Monolithic Indium Phosphide Dual Laser Photonic Integrated Circuit for Remote Sensing Lidar

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Abstract: A dual laser indium phosphide photonic integrated circuit for remote sensing lidar was realized. A twentyfold improvement in the long-term frequency stability of the master laser was demonstrated using an on-chip phase modulator.

1. Introduction

Integrated path differential absorption (IPDA) lidar is an active remote sensing lidar commonly used for earth science and sensing of trace gases in the atmosphere [1]. To enable deployment on smaller space platforms and subsequently more frequent science and monitoring, compact implementations will be required. The indium phosphide (InP) photonic integrated circuit (PIC) platform is ideal for this application [2]. In this work, we have designed and fabricated a monolithic InP PIC with an IPDA architecture suitable for monitoring carbon dioxide (CO_2) sources and sinks by stepping through multiple points across an absorption line at a wavelength of 1572.335 nm [3].

By engineering the epitaxial structure and laser gratings, InP PICs can be used for IPDA lidar over a broad range of wavelengths that include the O, C, and L optical bands. Furthermore, several photonic devices can be monolithically integrated with lasers, thus significantly reducing system cost, size, weight, and power compared to lidar counterparts constructed from stand-alone discrete optical components. Here we report the subsystem operation of our fabricated InP lidar PIC onto which we have monolithically integrated two sampled grating distributed Bragg reflector (SGDBR) lasers, a phase modulator (PM), and a pulse carver [4,5].

2. Test Setup and Measurement

Figure 1 shows a simplified block diagram of the IPDA lidar PIC and subsystem test setup. An SGDBR master laser (ML) is stabilized using a frequency modulation technique [6] utilizing an on-chip PM. The PM is modulated at 125 MHz and a modulation depth of π. Frequency modulated light is coupled off chip to a CO_2 gas cell reference using a lensed fiber. Coherent phase detection of a beat note generates an error signal proportional to the frequency deviation from the line center. The filtered error is fed back to the ML phase section to correct the laser wavelength.

Figure 2(a) shows the PM efficiency at a 10 mA forward bias with a comparison to a commercial-off-the-shelf lithium niobate PM. The efficiency is measured using a fiber coupled setup similar to [7], where the optical modulation is transferred to the RF domain and demodulated using an IQ receiver. The drive levels indicated are assumed for 50Ω loads. Figure 2(b) shows the frequency discriminating error signal and absorption as the ML is swept across the absorption line. The long-term ML frequency stability is characterized by generating a beat note between the ML and a stable bench-top external cavity laser. A frequency counter measures the beat frequency over a 10-minute period for 1-second gate times. As illustrated in Fig. 2(c), the peak-to-peak and standard deviation in the ML frequency stability improved twentyfold from 151 MHz and 30.2 MHz without feedback to 7.6 MHz and 1.54 MHz with feedback, respectively.

Since CO_2 has diurnal vertical transport, the absorption line is sampled at points offset from the center. This maintains uniform measurement sensitivity to concentrations in the lower troposphere. To accomplish this, a slave laser (SL) is offset phase locked to the stabilized ML using an optical phase locked loop (OPLL). A beat note between the two lasers is detected off chip and processed by the OPLL. The OPLL charge pump output is filtered and fed back to the SL phase section to maintain wavelength stability at offsets from the ML ranging from 1-15 GHz. The accuracy and precision of the SL offset to the stabilized ML is obtained by beating the two lasers and comparing the results with and without OPLL operation. The results are illustrated in Fig. 2(d) over 10 minutes for 1-second gate times for a 2 GHz SL OPLL offset setting. In this case the mean frequency offset was measured to be 2.000087 GHz with a standard deviation of 5.08 MHz. The accuracy and stability are degraded somewhat due to systematic sources of noise in the setup such as coupling from the PM driver to the ML. Figure 2(e) shows the spectra of a stabilized ML and overlapped locked SL waveforms ranging in offset from 1-15 GHz.

Finally, an on-chip semiconductor optical amplifier (SOA) is used to generate amplified SL 1 μs pulses at a 133 μs period to eliminate crosstalk from cloud scattering. Figure 2(f) shows the SL pulses generated using the on-chip SOA pulse carver. The pulses are driven using a pulsed current source and detected with a photodiode (PD) and transimpedance amplifier (TIA). The pulse is then viewed on an oscilloscope, which shows rise and fall times of 262 ns and 169 ns, respectively. Because the pulse extinction is below the PD noise floor, we estimate the extinction ratio at DC using a power meter and obtain more than 40 dB extinction between the on and off states at 100 mA and 10 mA, respectively. Such a high extinction ratio is critical to avoid power robbing from a booster EDFA before transmission to free space. The SL peak power, directly coupled from the PIC with a lensed fiber, exceeds 3 dBm.

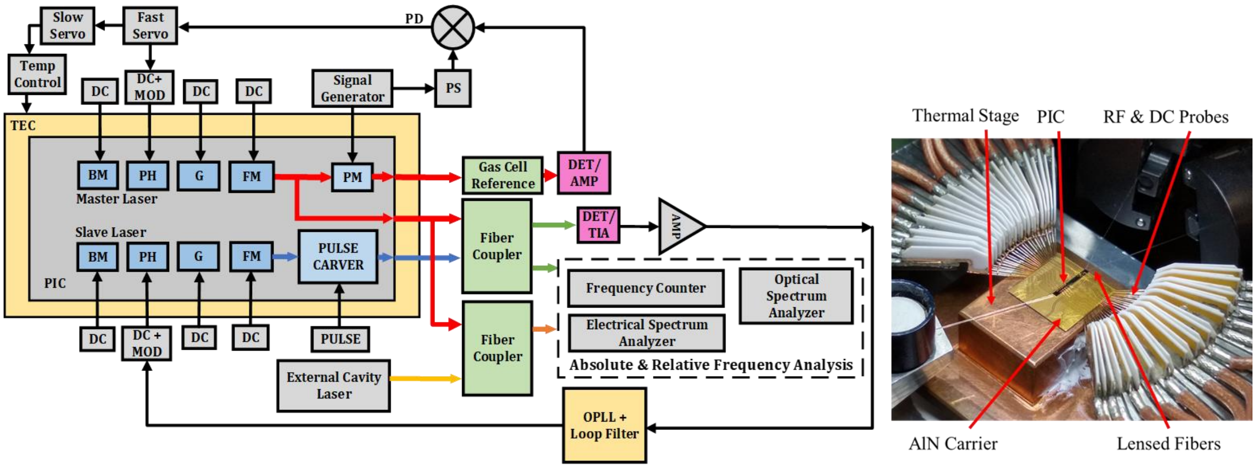

Fig. 1. PIC subsystem characterization test setup and photograph of PIC on carrier under test.

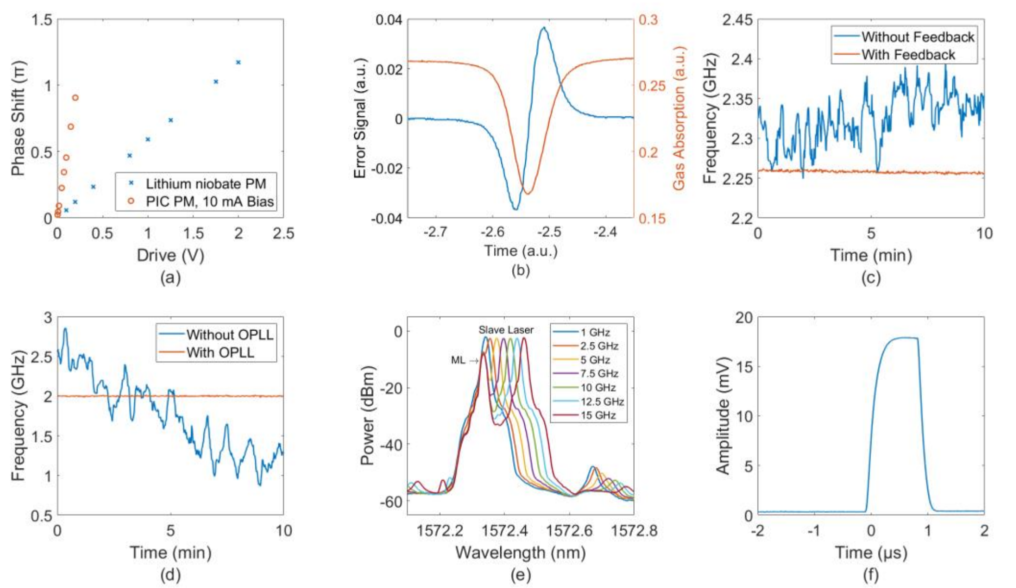

Fig. 2. (a) PM efficiency for 10 mA bias; (b) error signal and gas absorption; (c) ML stability for 1-second gate times; (d) SL stability, 2 GHz offset from ML; (e) ML/SL overlapped spectra at 1-15 GHz offsets; (f) SL amplified 1 μs pulse.

4. Conclusions

We designed and fabricated an IPDA remote sensing lidar monolithic InP PIC with two SGDBR lasers, a PM, and pulse carver. We illustrated efficient device operation and subsystem performance of the PIC. The results show a stabilized ML and SL offset locked up to 15 GHz. This demonstration illustrates the feasibility to realize compact lidar instruments for space platforms. Gas sensing measurements will be carried out in future work.

5. References

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