

INTEGRATED MICRO-PHOTONICS FOR REMOTE EARTH SCIENCE SENSING (IMPRESS) LIDAR

Mark Stephen¹, Jonathan Klamkin², Larry Coldren², Joseph Fridlander², Victoria Rosborough²,
Fengqiao Sang², Jeffrey Chen¹, Kenji Numata¹, Randy Kawa¹

¹NASA-GSFC – Greenbelt, MD 20771

²UCSB - Electrical and Computer Engineering Department, Santa Barbara, CA 93106

ABSTRACT

We present recent progress on a wavelength tunable, pulsed laser source for laser spectroscopy of CO₂ at 1572 nm. An integrated photonics design in indium phosphide (InP) is presented and compared to a fiber-component-based implementation. Significant improvement in size, weight and complexity is demonstrated.

Index Terms— Lasers, photonics, environmental monitoring, remote sensing,

1. INTRODUCTION

Photonics integrated circuit (PIC) technology has seen significant investment from the communications and data center industries. As a result, a highly functional set of photonic components exist which can find use in a much wider set of applications like automotive sensors, medical devices, defense and science instrumentation. NASA's desire for small, lightweight, rugged, efficient and highly functional optical sensors makes PIC technology an excellent choice for the next generation of hardware. NASA is working with several partners on developing integrated photonics technology for future space missions [1-5].

Goddard Space Flight Center has spent several years developing an atmospheric carbon dioxide (CO₂) sensor based on laser absorption spectroscopy that uses a tunable laser to scan through a CO₂ gas absorption line centered at 1572 nm [6-9]. The current laser transmitter implementation uses mature technologies and meets all the optical performance requirements [10] but is relatively bulky and inefficient compared to an integrated photonic solution. UCSB and GSFC have initiated a program to replace the tunable seed laser with a PIC version to significantly improve the implementation for a resource constrained space-flight mission platform.

We expect to improve the implementation of this particular application and demonstrate the efficacy of the technology for an array of future applications.

2. DESIGN AND RESULTS

The seed laser being developed is a pulsed laser with tunable wavelength output. Consecutive pulses are emitted at different wavelengths that step across the absorption feature of interest. The wavelength of each pulse is individually locked to an exact value. This is achieved by using a master laser locked to the center of the CO₂ absorption as an absolute reference and using offset locking to tune a slave laser by means of an optical phase-locked loop (OPLL). Details on the previous wavelength tuning and locking techniques can be found in [11, 12]. The requirements for the laser seed system are tabulated below:

TABLE 1: Target performance for laser output

Parameter	Value
Center wavelength	1572.3 nm
Pulse Width	1 μ s
Repetition rate	7.5 KHz
Pulse modulation extinction	35 dB
Optical power (peak)	10 mW
Polarization (linear) extinction	20 dB
SMSR	40 dB
Linewidth (over 1 μ s)	<50MHz
Center wavelength drift (over 1s)	< 100 MHz
Standard deviation of center wavelength	<3 MHz
Wavelength tuning	\pm 15 GHz

The photonics block diagram for achieving this functionality is shown in Figure 1. The main integrated design elements include a distributed feedback (DFB) master laser diode, a phase modulator, a sampled grating distributed Bragg reflector (SG-DBR) slave laser diode, a Mach-Zehnder modulator (MZM), a semiconductor optical amplifier (SOA), and a high-speed photodiode. The DFB frequency is stabilized to a reference CO₂ gas cell using a frequency modulation technique. The frequency of the DFB is modulated using the integrated phase modulator. Closely integrated electronic circuitry will then generate a frequency discriminating error signal

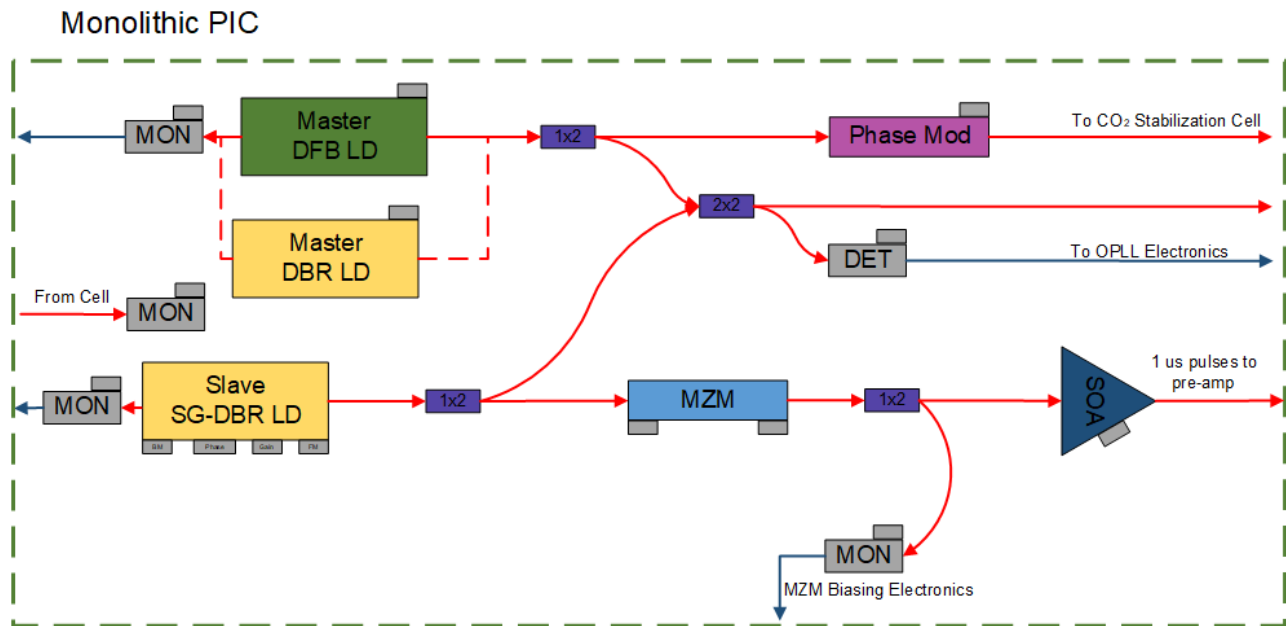


Figure 1 – PIC functional block diagram illustrating the components integrated onto a single photonic chip.

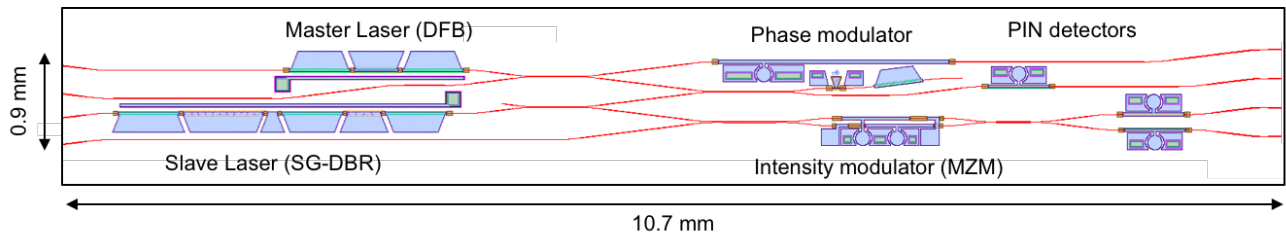


Figure 2 – PIC design layout

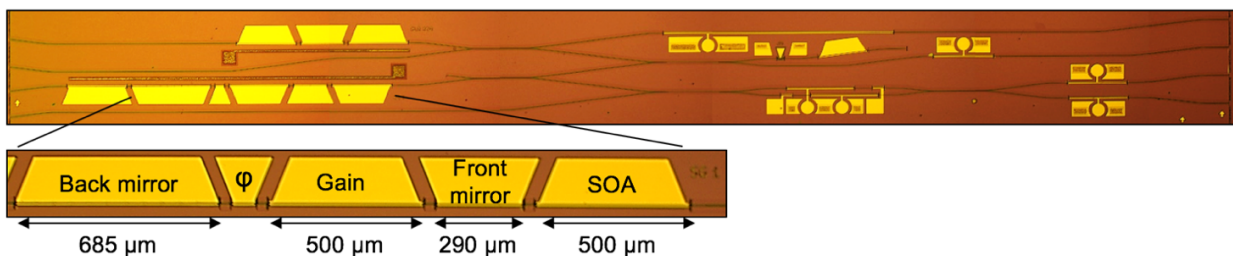


Figure 3 – Image of fabricated PIC with zoomed in SG-DBR laser section.

which is fed back into the DFB. The DFB itself is driven with low noise bias circuitry and the temperature is controlled using a thermo-electric-cooler (TEC). The widely-tunable, integrated SG-DBR is stepped across the absorption line feature at selective wavelengths using an OPLL offset-locking scheme. This offset-locking scheme is facilitated using the integrated high-speed photodetector which detects a beat note between the

master and slave lasers. OPLL circuitry feeds back an error signal to ensure the offset frequency maintains the frequency stability characteristics of the master laser. Additional circuitry will drive the SOA for lidar pulse carving and amplification. The MZM offers an alternative for pulse carving.

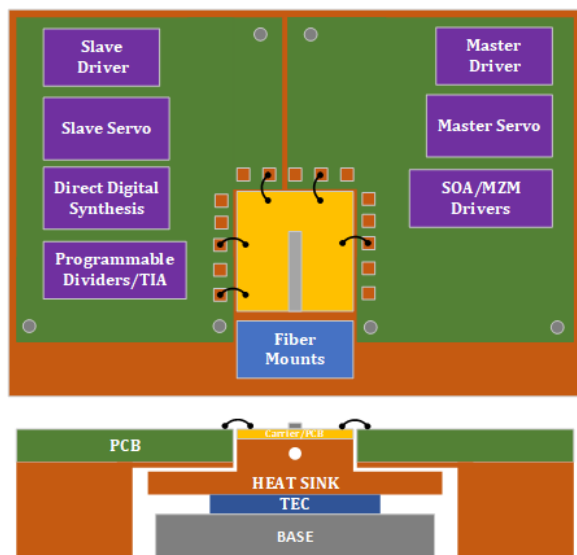


Figure 4 – Electrical and Photonic package design. The PIC is the gray rectangle mounted in the middle of the gold carrier. The carrier is cooled through TEC and heatsink and is wire bonded to the printed circuit boards (PCBs).

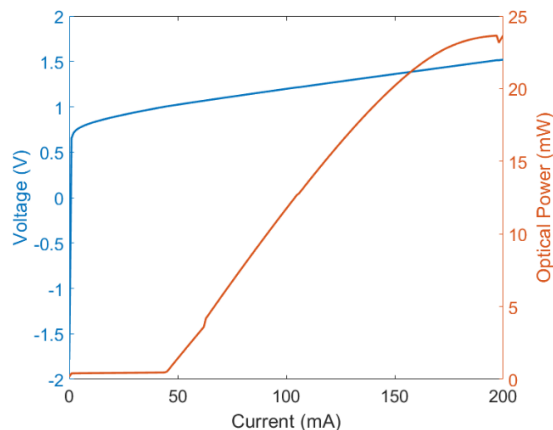


Figure 5 –Light-Current-Voltage (LIV) characteristics of integrated tunable laser from completed PIC

To realize the true potential of integrated photonics, close integration of the PIC with electronics is desirable. This makes the entire package smaller, lighter and more rugged and reduces losses due to transmission of high-speed electrical signals. A block diagram of the system design with closely integrated electronic PCBs is shown in Figure 4.

UCSB has completed fabrication of the designed photonic circuits and begun characterizing the performance. A sample PIC is shown in Figure 3. Figure 5 shows the light-current-voltage (LIV) characteristics of a tunable SG-DBR laser from the fabrication. The results to date are promising and we will show further test data of the PIC in the future.

3. CONCLUSIONS

We have demonstrated promising results on an integrated photonic circuit implementation for wavelength-tunable, amplitude-modulated laser system. This work shows the potential for orders of magnitude improvement in volume and mass while improving efficiency, ruggedness and reliability. The technology and component performance continues to improve rapidly due to increased investment from communications and data center applications. Space flight and other remote sensing applications can benefit significantly from the application of integrated photonics technology.

ACKNOWLEDGMENTS

The authors gratefully acknowledge funding from NASA's Earth Science Technology Office (ESTO) Advanced Component Technology (ACT) program.

6. REFERENCES

- [1] Krainak, M. A., Stephen, M. A., Troupaki, E., Tedder, S. A., Reyna, B., Bergman, K., Lipson, M., Rizzo, A. J., Datta, I., Abrams, N. C., Klamkin, J., Zhao, H., Song, B., Ho, S. T., Bei, Q., Huang, Y., Tu, Y., Moslehi, B., Harris, J., Matsko, A. B., Savchenkov, A., Liu, G., Proietti, R., Ben Yoo, S. J., Johansson, L., Dorrer, C., Qiao, J. X., Gong, S., Gu, T., Ohanian, O. S., Tran, M., Bowers, J. E., Ni, X., Ding, Y., Duan, Y., Dalir, H., Chen, R. T., Sorger, V. J., Komljenovic, T., Mookherjee, S., Wang, X., "Integrated photonics for NASA applications," SPIE: Photonics West 2019: 10899-14, 2019
- [2] H. Zhao, S. Pinna, B. Song, L. Megalini, S. T. Suran Brunelli, L. Coldren, J. Klamkin, "Indium Phosphide Photonic Integrated Circuits for Free Space Optical Links," IEEE Journal of Selected Topics in Quantum Electronics, vol. 24, no. 6, 2018.
- [3] H. Zhao, S. Pinna, B. Song, L. Megalini, S. T. Suran Brunelli, L. Coldren, J. Klamkin, "Integrated Indium Phosphide Transmitter for Free Space Optical Link," Integrated Photonics Research, Silicon and Nanophotonics Conference, paper ITu4B.6, 2018.
- [4] J. Klamkin, H. Zhao, B. Song, Y. Liu, B. Isaac, S. Pinna, F. Sang, L. Coldren, "Indium Phosphide Photonic Integrated Circuits: Technology and Applications," IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium, 2018.
- [5] J. Fridlander, S. Pinna, V. Rosborough, S. Estrella, L. Johansson, J. Klamkin, "RZ-DPSK Photonic Integrated Transmitter for Space Optical Communications," Proc. SPIE vol. 10524, 2018.
- [6] Active Sensing of CO₂ Emissions over Nights, Days, and Seasons (ASCENDS) Mission, Science Mission Definition Study 2015, ASCENDS Ad Hoc Science Definition Team, April 15, 2015,

http://cce.nasa.gov/ascends_2015/ASCENDS_FinalDraft_4_27_15.pdf

[7] Kawa, S. R., J. Mao, J. B. Abshire, G. J. Collatz, X. Sun, and C. J. Weaver, "Simulation studies for a space-based CO₂ lidar mission," *Tellus B*, 62, 759–769, doi:10.1111/j.1600-0889.2010.00486.x, 2010.

[8] Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future, National Research Council, ISBN: 0-309-66714-3, 456 pages, 2007, <http://www.nap.edu/catalog/11820.html>

[9] Abshire, J. B., Ramanathan, A., Riris, H., Allan, G. R., Sun, X., Hasselbrack, W. E., Mao, J., Wu, S., Chen, J., Numata, K., Kawa, S. R., Yang, M. Y., and DiGangi, J., "Airborne Measurements of CO₂ Column Concentrations made with a Pulsed IPDA Lidar using a Multiple-Wavelength-Locked Laser and HgCdTe APD Detector," *Atmos. Meas. Tech.*, 11, 2001–2025, 2018.

<https://doi.org/10.5194/amt-11-2001-2018>

[10] A. Yu, J. Abshire, M. Stephen, J. Chen, S. Wu, B. Gonzalez, L. Han, K. Numata, G. Allan, W. Hasselbrack, J. Nicholson, M. Yan, P. Wisk, A. DeSantolo, B. Mangan, G. Puc, D. Engin, B. Mathason, and M. Storm, "Fiber-Based Laser Transmitter Technology at 1.57 μm for Atmospheric Carbon Dioxide Satellite Remote Sensing," in *Advanced Solid State Lasers, OSA Technical Digest (online)* (Optical Society of America, 2015), paper ATh1A.1.

[11] K. Numata, J. R. Chen, and S. T. Wu, "Precision and fast wavelength tuning of a dynamically phase-locked widely-tunable laser," *Opt. Express* 20, 14234-14243 (2012).

[12] K. Numata, J. R. Chen, S. T. Wu, J. B. Abshire, and M. A. Krainak, "Frequency stabilization of distributed-feedback laser diodes at 1572 nm for lidar measurements of atmospheric carbon dioxide," *Appl. Opt.* 50, 1047-1056 (2011).