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Integrated Indium Phosphide Transmitter for Free Space Optical Link

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Abstract: An integrated indium phosphide transmitter with 44-nm wavelength tuning range was demonstrated and inserted in a free space optical link. Error-free operation was achieved at 1 Gbps for an equivalent link length of 120 m. © 2018 The Author(s)
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1. Introduction

Free space optical links can support much higher data rates than radio-frequency technologies and allow for greater flexibility in transmitter and receiver design and optimization [1]. Commercial-off-the-shelf (COTS) components provide a ready solution to assemble free space optical systems. However, communications from small spacecraft, where both performance and reliability are crucial, require optical components with lower cost, size, weight and power (CSWaP). 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 [2-4]. In this work, an InP PIC transmitter was demonstrated comprising a widely tunable 1550-nm laser, a semiconductor optical amplifier (SOA) and a Mach-Zehnder modulator (MZM). With the fabricated PIC transmitter, a free space optical link was demonstrated; the bit error rate was measured at 1 Gbps and under different attenuation scenarios.

2. Transmitter Design and Characterization

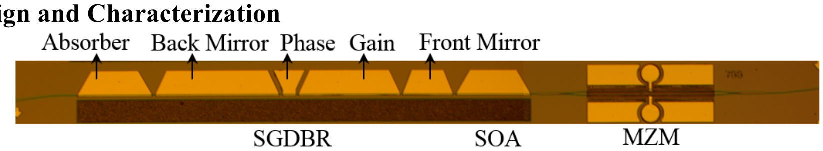

Fig. 1. Microscope image of fabricated InP PIC transmitter.

A microscope image of the fabricated InP PIC is shown in Fig. 1. The PIC consists of a widely tunable sampled grating distributed Bragg reflector (SGDBR) laser, SOA, and MZM. The PIC has a footprint of 4.4 mm × 0.36 mm. The indium gallium arsenide phosphide (InGaAsP) multiple quantum well structure was grown on an InP substrate by metalorganic chemical vapor deposition (MOCVD). The active/passive integration technique utilizes an offset structure with a single p-cladding regrowth [4]. The SGDBR laser consists of five sections: absorber, back mirror, phase section, gain section and front mirror. By tuning the injected current in the front/back mirrors, as shown in Fig. 2(a), the emission wavelength can be shifted from 1521 nm to 1565 nm. Figure 2(b) illustrates how the emission wavelength changes with the current applied to either the front or back mirror. Across the entire tuning range, the average side mode suppression ratio (SMSR) is 50 dB. A maximum SMSR of 55 dB was measured near 1550 nm, as shown in Fig. 2(c). The light-current-voltage (LIV) characteristics of the SGDBR laser (Fig. 2(d)) were measured by using the output SOA as a photodiode by applying a reverse bias and measuring the photocurrent. The threshold current of the laser is 45 mA and the optical power is 18 mW at a gain section current of 120 mA.

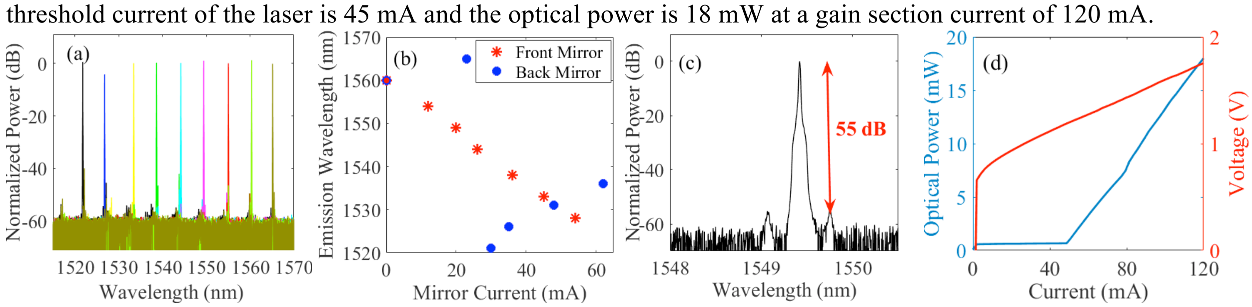

Fig. 2. SGDBR laser characteristics: (a) Overlaid lasing spectra; (b) Tuning characteristics; (c) Lasing spectrum near 1550 nm; (d) LIV characteristics.

The optical power from the SGDBR laser was boosted by a 400-µm-long SOA. Figure 3(a) shows the gain characteristics of the SOA at different input power levels. To measure the high-speed performance of the PIC transmitter, a high-speed ground-signal-ground probe was contacted to the on-chip pads of the 700-µm-long MZM. The eye diagrams for 500 Mbps and 1 Gbps non-return-to-zero (NRZ) on-off keying (OOK) modulation are shown in Fig. 3(b), demonstrating an extinction ratio (ER) of 12.0 dB and 12.1 dB, respectively.

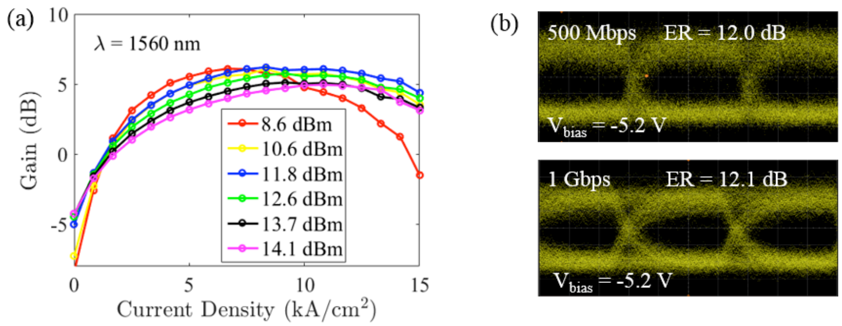

Fig. 3. (a) Gain as a function of SOA current density at different input power levels; (b) Eye diagrams for 500 Mbps and 1 Gbps NRZ OOK modulation.

3. Free Space Optical Link Demonstration

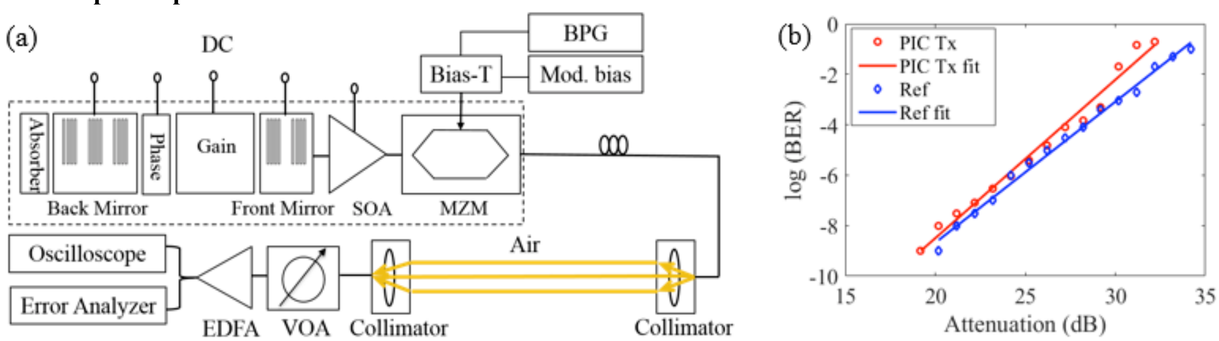

Fig. 4. (a) Schematic of free space optical link setup; (b) BER for 1 Gbps NRZ OOK transmission.

Utilizing the fabricated InP PIC transmitter, a free space optical link was constructed as shown in Fig. 4(a). The transmitter signal was collected by a single mode fiber (SMF) and coupled to an optical collimator, and then transmitted in air. At the receiver side, the light was collected by a second identical collimator (the two collimators are 1.35 m apart), and coupled to a SMF. An in-fiber variable optical attenuator (VOA) was used to simulate the geometric attenuation of the free space optical link. The equivalent length of the free-space transmission path, considering a beam divergence angle of 0.016°, spans from 0 m to 600 m (corresponding to from 0 dB to 34 dB of attenuation). At the receiver, an erbium doped fiber amplifier (EDFA) partially recovered the link loss and the signal was then detected by a PIN photodiode. Figure 4(b) shows bit error rate (BER) measurements at 1 Gbps as a function of the link attenuation. With the InP PIC (red), link operates free of errors (BER $< 1\times10^{-9}$) up to approximately 20 dB attenuation (120 m distance) and below the forward error correction limit (BER $< 2\times10^{-3}$), up to approximately 30 dB attenuation (400 m distance). Comparing the InP PIC performance with a reference 10 GHz commercial MZM and external cavity laser source (blue), the link power penalty associated with the integrated transmitter is less than 1 dB (at BER $< 1\times10^{-9}$).

4. Conclusions

A widely tunable InP PIC transmitter operating around 1550 nm was demonstrated for free space optical communications. The integrated SGDBR laser demonstrates a 44-nm tuning range and high SMSR (on average 50 dB) across the entire C band. Using the PIC transmitter, a free space optical link experiment was performed operating at 1 Gbps and demonstrating error free operation.

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