3 Gbps Free Space Optical Link based on Integrated Indium Phosphide Transmitter

Hongwei Zhao, Sergio Pinna, Bowen Song, Ludovico Megalini, Simone Tommaso Šuran Brunelli, Larry Coldren and Jonathan Klamkin

Electrical and Computer Engineering Department, University of California Santa Barbara, Santa Barbara, CA 93106, USA

Email: hwzhao@ece.ucsb.edu / Phone: (857) 600-7938

In the last half century, advances in radio frequency (RF) and microwave technology have paved the way for space communications. Then in 2013, NASA demonstrated a two-way laser link between earth and a satellite in lunar orbit over 239,000 miles at a data rate of 622 Mbps, which is more than six times faster than previous state-of-the-art radio systems deployed to the moon [1]. The free space optical systems can be assembled with commercial-off-the-shelf (COTS) components. However, for deployment on small spacecraft, lower cost, size, weight and power (CSWaP) is required, while still demonstrating high output optical power and power-efficient modulation formats [2]. The indium phosphide (InP) photonic integrated circuit (PIC) platform is attractive for free space links since it enables complex single-chip implementations of advanced transmitters and receivers [3-5]. In this work, a free space optical link based on an InP PIC transmitter has been demonstrated. The transmitter is tunable from 1521 nm to 1565 nm, covering the entire C band. Error-free operation was achieved at 3 Gbps for an equivalent link length of 180 m (up to 300 m with forward error correction), and this distance can scale with the use of a high-power amplifier at the output.

The monolithic transmitter was fabricated on an n-type (001) InP substrate. The indium gallium arsenide phosphide (InGaAsP) multiple quantum well structure was grown on the InP substrate by metalorganic chemical vapor deposition (MOCVD). The active/passive integration technique utilizes an offset structure with a single p-cladding regrowth [6]. The InP PIC transmitter consists of a widely tunable sampled grating distributed Bragg reflector (SGDBR) laser, a high-speed semiconductor optical amplifier (SOA), a high-speed Mach-Zehnder modulator (MZM), and a two-section high-power output SOA. Figure 1(a) shows a microscope image of the fabricated PIC transmitter. The PIC has a footprint of 5.5 mm × 0.36 mm. SEM images at various stages of the fabrication process are shown in Fig. 1(b)-(e). The emission wavelength of the PIC transmitter can be shifted from 1521 nm to 1565 nm, as shown in Fig. 2. Across the entire tuning range, the maximum SMSR of 55 dB was measured near 1550 nm and the minimum SMSR of 45 dB at 1521 nm. The optical power from the SGDBR laser was boosted by a 400-μm-long SOA (SOA 1), which can compensate the insertion loss in the following MZM. The two-section high-power output SOA (SOA 2) has a flared waveguide width to increase the saturation output power. To measure the high-speed performance of the transmitter, the chip was mounted on a high frequency ceramic submount. The eye diagrams for 1 Gbps and 3 Gbps non-return-to-zero (NRZ) on-off keying (OOK) modulation at a reverse bias of 3.9 V are shown in Fig. 3, demonstrating an extinction ratio of 13.4 dB and 16.8 dB, respectively.

The fabricated InP PIC transmitter was inserted in a free space optical link, as the setup shown in Fig. 4. A NRZ 2^{10} -1 pseudo random binary sequence (PRBS) was generated and used to drive the MZM through a bias-Tee. The optical signal from the transmitter was collected by a lensed single mode fiber (SMF) and coupled to an optical collimator (with a beam divergence angle of 0.016°), and then transmitted in air. At the receiver side, an identical collimator collected the light. The distance between the two collimators is 1.35 m. An in-fiber variable optical attenuator (VOA) was used to simulate the geometric attenuation of the free space optical link. The bit error rate (BER) measurements at 1 Gbps and 3 Gbps as a function of the link attenuation are shown in Fig. 5. At the data rate of 3 Gbps, the free space link operates free of errors (BER $< 1\times10^{-9}$) up to approximately 24 dB attenuation (180 m distance). With forward error correction (BER $< 2\times10^{-3}$), the equivalent link length can be up to 300 m (28 dB attenuation). At a lower date rate of 1 Gbps, the performance can be further improved. The corresponding link lengths at error free and forward error correction limit are 300 m and 400 m, respectively. A reference transmitter with a 10 GHz commercial MZM and an external cavity source was also tested in the link under the same setting.

In conclusion, a free space optical link with a widely tunable InP PIC transmitter around 1550 nm was demonstrated. Error-free operation was achieved at a data rate up to 3 Gbps with an equivalent link length of 180 m (up to 300 m with forward error correction).

[1] R. Cesarone *et al.*, *Proc. Space Opt. System App.,* p. 410, 2011. [2] D. Caplan *et al.*, *J. Opt. Fiber Comm*. vol. 4, p. 225, 2007.
[3] V. Rosborough *et al.*, *Advanced Photonics Congress,* p. ITu2A.3, 2016. [4] H. Zhao *et al.*, *CLEO*, p. JW2A.52, 2018.
[5] H. Zhao *et al.*, *Advanced Photonics Congress,* p. ITu4B.6, 2018. [6] L. Coldren *et al.*, *J. Lightw. Technol*. 29 (4), 2007.

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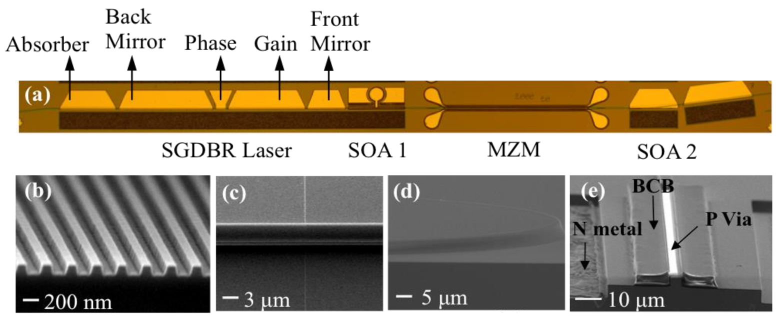

Fig. 1. (a) Microscope image of the InP PIC transmitter; (b)-(e) SEM images at various stages of the fabrication process: (b) The sampled gratings, (c) Dry etched waveguide ridge, (d) Sidewall of the BCB pattern, (e) Cross section of the high-speed SOA.

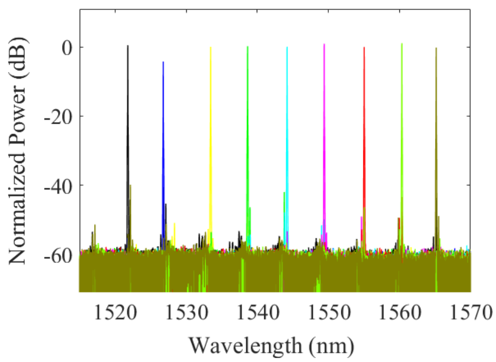

Fig. 2. Overlaid lasing spectra of the SGDBR laser.

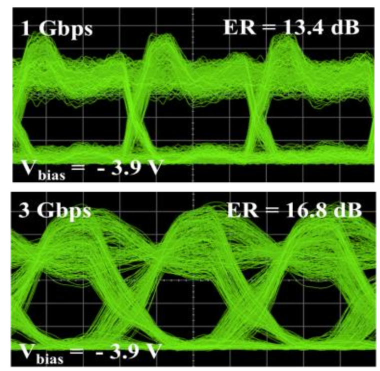

Fig. 3. Eye diagrams for 1 Gbps and 3 Gbps NRZ OOK modulation.

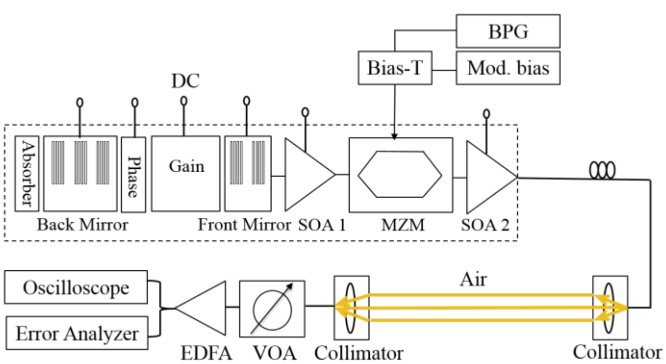

Fig. 4. Schematic of free space optical link setup.

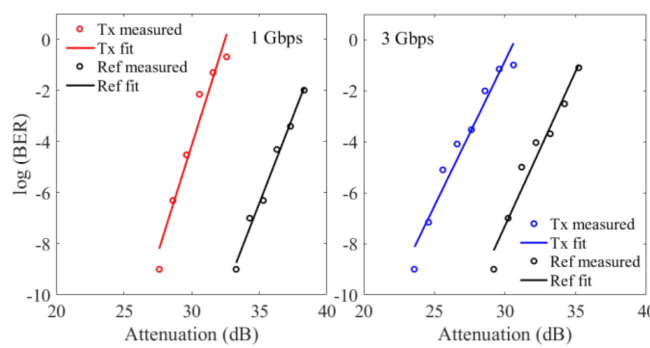

Fig. 5. BER for 1 Gbps and 3 Gbps NRZ OOK transmission.