Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Compact gain switched optical frequency comb generator for sensing applications

To cite this article: M N Hammad *et al* 2019 *J. Phys.: Conf. Ser.* **1289** 012048

Compact gain switched optical frequency comb generator for sensing applications

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Abstract. We present a novel InP photonically integrated optically injected device that is gain switched for the generation of an optical frequency comb. Using this technique, an optical frequency comb with a free spectral range of 6.25 GHz and nine spectral lines within a 3 dB spectral window is obtained. Such a device provides tunability of both the free spectral range and the centre emission wavelength, which facilitates the matching of the wavelength to the signature of a target gas. The stable spacing and high phase correlation between the comb lines confirms the potential of the device to be used in various applications such as spectroscopy, telecommunications and gas sensing.

1. Introduction

Laser based trace-gas sensing technology has garnered increasing attention in recent years as an effective method for the detection of gases. A photonic gas sensor can interrogate a gas sample utilising a swept single frequency laser or a broadband light source. At a particular frequency, the light will encounter a higher loss. This frequency corresponds to the absorption profile (frequency signature) of a certain gas. While a laser can offer high spectral resolution due to their narrow linewidth, sweeping across a sample renders this method low speed. A broadband light source can achieve high speed sensing, as they cover the entire spectral profile, but this method suffers from lower spectral resolution compared to laser-based methods [1]. To achieve both high resolution and high speed, optical frequency combs (OFCs) that cover a large spectral bandwidth with discrete spectral lines of narrow linewidth [2] can be used.

2. Optical frequency combs

An OFC source is a type of laser that generates a large stable array of equally spaced, highly coherent, narrow-band spectral lines. These features have resulted in them being considered for use in wide range of applications spanning over many disciplines such as millimeter wave and terahertz signal generation [3], efficient optical transceivers [4], and spectroscopy [5]. Mode locking [6], electro-optic [EO] modulators [7], micro-ring resonators (MRR) [8] and gain switching [9] are some of the techniques that can be used to generate an OFC. While mode locked lasers can generate a wide bandwidth OFC, they don’t offer tunability of the free spectral range (FSR) as the comb line spacing is mainly determined by the laser cavity length. OFCs generated using EO modulators introduce more complexity and large insertion loss to the sub-system. MRR based combs require high power and stable pumps to ensure optimum comb generation. An attractive alternative is the gain switching technique that is simple and cost efficient. In addition, it provides a highly coherent and stable OFC with tunable FSR.

2.1. Gain switching

Gain switching is a simple and cost-effective OFC generation technique as it entails directly modulating a semiconductor laser with a large amplitude radio frequency (RF) signal [10]. This large RF signal switches the laser above and below threshold and can also be used to control the free spectral range (FSR) of the generated OFC. However, the gain switched OFC suffers from a limited bandwidth and large phase noise [11]. These shortcomings can be solved by applying external injection [12] to the laser.

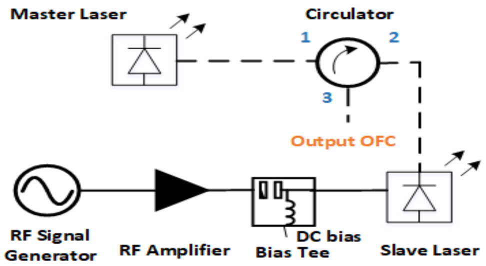

Figure 1. Set-up of externally injected gain switching scheme.

A typical externally injected gain switched laser setup is shown in figure 1, where light from a master laser is injected into the gain switched slave laser through a circulator. The light coupled from the external laser source improves its performance [13]. A set-up consisting of discrete components, as in figure 1, can suffer from instability due to the change of polarisation. Mitigation of such polarisation-based instability effects can be achieved through monolithic integration. In addition, photonic integration can also offer compactness, cost-efficiency and low power consumption.

3. Photonically integrated circuit

The InP photonically integrated device realised for the implementation of both gain switching and external injection is shown in figure 2(a) [14]. The device consists of two integrated discrete mode lasers in a master slave configuration. The length of the device is ~1.5 mm and consists of four electrically independent sections. The device is fabricated using a 1550 nm laser material, with five strained AlGaInAs quantum wells in the active region, placed on an n-doped InP substrate [14].

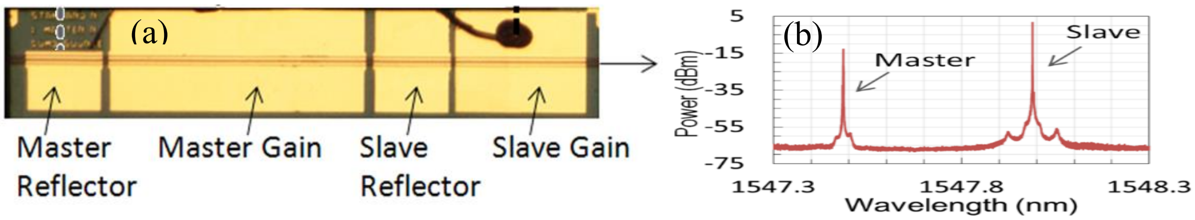

Figure 2. (a) Four section PIC device structure, (b) CW optical spectra of the two integrated lasers.

The master laser consists of a long gain section that is surrounded by two reflector sections at each side to provide reflection to create a lasing cavity and single-mode emission. Both master and slave lasers share the same reflector which tends to reduce the overall length of the PIC device. Figure 2(b) shows an optical spectrum where both the master and the slave emit single mode light. The wavelengths are moved apart from each other by tuning the currents applied to the reflector sections. However, when the slave laser is directly modulated with the large amplitude sine wave (gain switched), the master grating current is tuned to ensure that injection locking is achieved (overlapping of the two wavelengths). The slave laser is then subsequently gain switched by modulating with a sine wave at a frequency of 6.25 GHz. Figure 3 shows the output spectra of the PIC device (a) with and (b) without external injection. It is clear that external injection provides a major improvement in the spectral characteristics of the output OFC. In figure 3(a), the master section was turned off while the slave gain section and the shared reflector were biased at 60 mA and 47 mA, respectively. This produces 10 clearly resolved comb tones within 20 dB of the spectral peak, corresponding to a 20 dB bandwidth of 62.5 GHz. The comb tones exhibit an optical carrier to noise ratio (OCNR) of around 45 dB, but the resultant flatness consists of only two comb tones within a 3 dB spectral window.

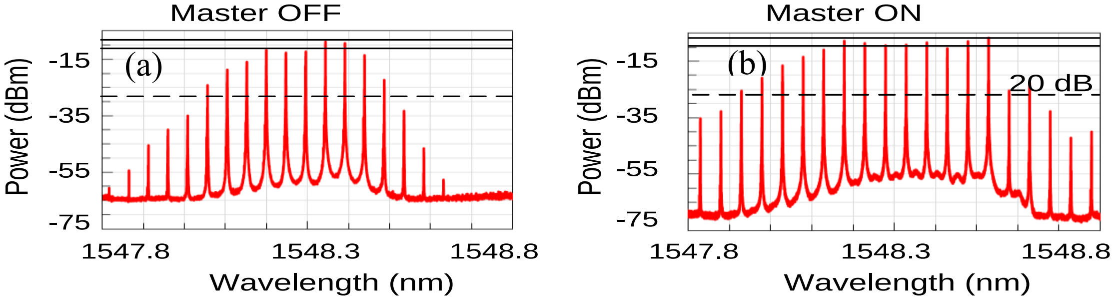

Figure 3. Gain switched OFC with FSR of 6.25 GHz (a) without injection (b) with injection.

In figure 3(b), the master section is turned on and biased at 80 mA. It can be clearly observed that optical injection improves both the flatness and the bandwidth of the output OFC. The overall 20 dB bandwidth increases to 94 GHz, composed of 15 clearly resolved comb tones. Moreover, a total number of nine comb tones could be observed within the 3 dB spectral window. The OCNR of the generated OFC after applying external injection ranges from 46 to 52 dB. Hence, implementing external injection clearly improves many spectral properties of the generated comb.

4. Conclusion

We have reported on a photonically integrated device that uses both gain switching and external injection techniques to produce an OFC. The device consists of two integrated discrete lasers in a master-slave configuration. It has been demonstrated that through external injection, the device generates an OFC with a FSR of 6.25 GHz, improves the OCNR by about 5 dB and enhances the number of tones within a 3 dB range from the peak of the spectrum to nine spectral lines.

The use of photonic integration is currently being considered for many optical sensing applications. Most efforts have been focused on bio-sensors. However, the reduction of footprint, cost and energy efficiency through photonic integration may serve advantageously in photonic gas sensing applications.

Acknowledgments

This work was supported in part by Science Foundation of Ireland's (SFI) career development award (15/CDA/3640) and the Enterprise Ireland commercialisation fund (CF-2017-0683A-P).

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