Monolithically integrated optical phase lock loop with 1 THz tuneability

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***Abstract*—We have demonstrated a monolithically integrated optical phase lock loop based on a foundry fabricated photonic integrated circuit. The InP chip contains PIN photodiodes integrated with a 1.5 µm DBR laser which can be phase stabilised with respect to an external optical reference tone at all wavelengths throughout its 1 THz (8 nm) tuning range. The frequency offset between the two lasers can be set to any value between 4 GHz and 12 GHz. The phase noise of the heterodyne signal is also reported. Such an OPLL, together with an optical frequency comb and broad-bandwidth photodetector, could be used for high purity, tuneable mm-wave / THz signal generation.**

I. Intoduction

Semiconductor lasers offer the advantages of small size and low manufacturing costs. However, the typically broad linewidth and frequency jitter of these lasers pose a significant limitation to many potential applications. These shortcomings can be overcome through laser phase locking techniques, such as optical injection locking (OIL) or optical phase lock loop (OPLL). The main challenge in realising an OPLL based on a diode laser is to achieve the nanosecond feedback loop delay required to phase control lasers with linewidths in the MHz range [1]. This becomes even more significant in the case of multi-section tuneable distributed Bragg reflector (DBR) lasers, which are expected to have frequency jitter due to the low-frequency noise introduced by the Bragg grating current [2].

The OPLL has been previously demonstrated in photonic-based sub-THz sources [3] and optical transmission links [4]. In fact, OPLL can prove advantageous in numerous applications where a phase and frequency stabilized optical local oscillator can improve system sensitivity or reduce the amount of post processing operations.

In this paper, we demonstrate the ability of the recently developed OPLL [5] to stabilise the frequency and phase of the integrated DBR laser across the whole of its 1 THz tuning range. The OPLL is realised using a foundry fabricated photonic integrated circuit (PIC) and commercially available RF components, which significantly reduce the cost of the OPLL sub-system. Two such OPLLs could be used to select two lines of an optical comb [6], so that a high-purity and broadly tuneable GHz to THz signal could be generated through photomixing in a broad bandwidth photodiode [7]. The advantage of such a photonic-based mm- and THz-wave generation is that broad frequency tuneability of the laser is directly translated onto tuneability of the electrical signal which is generated through heterodyning.

II. Results

The presented OPLL consists of an InP-based PIC which measures 2 mm x 6 mm and includes a DBR laser followed by a semiconductor optical amplifier (SOA), PIN photodiodes (PIN-PD), and a range of passive waveguides and couplers/splitters. The PIC on the carrier together with off-the-shelf RF components (RF amplifier, double-balanced mixer acting as a phase detector, RF reference synthesiser) create an heterodyne OPLL, schematically presented in Fig. 1.

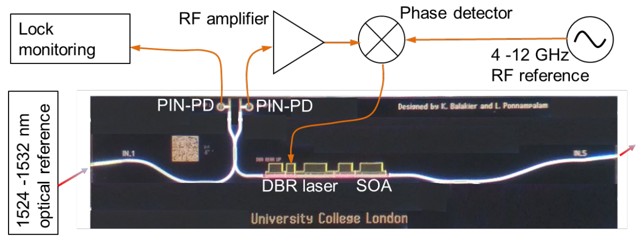

Fig. 1. Schematic representation of the OPLL that includes a photograph of the 2 mm x 6mm photonic chip.

The frequency offset between the DBR laser and optical reference tone is defined and controlled by the external RF local oscillator and can be fine-tuned between 4 GHz and 12 GHz. The loop hold-in range has been measured to be less than 200 MHz, which means that the DBR laser wavelength can be continuously tuned and adjusted by simply tuning the frequency of the RF reference over 200 MHz. The hold-in range can be further increased by including the integrator function in the loop filter.

The DBR laser consists of gain and phase sections between two Bragg grating sections at the front and rear of the laser structure. The laser wavelength can be finely tuned through phase section current adjustment, which is used in the feedback loop. The broad wavelength tuning across 1 THz range (from 1532 nm to 1524 nm) can be obtained by varying the Bragg grating currents between 0 mA and 27 mA. The single mode operation of the laser across the 1 THz range is demonstrated in Fig. 2.

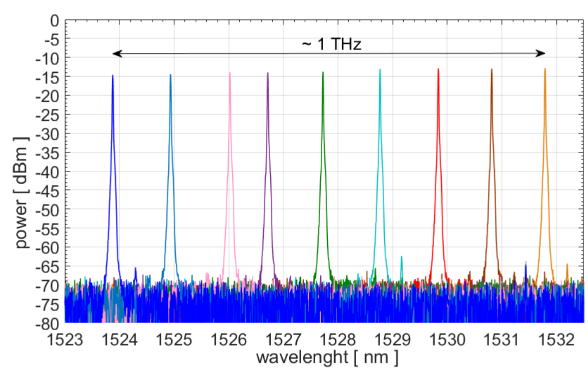

Fig. 2 Optical spectra of the DBR laser tuning range

Fig. 2 demonstrates that a broad range of wavelengths can be accessed, allowing for continuous tuning by applying a combination of control currents to the grating and phase section. This continuous wavelength tuning translates into continuous tuneability of the mm-wave and THz signal, assuming OPLL is implemented together with a wide range optical frequency comb and broadband photodetector.

Changing grating current has also an effect on the laser linewidth which increases from its minimum value of 1.25 MHz (measured when the grating currents were 0 mA) to tens of MHz for higher currents. This broadening is demonstrated by the phase and frequency jitter of the free running heterodyne signal, as seen in Fig. 3 (dashed line). Despite increased linewidth of the laser, the described OPLL can still successfully control and phase-lock the DBR laser to the reference laser (continues line).

When the OPLL is in operation, the DBR laser follows phase changes of the reference signal allowing a high spectral purity and absolute frequency signal to be generated on the PD. Moreover, the frequency difference between the lasers can be precisely selected by adjusting the RF reference to any frequency between 4 GHz and 12 GHz [5]. In this paper, locking has been demonstrated at the frequencies of exactly 4.8 GHz, 5 GHz and 5.2 GHz, when lasers were operating around 1532 nm, 1528 nm and 1525 nm, respectively, as presented in Fig. 3. A large reduction in linewidth and increase in the peak power can be seen in the spectra of the phase-locked heterodyne signal compared to the signals generated by the same lasers in the free running mode.

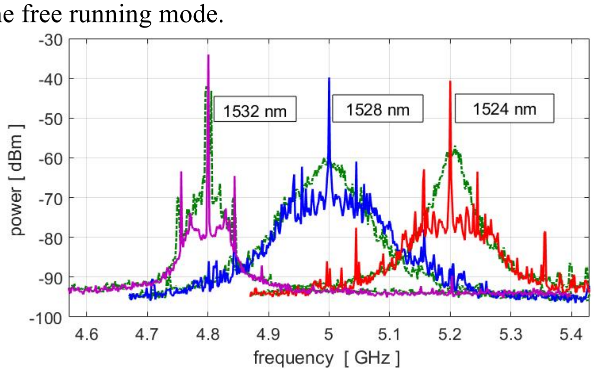

Fig. 3. Locked (continues line) and free-running (dashed line) heterodyne signals generated by lasers at 1532nm, 1528nm and 1524nm (RBW = 200 kHz, VBW = 10 kHz).

All spectra in Fig. 3 and Fig. 4 were measured at the output of the lock-monitoring PD (see Fig.1).

To assess the quality of locking, the phase noise of each heterodyne signal was measured up to 1 GHz frequency offset from the carrier and presented in Fig 4.

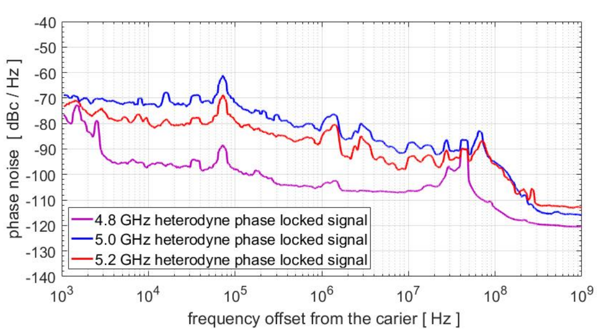

Fig. 4 The single sideband phase noise spectra of the heterodyne signal at 4.8 GHz (1532 nm), 5 GHz (1528 nm), 5.2 GHz (1524 nm)

At 10 kHz offset, the phase noise was measured to be between -96 dBc/Hz and -72 dBc/Hz, depending on the linewidth of the free running heterodyne, which changes with the current applied to the laser Bragg grating sections.

III. Conclusions

In this paper we present the phase locking of monolithically integrated DBR laser across its entire tuning range of 1 THz (from 1532 nm to 1524 nm). The stable locking has been achieved despite the increased laser linewidth, due to applied Bragg grating currents, demonstrating robustness of the phase locking loop. The phase noise of the heterodyne signal has also been measured showing the phase noise suppression below -72 dBc/Hz for the worst, and -96 dBc/Hz for the best locking condition.

This is the first OPLL based on generic foundry fabricated PIC and off-the-shelf electronics which allows the DBR laser to be phase stabilised with the variable frequency offset of 4 to 12 GHz from the reference laser. Such OPLL can be used in a range of applications, including coherent communication, mm-waves and THz signal synthesis and high resolution spectroscopy.

Acknowledgments

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