A Highly Integrated Optical Phase-locked Loop with Single-sideband Frequency Sweeping

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Abstract: An optical phase-locked loop with a frequency detector and a single-sideband mixer has been proposed and demonstrated for the first time. Continuous frequency sweeping has been achieved.

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Optical phase-locked loops synchronize the phase of a laser to that of an external laser, which is highly desirable for many applications, such as coherent receivers, linear frequency sweeping for LIDAR applications, and phased array microwave photonics systems. [1-3]

In this work, a highly integrated optically-locked loop has been demonstrated. Integrated with a 90 degree hybrid, an XOR gate as the frequency detector and a single-sideband mixer (SSBM), this OPLL has both phase detection and frequency detection modes. Furthermore, the optical 90 degree hybrid and the SSBM make the single-sideband locking possible. The testing results show that by simply changing the RF clock frequency, the offset frequency between the reference laser and the slave laser can be continuously tuned within a large frequency range. We achieved frequency detection and offset phase locking ranging from -9.5 GHz to +7.5 GHz. The sign of the frequency is defined by a control input of the EIC.

The architecture of the OPLL is shown in Fig. 1. It is composed by three parts: an InP photonic integrated circuit (PIC), an InP electronic integrated circuit (EIC), and a hybrid circuit as a loop filter. On the PIC, we integrated a sampled-grating DBR (SG-DBR) laser [4] with 40 nm continuous tuning range, a star-coupler-based optical 90 degree hybrid [5], four single-ended high-speed photodetectors, and microstrip transmission lines. The 90 degree hybrid provides both in-phase and quadrature signals, which are used for frequency detection and single-sideband mixing. The signal finally negatively feeds back to the SG-DBR laser phase section through the loop filter.

The PIC is designed and fabricated based on InGaAsP/InP centered quantum well structure requiring 18 lithography layers and one p-cladding regrowth. The quantum well intermixing (QWI) approach was used to define active and passive regions, and gratings were defined by e-beam lithography. For better heat dissipation and compactness, both surface ridge and deeply etched waveguides were fabricated on one PIC, and a low-loss waveguide transition was defined. BCB was used as the dielectric of the microstrip transmission lines.

On this EIC, we integrated four transimpedance limiting amplifiers as the first stage, following by a SSBM to introduce the frequency offset. A delay line and an XOR gate were also integrated on the EIC, together acting as a frequency detector. The designed frequency pull-in range is 50 GHz. The EIC is fabricated by Teledyne using 500nm InP HBT technology. The loop filter is a hybrid circuit using a current feedback operational amplifier as an active filter and integrator.

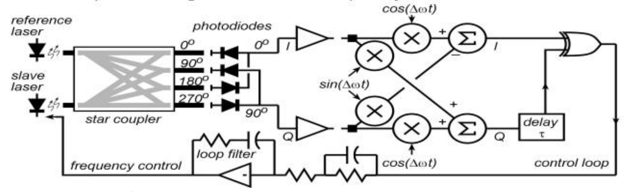


Fig. 1. The architecture of the OPLL consists of three parts: a photonic integrated circuit, an electrical integrated circuit and a loop filter.

Both PIC and EIC are soldered to AlN carriers and the loop filter is also built on an AlN carrier using discreet components and an operational amplifier. The PIC, EIC, and loop filter were connected together using wirebonds.

The carriers are carefully designed to decrease the loop delay as much as possible. The total loop delay in this system is estimated to be around 200 ps, and the designed loop bandwidth is approximately 500 MHz.

The experimental setup is shown in Fig. 2(a). Using lensed fibers, the reference laser was coupled into the PIC, and the SG-DBR laser was coupled out from the back mirror to beat with the reference laser off-chip for measurement purposes. The test setup is shown in Fig. 2(b).

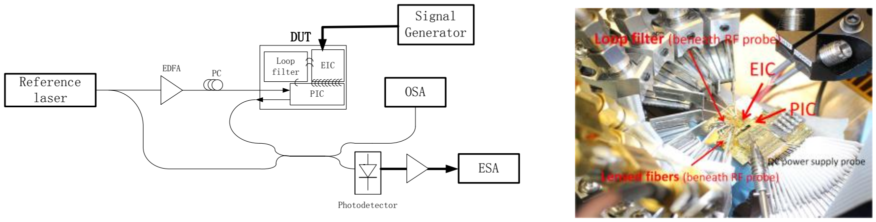
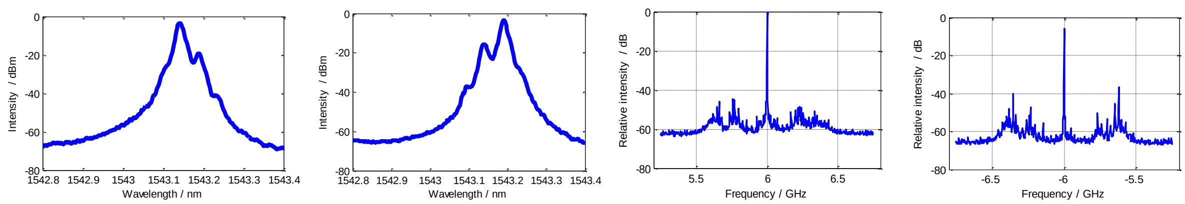


Fig. 2. The OPLL test setup. (a) The schematic of the test setup. Thinner lines show fiber connection and thicker lines show the RF cable connection. (b) shows the picture of the OPLL on the test setup.

We define the frequency different Δf as the frequency between the reference laser and the on-PIC SG-DBR laser, $\Delta f = f_{ref} - f_{SG\text{-}DBR}$. We successfully locked the SG-DBR laser to the reference laser with an offset Δf ranging from -9.5GHz to +7.5 GHz. By only changing the RF reference frequency, we continuously shifted the SG-DBR frequency within the range from -9.5 GHz to -2 GHz, and also from 2 GHz up to 7.5 GHz with phase locking to the reference laser, respectively. Fig. 3 shows the optical spectrums and electrical spectrums when two lasers are phase locked with an offset of +6 GHz and -6 GHz. The electric spectrums of the beating tones with different frequency offsets are shown in Fig. 4. The frequency sweeping is achieved by only changing the bias RF reference frequency on each figure. The loop bandwidth is around 400 MHz.



(a) (b) (c) (d)

Fig. 3. (a) and (b) show the optical spectrums when two lasers ara phase locked with a frequency different of +6 GHz and -6 GHz. (c) and (d) show the beating tones of the two laser when the offset frequency are +6 GHz and -6 Ghz respectively.

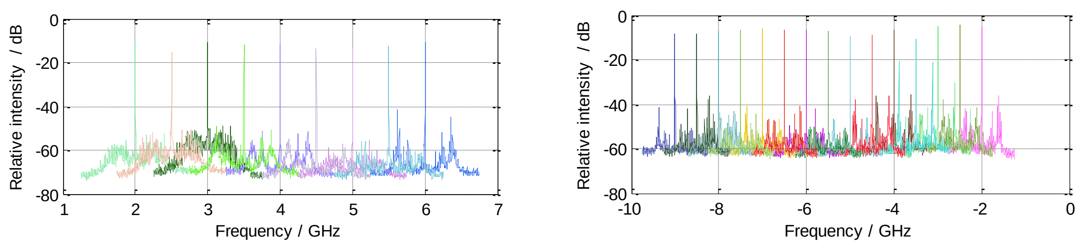


Fig. 4. Shows the beating tones of the two lasers when they are phase locked at different frequency offsets. All of them are 500 MHz apart.

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