Towards integration of a Pound Drever Hall frequency stabilized laser system on the InP platform

R. Jones,[1] E. Bente,[1] and K. Williams[1]

[1] Eindhoven University of Technology, Dept. of Electrical Engineering, Photonic Integration Group,
Groene Loper 19, 5612 AP Eindhoven, the Netherlands

Laser frequency stabilization schemes are opto-electronic control systems which enable the reduction of frequency noise and typically provide the long term ($> \mu s$) frequency stability of the laser output. Such systems consist of several optical components, yet only the semiconductor laser has thus far been successfully integrated. In this paper we present our work towards the further integration of other optical components, namely the electrical optical phase modulator (EOPM) of the Pound Drever Hall (PDH) frequency stabilization scheme onto a single monolithically fabricated PIC on the Smart Photonics InP platform. Previous attempts have been unsuccessful due to the electrical cross talk between the EOPM and the semiconductor laser. In this paper, we investigate whether fabrication on a semi-insulating InP substrate integration platform and the use of adjacent short circuited EOPMs sufficiently reduce the cross talk for frequency locking to be achieved.

Introduction

Optical sources with good frequency stability (linewidth < 100kHz), over short (<10μs) and long (>10μs) timescales are vital for sensing and metrology. Although free running lasers with intrinsic linewidths at 10 kHz have been monolithically integrated [1], their stability will significantly deteriorate over time due to environment disturbances and electrical noise. To enable stable sources over longer timescales, it is necessarily to employ a frequency stabilizing feedback system such as the Pound Drever Hall (PDH) system [2].

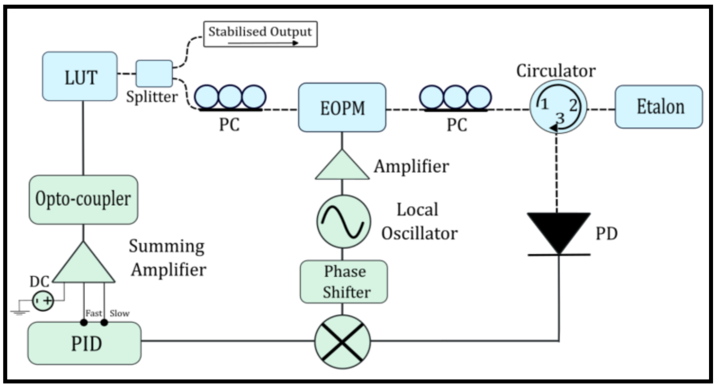

Figure 1: Schematic of the PDH locking scheme. The blue and green boxes indicate the optical and electrical components respectively.

Figure 1 is a basic schematic of the PDH system. Composed of large and expensive components, it is often advantageous to miniaturize the footprint of the circuit in terms of cost, size and power consumption. Whilst the integration of the electronic circuitry on a single CMOS IC has been demonstrated [3], with regards to the optical circuit, thus far, only the light source has been successfully integrated on a PIC [4]. Integration has been limited by electrical cross talk between the stabilized laser and other actives. In this work, we aim to investigate whether the EOPM, in addition to the laser, can be integrated on chip.

Circuit Design

Previous work on the n doped platform identified two explanations for the occurrence of electrical cross talk [4]. Firstly, under reverse bias voltage, the resistance of the EOPM (50MΩ) far outweighs the resistance of the isolation sections (few MΩ). This allowed current to leak through the connecting waveguide leading to the laser cavity, effectively making the waveguide a weak EOPM. This changed the length of the lasing cavity causing the frequency mode to be modulated. To prevent the flow of leakage current, we have included adjacent EOPMs, of length 50um, either side of the external EOPM, which are shorted on chip [5].We will refer to these as shorted blocks.

The second issue relates to the common ground shared between all active components. An EOPM is a PIN diode, which has an associated capacitance. In addition to this capacitance, a finite resistance exists between the diode and the common ground. When current flows from the n doped InP layer to the ground it causes an elevation of the common ground and subsequent tuning of all actives. To establish greater isolation of the grounds, we have fabricated on a semi-insulating platform. On this platform the n doped layer is on top of a semi-insulating substrate. Active components are grounded by etching to the n doped layer close (≈10um) to the P contact, allowing for a low resistance contact. So, although the common ground remains, the current should flow through a loop close to the device.

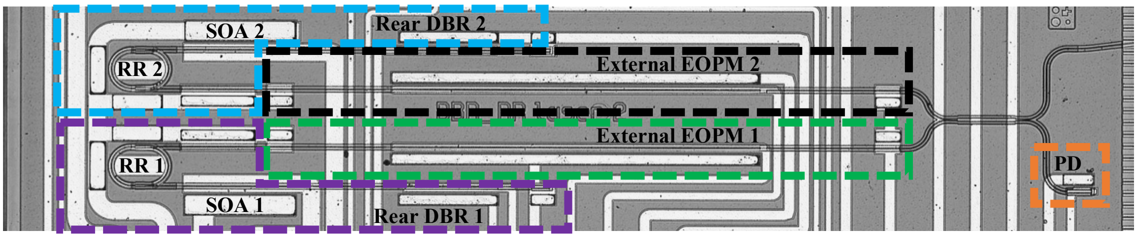

Figure 2: Microscopic image of InP PIC. The purple box and green boxes indicate the laser 1 and external EOPM 1 respectively. The blue and black boxes show the laser 2 and external EOPM 2 respectively. The orange box indicates a PD, used for monitoring purposes. Metallization is made from the topside.

Figure 2 shows a microscopic image of the integrated optical circuit. The green box encircles the EOPM structure (comprising the external EOPM 1 and the two adjacent shorted blocks) and the purple box encircles the narrow intrinsic linewidth semiconductor laser which we wish to frequency lock. EOPM 1 has a length of 1.5mm and a measured efficiency of 13.3 °/mm·V. As was shown in figure 1, there are two electrical inputs to the circuit. A reverse bias control signal from the PID controller is applied through an opto-coupler to one of the tuning elements (ring resonator or rear DBR) to correct for any frequency deviations, and a sinusoidal signal is applied to the external EOPM to modulate the carrier. To successfully integrate both the laser and the external EOPM onto the same PIC we must limit the electrical cross talk between the EOPM and the fine-tuning elements.

Measurement

To establish the presence of electrical cross talk in our circuit, we first examined the optical spectrum. The PIC in figure (2) was mounted on an aluminum sub-mount and wire bonded to a PCB to allow for electrical inputs. A lensed fibre was coupled to the angled facet to collect the optical signal. Figure 3 shows the spectrum from laser 2 (encircled by the blue box in figure 2) when EOPM 1, of circuit 1, was modulated with a 30MHz sinusoidal signal with an offset of -5V and an amplitude of 2V. Two effects are seen. Firstly, sidebands are induced on the carrier wave showing that EOPM 2 was being unintentionally frequency modulated and secondly the lasing mode is shifted 260 MHz. The DC and AC modulation respectively suggest that we have both resistive and capacitive coupling of electrical signals.

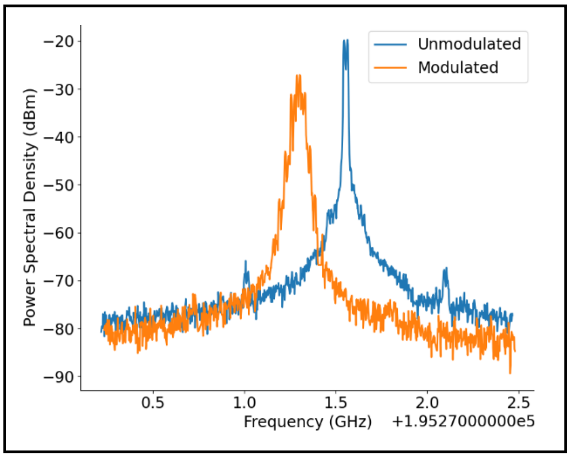

Figure 3: Spectrum of the laser 2 when the EOPM 1 is unmodulated (blue) and modulated (orange).

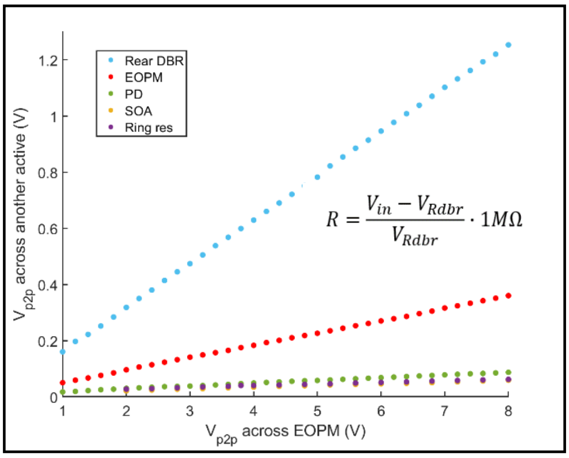

Figure 4: Vp2p across other actives components (rear DBR, EOPM 2, Photodiode, SOA and RR) as a function of Vp2p across EOPM 1.

To measure the resistance between the EOPM 1 and the active components in laser 1, a slow sinusoidal modulation of 100kHz (detectable using our equipment) was applied to the external EOPM. The voltage across one of the active components in the circuit 1, either the SOA 1, ring resonator 1, rear DBR 1 or PD was measured, whilst the other actives were grounded, including the shorted blocks, to the ground of the signal generator. We additionally measured the voltage across the EOPM 2 in circuit 2 which is connected via a waveguide that combines the output of the two laser systems. Figure 4 shows the peak-to-peak voltage (Vp2p) across the active component, connected via a waveguide to the EOPM 1, plotted against the Vp2p applied to EOPM 1. It can be seen that the rear DBR is most strongly affected. A 1V Vp2p to the EOPM results in 0.160mV Vp2p across the rear DBR. Using this data, we can estimate the resistance between the EOPM and the measured active. For the rear DBR this was found to be a resistance of 5.25MΩ.
As a diode under reverse bias typically has a resistance of 10 times this value, it suggests there is a short circuit between the EOPM 1 and the rear DBR.

The final measurement taken was to determine the capacitance of the circuit. We placed a 1kΩ resistor on the output of the signal generator and measured the voltage across it, allowing for the calculation of the current (I) through the EOPM (see figure 5). On an oscilloscope we recorded the V(t) across the EOPM and took the time derivative to determine the capacitance. Figure 6 shows a plot of the current across the EOPM, as a function of the time derivative of the voltage across it, the gradient of which is equal to the capacitance of the EOPM 1. This was calculated to be 190ρF.

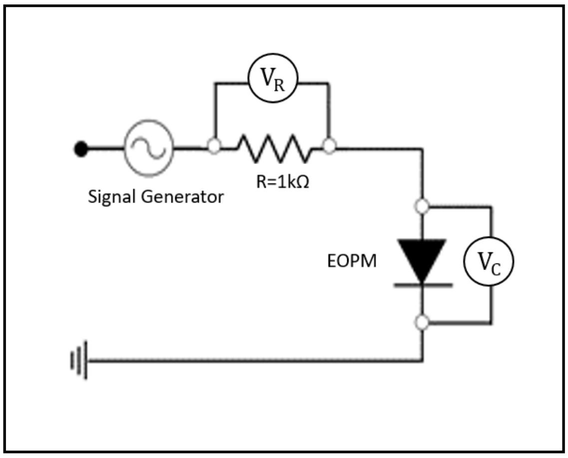

Figure 5: Circuit diagram of the measurement setup. Voltages across the 1kΩ resistor and the EOPM are measured as a function of time using real time oscilloscope.

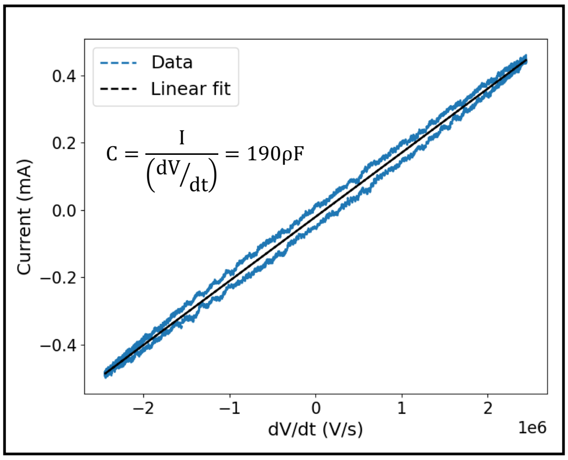

Figure 6: Plot of the current through the external EOPM vs time derivative of the voltage across it using an output impedance from the signal generator of 1kΩ.

Conclusion

Our results show that there is still significant electrical cross talk present on the semi-insulating platform and in the configuration presented here it does not allow for the integration of the EOPM and semi-conductor laser on a single monolithic PIC. In this work we have started to measure and identity the mechanisms in which electrical signals from one device are transmitted to others on the PIC. In future work, we will investigate how the use of an etch through the n doped layer, and a greater decoupling between the grounds, impacts the measured electrical cross talk.

References

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