Monolithic Indium Phosphide Photonic Integrated Circuit for Remote Lidar Active Carbon Dioxide Sensing

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Abstract: A monolithic indium phosphide photonic integrated circuit was designed and fabricated for remote active carbon dioxide sensing. Successful measurement of carbon dioxide in a laboratory setting under pulsed sampling was demonstrated.

1. Introduction

Several investigations and demonstrations have been carried out for passive carbon dioxide (CO_2) sensing and monitoring including the OCO-3 from NASA and GOSAT-2 from JAXA [1,2]. Different from passive sensing, which utilizes reflection of solar light, active sensing uses a laser light source for sensing. Laser remote-sensing techniques allow accurate measurements to be taken day and night, over ocean and land surfaces, in the presence of thin and/or scattered clouds, at all times of year, and with less susceptibility to bias errors [3], however space-based laser instruments can be large and power hungry. To reduce the size, weight, and power (SWaP) of such systems, one based on photonic integrated circuit (PIC) technology was designed and demonstrated for active CO_2 sensing. The indium phosphide (InP) PIC platform can integrate both active and passive components making it ideal for this application [4,5]. In this work, we have designed and fabricated InP PICs for active CO_2 sensing and successfully demonstrated sampling of the 1572.335 nm CO_2 absorption line under pulsed sampling.

2. Lidar Photonic Integrated Circuit Demonstration

The InP PIC leverages a dual-laser architecture that integrates a leader laser and a follower laser, splitters, a phase modulator, a photodiode, and a pulse carver based on a semiconductor optical amplifier (SOA). The PIC system is shown in Fig. 1. The system can be divided into two main parts, that for the leader laser stabilization and that for the follower laser offset locking. The leader and follower lasers are both sampled grating distributed Bragg reflector (SGDBR) lasers. The leader laser functions as an absolute optical reference for the follower laser; the leader is locked to the center of the CO_2 absorption line with a CO_2 reference cell using the frequency modulation technique [6-8]. While locked, it achieves a 44.5 dB side mode suppression ratio as shown in Fig. 2(a). The corresponding error signal

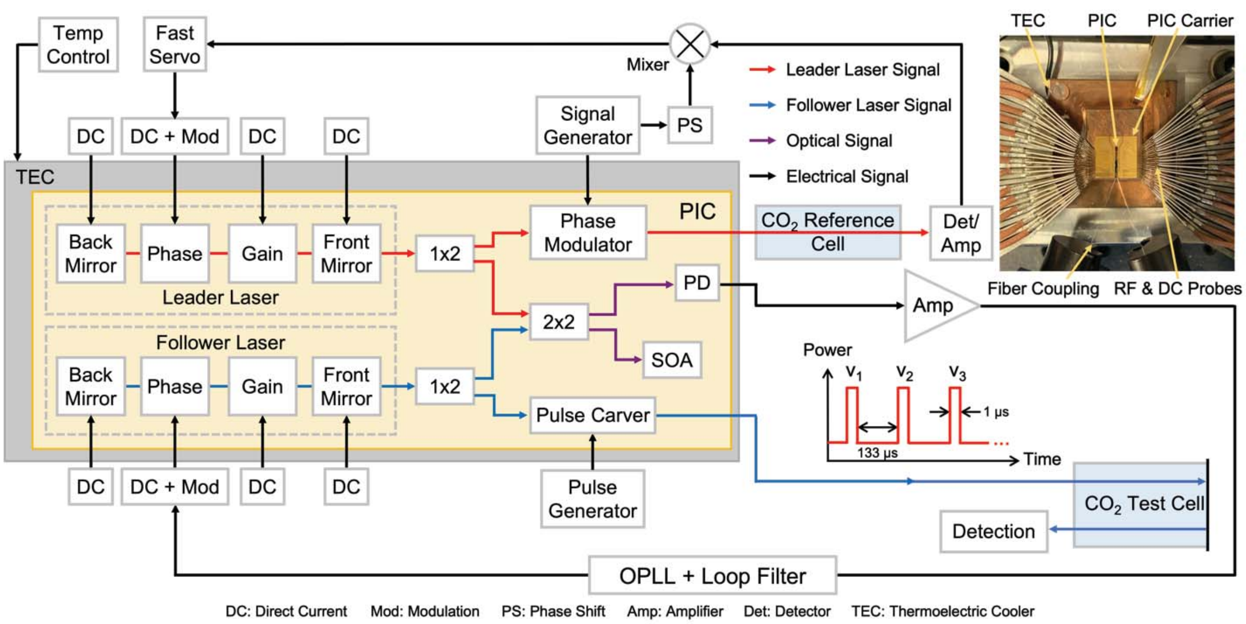

Figure 1: PIC details and system architecture for CO_2 sensing along with photograph of PIC on carrier under test.

used for the locking is shown in Fig. 2(c). The follower laser is offset locked to the leader laser by way of the integrated beat note photodiode and an optical phase lock loop (OPLL) [7-9]. From the OPLL electronics, the leader laser can be controlled to sweep over a 30 GHz range centered at 1572.335 nm to enable sensing measurement [9-11]. The SOA pulse carver converts the continuous wave (CW) output into a frequency-stepped pulse train with 1 μs pulse width and 133 μs period to prevent crosstalk between wavelengths due to cloud scattering [7,9]. The pulsed output achieved an extinction ratio of 45 dB as shown in Fig. 2(b).

The leader laser stabilization performance was also characterized, and results are shown in Fig. 2(d). Over a period of 30 minutes, the peak-to-peak frequency drift without feedback was around 675 MHz. With feedback, the drift was 2.7 MHz, demonstrating an improvement of 24 dB. The follower laser stabilization is shown in Fig. 2(e). The peak-to-peak frequency drift compared to leader laser without the OPLL engaged was around 1 GHz, and with the OPLL it was 29 kHz thereby demonstrating an improvement of more than 45 dB. Finally, a sensing experiment was successfully performed under pulsed sampling and the results are shown in Fig. 2(f). A Lorentzian fitted full-width half maximum of 1600 MHz was demonstrated.

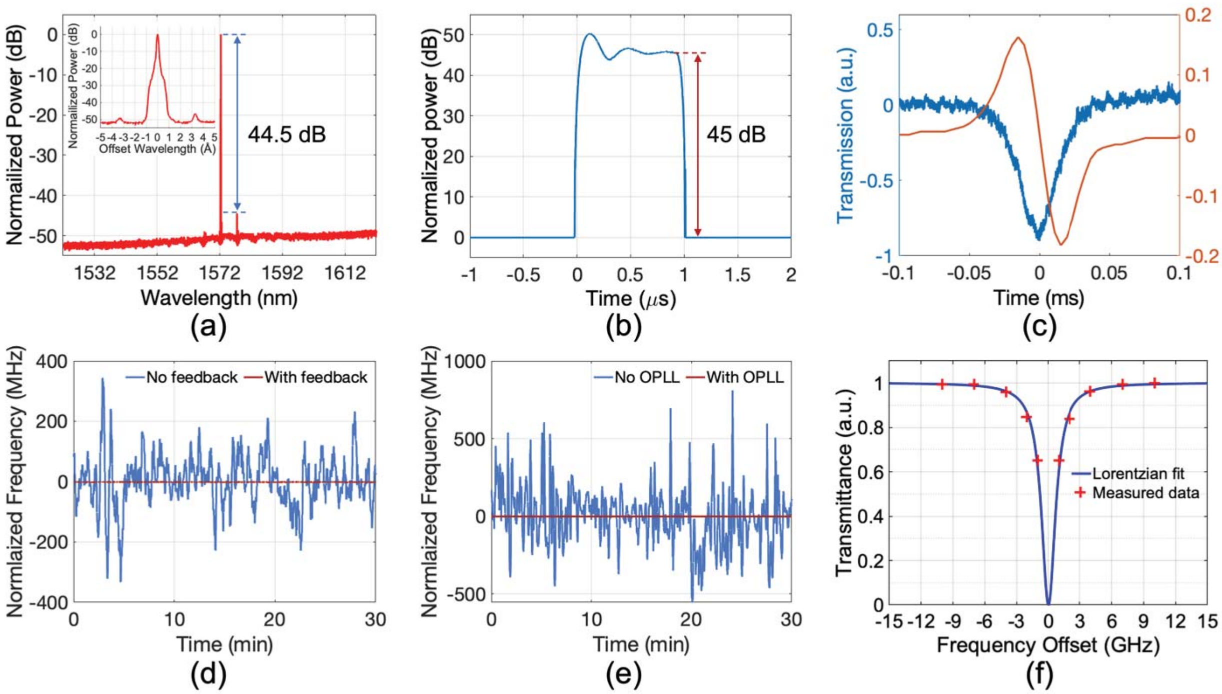

Figure 2: (a) Optical spectrum of leader laser when locked to 1572.335 nm with zoomed in spectrum inset. (b) Pulsed output optical signal after pulse carver. (c) CO_2 reference cell absorption and the frequency-discriminating error signal. (d) Beat note between the leader laser and an external cavity laser with and without feedback to the leader laser phase section. (e) Beat note between the leader and follower laser with and without the OPLL engaged. (f) Measured absorption of a CO_2 test cell at several wavelengths overlaid with a Lorentzian fit.

3. Conclusions

We designed and fabricated InP PICs for CO_2 active remote Lidar sensing. The PIC-based Lidar system successfully demonstrated CO_2 active sensing in a laboratory environment under pulsed sampling. Future work will focus on packaging and photonic-electronic integration to further reduce SWaP of the overall system.

4. References

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