A photonic, hybrid integrated, THz heterodyne source

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Abstract—**We present the first results on the integration of a photonic heterodyne source using a hybrid integrated optical phase lock loop to minimise loop propagation delay. The loop achieved phase noise of less than -80dBc/Hz at 10KHz offset and generated high spectral purity signals at frequencies up to 300GHz with an output power of -20dBm.**

Hybrid Integration; Heterodyne; Optical Phase Lock Loop; Photonic integration

I. INTRODUCTION

Photonic techniques are being used increasingly for frequency generation to access the millimetre-wave band (30 – 300 GHz) and beyond (terahertz waves). Potential applications in the mm-wave band include high-speed fixed wireless access and home area networks, with wireless links at 10 Gb/s data rates already having been demonstrated at 60 GHz [1] and 120 GHz [2] over spans of tens to hundreds of metres. At higher terahertz (THz) frequencies, there is interest in medical imaging, spectroscopy, and security screening [3].

This paper shows the potential of photonic hybrid integrated systems for high spectral purity frequency generation at frequencies above 30 GHz [4]. The high purity photonic heterodyne source was based on an hybrid integrated optical phase lock loop (OPLL) [5] with an overall delay of 1.4 ns, where the two slave tuneable lasers offered the potential for the generation of up to 1.8 THz. The integrated OPLL allowed for the generation of signals with a phase noise of – 80 dBc/Hz at 10 kHz offset.

II. THE HYBRID OPLL BOARD

The board was based on hybrid technology where active InP based components are integrated with passive silica waveguides on silicon substrates [6]. The advantage of such a technology is that while the overall optical delay of the loop is reduced, the individual active components (lasers and photodetectors) and the electronic filters are easily integrated with the board. The optical part of the board, shown in Fig. 1, comprise the mother board with the optical passive waveguides, coupler and the electrical connections for integration with the active optical components and electronic filters. The board also include a daughter board with a twin distributed Bragg reflector (DBR) laser chip. These twin DBR lasers are buried heterostructure lasers fabricated 30μm apart on a single InP/InGaAsP chip, each laser having 4 sections: front and rear grating, gain section and phase section. The waveguide of each laser was of different width to achieve a wavelength offset between them. The outputs were combined by a coupler, which was further integrated onto an angle tapered semiconductor optical amplifier (SOA) to boost the output power with minimum facet reflections to 10 dBm maximum per laser. Importantly, for the OPLL, the two laser output linewidths were about 1 MHz, thus permitting an overall loop delay of up to 1.5 ns [1]. The board also included two daughter boards for the 10 GHz 3dB bandwidth photodetectors. The integration meant that the optical part of the delay was only 40 ps.

This board was connected to a multilayer printed circuit board containing the electronic loop filter. The filter was based on two parallel paths. The first path was a short delay gain loop offering a total 1.4 ns delay that was essential to the operation of the phase lock loop. The second loop was a lower bandwidth integrating loop that was used to track the slow thermal drift of the slave laser frequency and allow for tuning of the frequency difference between the slave and the master. That frequency difference was limited to a 2 GHz to 7 GHz range, where the lower limit was due to the 90-degree power splitter used for reference signal distribution and the upper limit was due to the photodiode amplification stage.

III. LOCKING PERFORMANCE

The tuning performance of the integrated OPLL was studied by measurement of the heterodyne signal between the master and locked slave laser using a spectrum analyzer. The quality of the lock was measured in terms of phase noise with

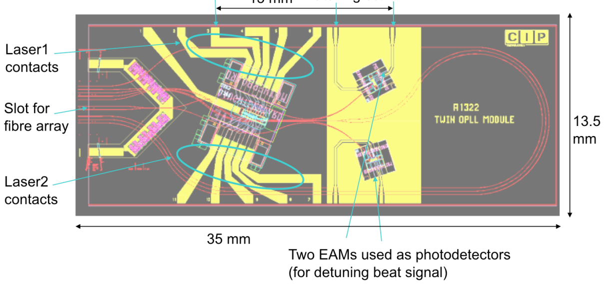

Fig. 1: Hybrid OPLL board with a dual DBR laser and two EAM detetectors

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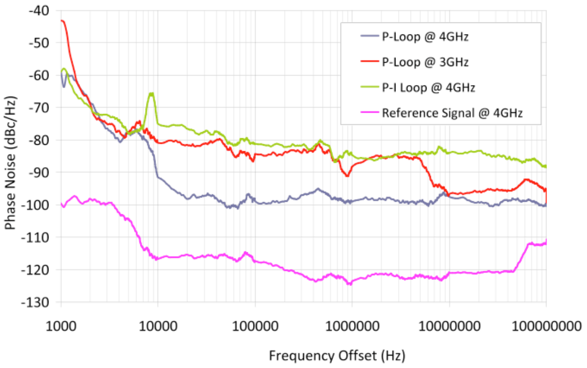

Fig. 2: Phase noise up to 10 MHz offset for the locked laser signal.

and without the slow tracking integrating loop. The measured phase noise results are shown in Fig. 2, together with the frequency reference source phase noise. The heterodyne linewidth (3 dB) was less than 1 kHz (instrument resolution bandwidth limited). At 10 kHz offset the phase noise was -80 dBc/Hz. As the gain of the proportional loop (P-loop) was frequency dependent, differences could be seen at different frequency offsets.

With the integral tracking loop on and an optimized photocurrent on the photodetector, the slave laser could be tuned over the full 2 GHz to 7 GHz offset range while remaining locked to the master laser.

IV. FREQUENCY GENERATION

To generate Frequencies above the maximum 9 GHz frequency offset an optical frequency comb generator was used as the master optical source [4]. Two comb lines were then used respectively to provide the optical reference signal to the OPLL and to lock a Distributed Bragg Reflector (DBR) laser by injection locking. The OPLL was first tuned close to the frequency of one of the comb lines before turning on the phase lock loop.

First this heterodyne system was tested at 100 GHz with a fast Uni-Travelling Carrier (UTC) photodetector [4] connected through a coplanar probe and an harmonic mixer to a spectrum analyzer. Figure 3 shows the resulting heterodyne spectrum at 1 kHz resolution bandwidth, with the expected high spectral purity (heterodyne linewidth < 1 kHz, resolution bandwidth limited). The system was then connected to partially depleted absorber photodetector integrated with a bow tie antenna on top of a silicon hemispherical lens with an injected optical power of 100 mW, while the lock quality was monitored. The power was then measured using a large area THz Thomas Keating power meter for frequencies between 130 GHz and 300 GHz, obtained by locking to different comb lines. Fig. 4 shows that the THz power was varied from -17 dBm to -22 dBm, thus demonstrating the potential of the integrated source for the generation of high spectral purity signals at frequencies up to 300 GHz.

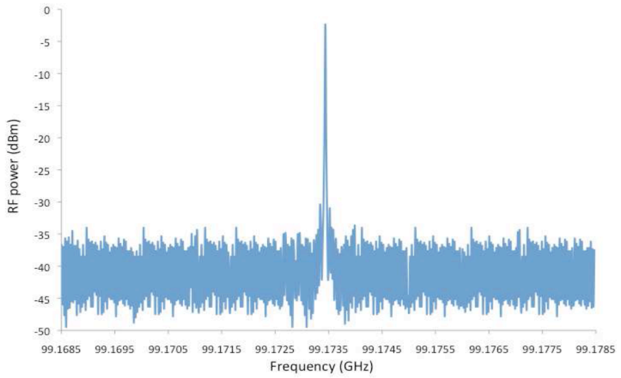

Fig. 4: Spectrum of the heterodyne signal at 99 GHz with 1 kHz resolution.

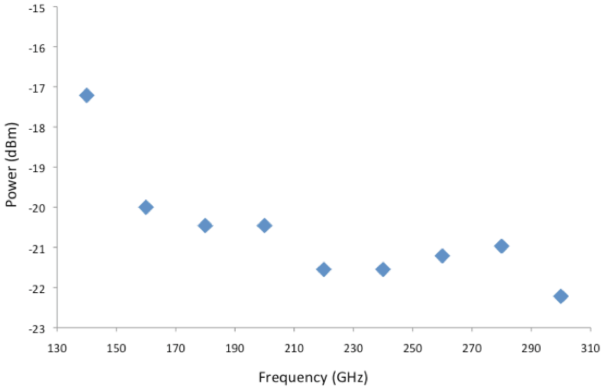

Fig. 3: Emitted power from a fast photodetector integrated with antenna connected to the hybrid OPLL

V. CONCLUSION

We have presented the first demonstration of an hybrid integrated photonic heterodyne OPLL frequency source. The required short loop delay that was achieved through integration enabling high spectral purity frequency generation from 2 GHz to 300 GHz with less than -80 dBc/Hz phase noise at 10 kHz offset. The optical output power of the photonic source was about 10 dBm per laser and with external amplification up to -3 dBm was generated at 110 GHz with an and -22 dBm at 300 GHz using UTC photodiodes.

REFERENCES

[1] A. J. Seeds and K. J. Williams, *J. Lightw. Technol.*, vol. 24, no. 12, pp. 4628-4641, 2006.

[2] A. Stöhr *et al.*, *J. Optical Networking.*, vol. 8, no. 5, pp. 471-487, 2009..

[3] A. Hirata *et al., IEEE Trans. Microwave Theory and Techniques*, vol. 54, no. 5, pp. 1937-1944, 2006.

[4] C. C. Renaud, L. Ponnampalam, F. Pozzi, E. Rouvalis, D. Moodie, M. Robertson, A. J. Seeds, (invited) International Topical Meeting on Microwave Photonics (MWP 2008), pp. 55-58, Gold Coast Australia, 2008.

[5] A. J. Seeds, F. Pozzi, C. C. Renaud, M. J. Fice, L. Ponnampalam, D. C. Rogers, I. F. Lealman, R. Gwilliam, (invited) 14th European Conference on Integrated Optics and Technical Exhibition, pp. 123-132, 2008

[6] G. Maxwell et al, “Very low coupling loss, hybrid-integrated all-optical regenerator with passive assembly” ECOC, Post Deadline Paper, 2002.