Integrated Indium Phosphide Pulse Position Modulation Transmitter for Free Space Communications

Victoria Rosborough[1], Fabrizio Gambini[1, 2, 3], John Snyder[4], Leif Johansson[5], and Jonathan Klamkin[1]
[1]*Electrical and Computer Engineering Department, University of California, Santa Barbara, CA 93106*
[2]*Scuola Superiore Sant'Anna, Pisa, Italy 56124*
[3]*CNIT – National Laboratory of Photonic Networks, Pisa, Italy 56124*
[4]*Electrical and Computer Engineering Department, Boston University, Boston, MA 02215*
[5]*Freedom Photonics, Santa Barbara, CA 93117*
klamkin@ece.ucsb.edu

Abstract: An integrated indium phosphide transmitter is demonstrated for pulse position modulation (PPM) free space optical communication. The transmitter demonstrates an 8-nm wavelength tuning range and a 28-dB extinction ratio for 16-ary PPM.
OCIS codes: (060.2605) Free-space optical communication; (130.3120) Integrated optics devices

1. Introduction

Recent lasercom missions have demonstrated the feasibility of free space optics for high data rate communications from spacecraft [1]. Optical channels can support data rates up to one hundred times greater than state-of-the-art radio frequency (RF) technology [2]. To date, free space communication systems have been assembled from discrete commercial-off-the-shelf (COTS) components. A preferred format is pulse position modulation (PPM) enabled by a master oscillator power amplifier (MOPA) with a pulse carver following the seed laser [3, 4]. Although solutions using COTS components can be qualified and launched in a relatively short time, their size, weight and power (SWaP) metric is typically much larger than desired for spacecraft.

A fully integrated transmitter designed to meet the unique demands of lasercom would vastly reduce system SWaP and provide a platform for adaptive modulation in dynamic link conditions [5]. In this work, we present an indium phosphide (InP) photonic integrated circuit (PIC) transmitter with high extinction ratio (ER) for M-ary PPM. With M-ary PPM, $\log_2(M)$ bits per symbol are encoded via the position of a pulse amongst M slots. Because of its low duty cycle, PPM is a power efficient option for improving receiver sensitivity in photon-starved links, but can also suffer from "power robbing" when used with an average power limited amplifier, such as an erbium-doped fiber amplifier, unless the ER exceeds the duty cycle by at least 15 dB [4].

The PIC transmitter presented here utilizes a driven semiconductor optical amplifier (SOA) to produce high ER pulses and a Mach-Zehnder modulator (MZM) to carve the pulses produced by the SOA. By modulating the two components in phase, an ER of 28 dB was obtained. The seed laser is a multi-section tunable distributed Bragg reflector (DBR) laser that demonstrates 8 nm of tuning. The PIC has a footprint of 4.5 mm x 0.5 mm.

2. Device description and characterization

The PIC was fabricated at Oclaro, Inc. in a multi-project wafer run coordinated by the Joint European Platform for InP-based Photonic Integrated Components and Circuits (JePPIX) using a monolithic InP integration platform [6]. Figure 1 shows a schematic of the PIC transmitter as well as a photograph of the chip with the tunable DBR seed laser followed by the SOA and MZM. The front DBR mirror reflectivity was designed to be 30% and that of the rear DBR was designed to be >90%. Light from an external source may be coupled into the MZM via one of a pair of 2x2 multimode interference (MMI) couplers. The second MMI coupler directs half of the power from the MZM output to a p-i-n diode photodetector, which can be used for characterization or as a monitor, and the other half of the power to an optical output port. Spot size converters at the input and output assist with edge coupling to and from single mode optical fiber.

Initially, DC measurements were performed to characterize the integrated components. Figure 2(a) shows the light-current (LI) characteristic of the DBR laser measured using the output SOA as a photodiode. Assuming a responsivity of 1 A/W for the SOA, the seed laser output 38 mW at an applied current of 100 mA. The threshold current of the laser was measured to be 18 mA. Figure 2(b) illustrates the laser tuning accomplished via carrier injection to the DBR mirrors. The laser is tunable over 8 nm and demonstrates an average side mode suppression ratio (SMSR) of 37 dB and a minimum SMSR of 30 dB throughout this range. A widely tunable external laser source was used to measure the DC response of the MZM at several wavelengths. The on-chip photodiode was used to monitor the output transmission. The measured MZM transfer functions are reported in Fig. 3 for four different wavelengths. At a nominal wavelength of 1540 nm, the ER was measured to be 9.7 dB and the half-wave voltage (V_π) was measured to be −8 V.

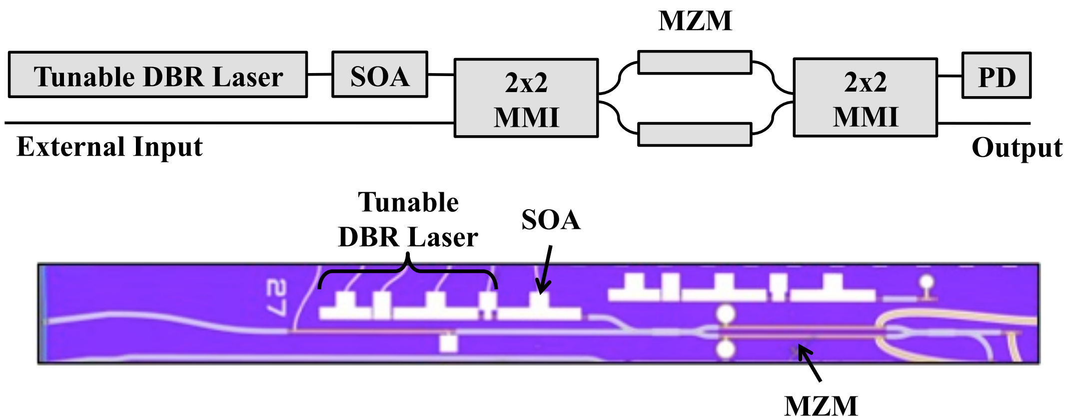

Fig. 1. InP PIC transmitter layout (top). Photograph of the chip (bottom) showing the DBR laser, SOA, and MZM.

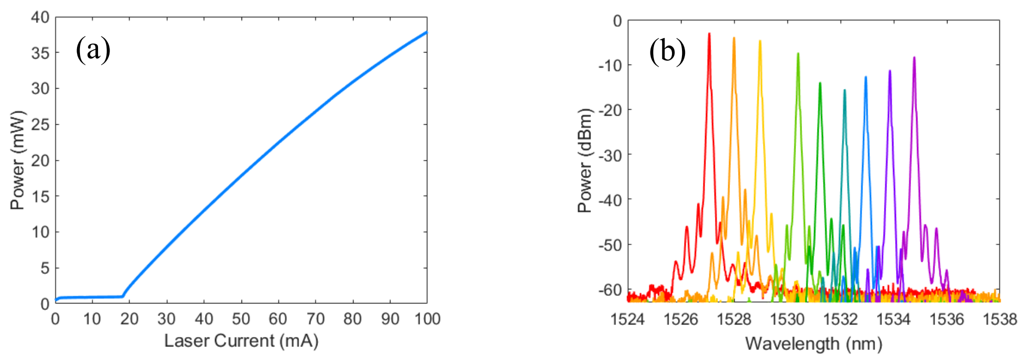

Fig. 2. (a) Seed laser LI curve measured using the SOA as a photodiode. (b) Overlaid tuning spectra of the seed laser.

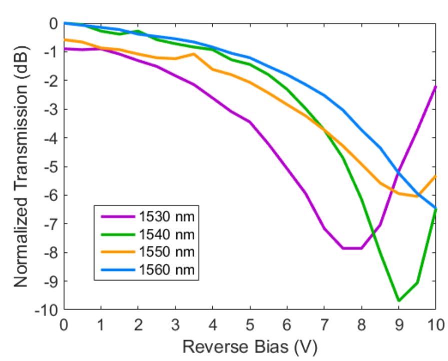

Fig. 3. DC response of MZM from 1530 to 1560 nm.

Figure 4 illustrates the RF test setup used to simultaneously modulate the SOA and MZM. Two arbitrary waveform generators (AWGs) produced 50 MHz return-to-zero (RZ) pulses with a 50% duty cycle. By triggering the second AWG with the first, the phases of the two electrical signals were aligned as shown in Fig. 5(a). A 50% duty cycle was used to test the case of two consecutive PPM pulses, which is considered a worst-case scenario. An oscilloscope was used to observe the resulting optical waveform and an optical power meter was used to measure the high, low and average power levels. In Fig. 5(b), the resulting optical output is shown demonstrating an ER of 28 dB. The one power level was measured to be +6.1 dBm and the zero power level was −22 dBm. Operating the SOA below transparency and into its absorptive regime allowed the zero level to be at least as low as the sensitivity of the oscilloscope used for measurements. The ER, therefore, could likely be greater than 28 dB and future experiments will investigate this further.

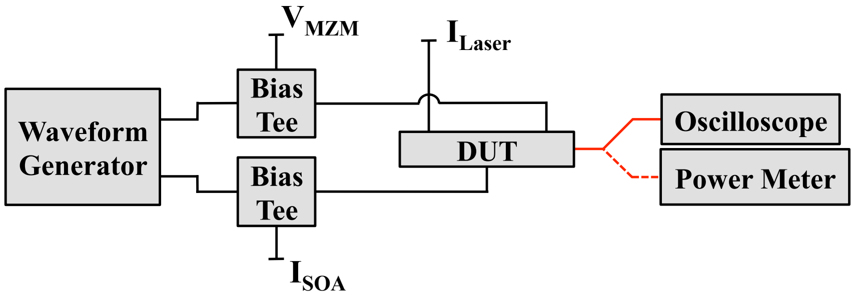

Fig. 4. Experimental setup for modulating the SOA and MZM with two in-phase AWGs.

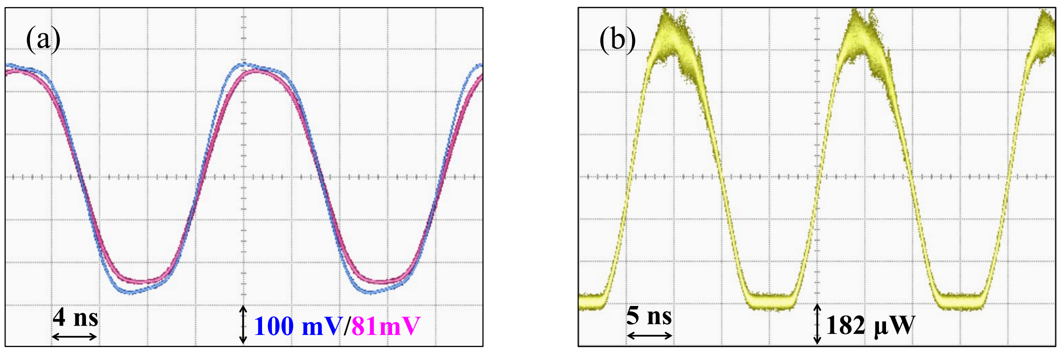

Fig. 5. (a) Phase-aligned RZ waveforms used to modulate the SOA (pink) and MZM (blue). (b) Output optical waveform exhibiting a 28-dB ER. The one power level was +6.1 dBm and the zero power level was −22 dBm.

3. Conclusions

The PIC transmitter presented here, which includes a multi-section tunable DBR laser, a SOA, and a MZM, could be used in a 16-PPM, 12.5 Mbps MOPA transmitter. The measured ER exceeds the 12-dB duty cycle by 16 dB, so that power robbing would be limited when coupling to an erbium doped amplifier in a MOPA configuration. In addition, modulating the SOA and MZM in phase prevents power from being wasted on amplification while the signal is at the zero level, resulting in significant savings for low duty cycle modulation formats such as M-ary PPM. Future measurements will include a study of peak power with varying duty cycle to determine if the ER is in fact greater than 28 dB, as well as characterization at higher frequencies. Future designs could include a high power SOA as well as nested and/or cascaded MZMs for greater ER and adaptive modulation, although the SOA-MZM configuration is quite simple and compact. The transmitter presented here suggests that low SWaP integrated devices are viable for free space optical communications.

4. Acknowledgements

The authors acknowledge NASA for support through the Early Career Faculty Space Technology Research Grant. The authors also acknowledge Pietro Contu for assistance with designs, and Michael Krainak and Bryan Robinson for technical discussions.

5. References

[1] NASA Goddard Space Flight Center, "Lunar Laser Communications Demonstration," *http://esc.gsfc.nasa.gov/267/271.html* (2015).
[2] H. Hemmati, *Deep Space Optical Communications* (JPL, 2005), Preface.
[3] R. W. Kingsbury, D. O. Caplan and K. L. Cahoy, "Compact optical transmitters for cubesat free-space optical communications," Proc. of SPIE **9354** (2015).
[4] D. O. Caplan, "Laser communication transmitter and receiver design," J. Opt. Fiber Commun. **4**, 225-362 (2007).
[5] L. A. Johansson, et. al., "Integrated indium phosphide coherent optical receivers and transmitters," Proc. ICSOS **9-3**, (2012).
[6] JePPIX, *http://www.jeppix.eu/home.html* (2014).