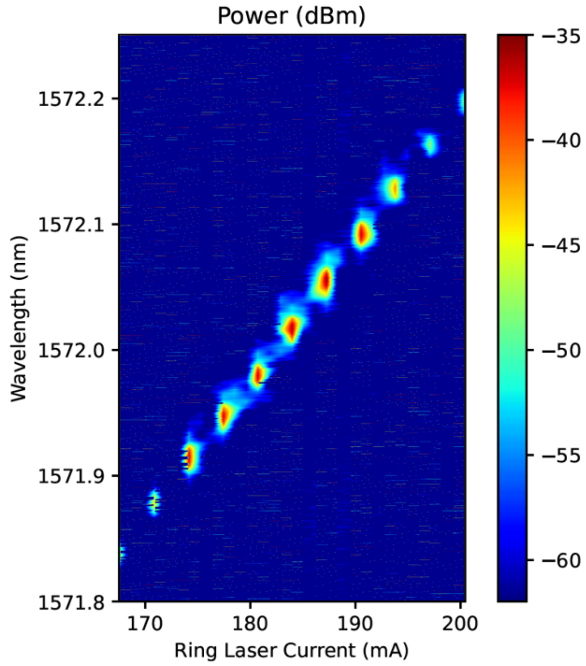

Fig. 4: Colour plot depicting the power of the spectra detected through Port D as the current through the ring laser changes.

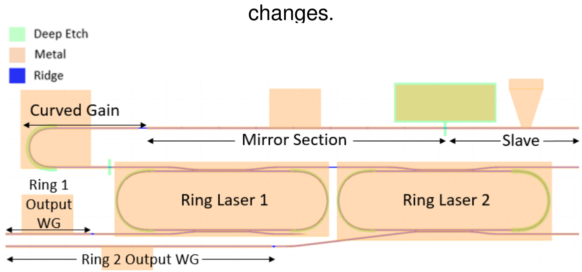

Fig. 5: Schematic of next generation PIC.

Conclusions

This PIC demonstrates how a coherent optical comb can be created and de-multiplexed. An optical frequency comb was obtained from the PIC by gain switching a slave laser that has been injection locked with a single mode master laser. Due to the reflective defects caused by the slots used in the mirror of the master, the master laser was shown to have a tunable wavelength. The integrated ring laser allowed for the injection locking of the individual comb lines and therefore the selective or tunable filtering of the comb. A future design of a PIC that can filter out two individual comb lines is also demonstrated by integrating the PIC with a second ring laser. By using a network of these ring lasers, a comb can be generated and de-multiplexed on a monolithically integrated chip.

Acknowledgements

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