Optoelectronic comb generation and cross-injection locking of photonic integrated circuit for millimetre-wave generation

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Abstract *We demonstrate how a monolithically integrated heterodyne source was used for a 33.6 GHz signal generation using an optical solution by a combination of cross-optical injection locking inside the chip and electrical injection locking at the RF signal 7th sub-harmonic.*

Introduction

Monolithically integrated tunable heterodyne sources designed for generation and modulation of millimeter-wave signals is of great interest in modern wireless communication systems[1]. They can exploit all the key advantages of the photonic systems such as compactness, fewer alignment issues, lower power consumption and well reduce production costs. In the previous work[2], we have reported generation of a signal tunable from 5 to 110 GHz only with elements integrated in the photonic circuit containing two Distributed Feedback Lasers (DFB), Semiconductor Optical Amplifiers (SOAs), passive waveguides, UTC-type high speed photodiodes, electro-absorption modulators (EAMs) and Multimode Interference (MMI) couplers based upon the same InP chip. A high order optoelectronic cross injection technique to phase lock above mentioned photonic integrated circuit (PIC) has been successfully demonstrated. In this paper we present the optical combs generation at different bias condition of SOAs and stabilization of the generated signal by cross-injection locking up to 33.6 GHz.

Device description

The PIC used in the experiment is shown in Figure 1. It consists of two 1.1 mm-long DFB lasers operating at around 1555 nm wavelength. The MMI coupler combines the laser beams and SOAs are used to amplify and adjust the signal levels at different positions of the circuit. The UTC photodiode receive optical beat which passes through two SOAs and one modulator (EAM) that is inserted before photodiode to modulate the beat-note, which is used as a carrier frequency. The UTC photodiode converts received signal into a RF signal. The RF output frequency corresponds to the difference between the two optical frequencies and, after connecting mmW antenna to the photodiode output, PIC can be utilized for free space data transmission[1]. An optical access to the DFB lasers is provided on the other side of the chip (left-hand side in Fig. 1). The whole device is 4.4 mm long and 0.7 mm wide. The DFBs wavelengths are adjusted and tuned thermally by the driving current. A continuous tuning from 5 GHz up to 110 GHz was demonstrated[1], what also confirms continuous tunability of the beat-note and high frequency response of integrated UTC photodiode.

Frequency comb generation and cross-injection locking

In our experiment, we use one of the two DFB lasers integrated on the chip for optical frequency comb generation. The DFB output signal is modulated twice, before and after reflection on the back of the photodiode[2]. This causes generation of sidebands, which form an optical frequency comb. Figure 2 presents the principle of the experiment. The modulator is driven with 20 dBm RF signal.

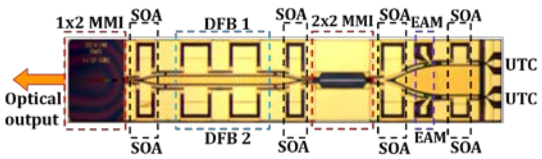

Fig. 1: Microscope view of the integrated photonic chip.

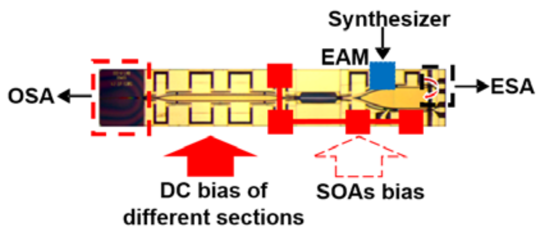

Fig. 2: Configuration for optical frequency comb generation.

The SOAs bias current values are tuned from 5 mA up to 200 mA, and the synthesizer frequency is fixed successively at 1 GHz, 2 GHz and at 10 GHz. An optical spectrum analyzer (OSA) is used to monitor the spectrum. The PIC temperature for cross-injection locking and for optical frequency comb generation is maintained at 25 °C with thermoelectric cooler. Measurement results at different bias conditions and RF signals are presented in Figure 3 and Figure 4. From these measurements we clearly see that use of amplitude modulation assisted by integrated SOAs is an efficient way to generate an optical frequency comb. This is attributed to a combination of contribution from four wave mixing in SOAs and four wave mixing in the self-injected DFB laser. Increasing the bias current increases the optical power being self-injected in the laser and SOAs, and as a consequence, increase the span of the comb as can clearly been seen on the figures. The highest number of harmonics is measured at 200 mA bias current. For 2 GHz RF signal (Fig. 4), the generated optical frequency comb is slightly less wide compared to the 1 GHz case. Figure 5 presents a comparison between optical frequency combs at the same bias condition, but at different frequencies. The most narrow optical frequency comb is observed at 10 GHz RF signal. This is due to the limited modulation bandwidth of the modulator that is below 2 GHz.

A solution to use optical injection locking (OIL) assisted by sub-harmonic injection locking with a synthesizer is reported in one of our previous publications[2]. Injecting a slave laser (SL) with low-phase-noise master laser (ML) forces the SL to work at the same wavelength and the phase noise is similar to ML. This condition is satisfied when the wavelengths of two lasers are close enough and injected optical power is optimized. When the ML is a comb of optical tones, the SL can lock to the nearest tone, as it has been successfully tested on one of our PIC[3]. This solution requires an additional stable laser to generate the comb. To overcome this limitation, a generation of frequency comb around each DFB line and optical reinjection of this dual-comb into the PIC is applied. For the experiment presented here we use integrated EAMs and residual reflection on the back of the high speed photodetectors. The beat note frequency delivered by the PIC is tuned to 33.6 GHz.

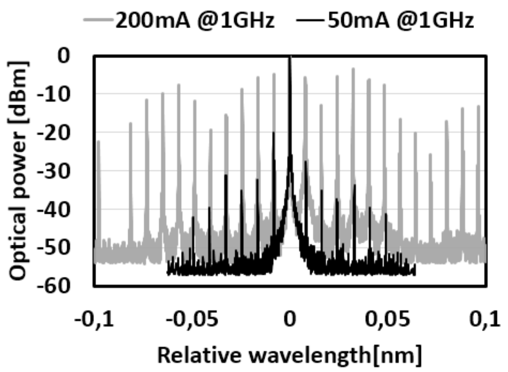

Fig. 3: Optical frequency comb at different bias condition of SOAs at 1 GHz RF signal.

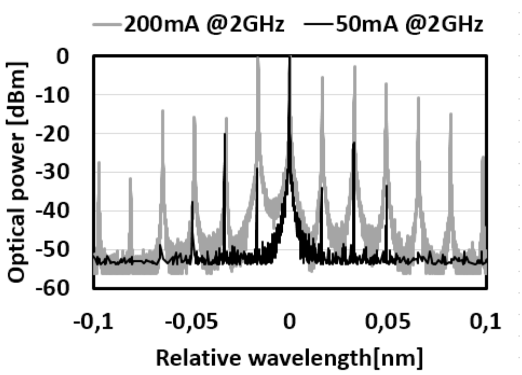

Fig. 4: Optical frequency comb at different bias condition of SOAs at 2 GHz RF signal.

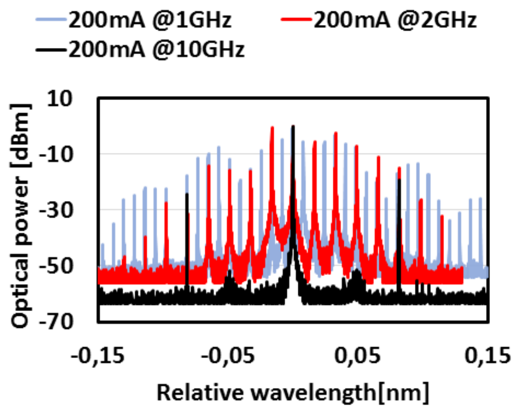

Fig. 5: Comparison of optical frequency combs at different frequencies for 200 mA bias current.

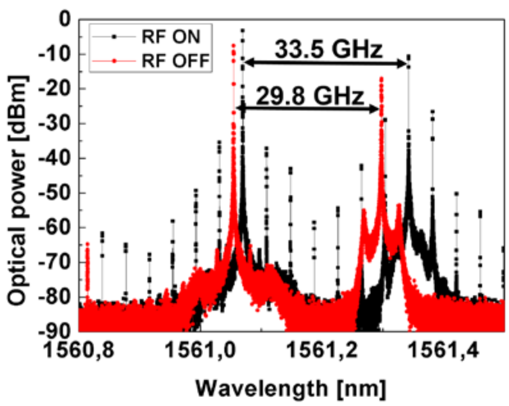

Fig. 6: Optical spectrum for cross injection locking with sub-harmonic injection locked.

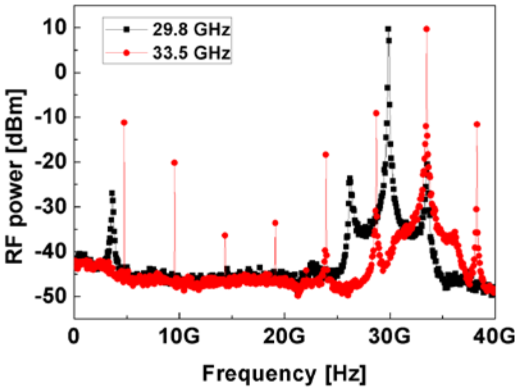

Fig. 7: Electrical spectrum for cross injection locking with sub-harmonic injection locked with 20 dBm electrical injection.

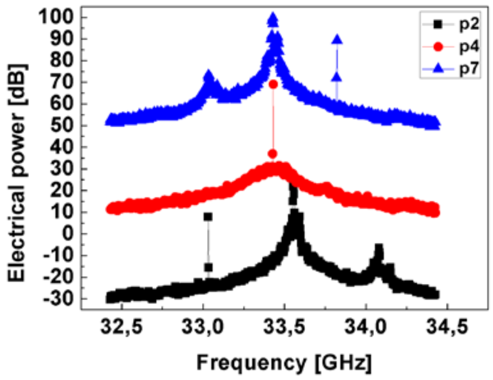

Fig. 8: Electrical spectrum of the beat-note for lock-in condition at 33.5 GHz.

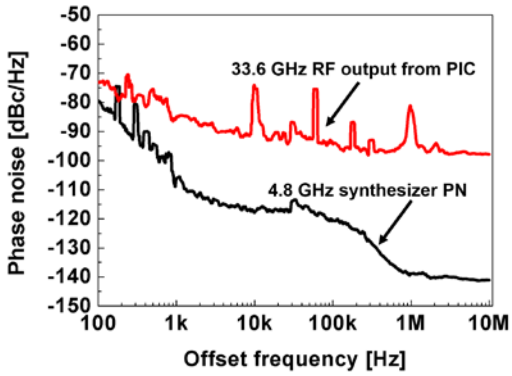

Fig. 9: Comparison between the synthesizer and the self-injected beat-note phase noise.

Figure 6 and Figure 7 present optical spectra measured with 0.04 pm resolution of the OSA (model APEX AP2043B) and ESA for cross injection locking with sub-harmonic injection locked, with and without RF modulation. The modulator is driven at 4.8 GHz what corresponds to the 7th sub-harmonic of the generated signal. Thanks to fine adjustment of the modulation frequency, a narrow linewidth of the beat-note can be established. Figure 8 presents the beat-note of generated signal at 33.5 GHz for different injected frequencies at the optimum adjustment and around showing efficient injection locking (the measurement for effective injection locking is represented by curve p4 on Fig. 8). The phase noise of the self-injected beat-note was measured using ESA (Fig. 9). For comparison, the phase noise spectral density of the synthesizer is presented as well. Measured phase noise level of self-injected beat-note is below -90 dBc/Hz at 10 kHz offset from the 90 GHz carrier.

Conclusions

The optical frequency comb generation from a monolithically integrated heterodyne source has been tested for different bias conditions and for different frequency spacing between the comb lines. Cross-injection locking of a monolithically integrated circuit for millimeter-wave generation for up to 33.5 GHz has been successfully demonstrated base on optical self-injection locking inside the chip assisted by an external RF modulation at the 7th sub-harmonic. The solution has demonstrated efficient low phase noise generation in the millimetre wave range without any external optoelectronic device. These results support promising prospect of photonic integrated circuits in future systems for generation of frequency stabilized RF signals at higher frequencies.

Acknowledgements

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References

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