Widely Tunable Integrated Laser Transmitter for Free Space Optical Communications

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Abstract: *Integrated laser transmitters are demonstrated for free space communications. The sampled grating DBR laser is tunable from 1521 nm to 1565 nm while maintaining >45 dB side mode suppression ratio. The transmitters demonstrate a 3-dB linewidth of 6.4 MHz and 7 Gbps data rate.*
Keywords: *Free space communication, photonic integrated circuits, sampled grating DBR laser, semiconductor optical amplifier, Mach-Zehnder modulator.*

1. INTRODUCTION

Free space optical communications is of great interest recently for its promise to replace radio frequency systems for providing low-cost, reliable, high-speed connectivity for long-haul intersatellite and deep-space links [1, 2]. Compared to optical systems assembled with discrete commercial-off-the-shelf components, photonic integrated circuits (PICs) will dramatically reduce system cost, size, weight, and power (CSWaP) for free space links [3]. In our previous work, a 1-Gbps free-space optical link was demonstrated with a widely tunable indium phosphide (InP) PIC transmitter operating near 1550 nm, which is one of the key wavelengths utilized for space optical communications [4, 5]. Here the tuning characteristics and laser linewidth were studied and the InP PIC was implemented in a free-space optical link operating up to 7 Gbps.

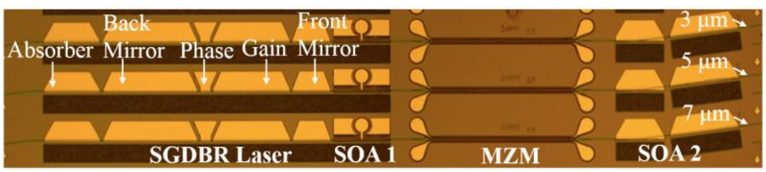

Fig. 1. Microscope image of fabricated InP-based PIC transmitters with different output booster SOA designs.

2. DEVICE CHARACTERIZATION

The InP-based PIC transmitter was fabricated with an indium gallium arsenide phosphide (InGaAsP) multi-quantum-well structure grown by metalorganic chemical vapor deposition (MOCVD). Figure 1 shows a microscope image of three different PIC transmitters. Each transmitter consists of a widely tunable sampled grating distributed Bragg reflector (SGDBR) laser, high-speed semiconductor optical amplifier (SOA), high-speed Mach-Zehnder modulator (MZM), and two-section output booster SOA. The ridge waveguide widths of the second section of the output SOAs are 3 μm, 5 μm and 7 μm, respectively, otherwise the three PICs are identical. With the flared waveguides, a higher output saturation power can be achieved. Each PIC transmitter has a footprint of 5.5 mm × 0.36 mm. For characterization, the PIC was solder mounted to a ceramic carrier and wirebonded. The device submount was fixed to a temperature-controlled stage.

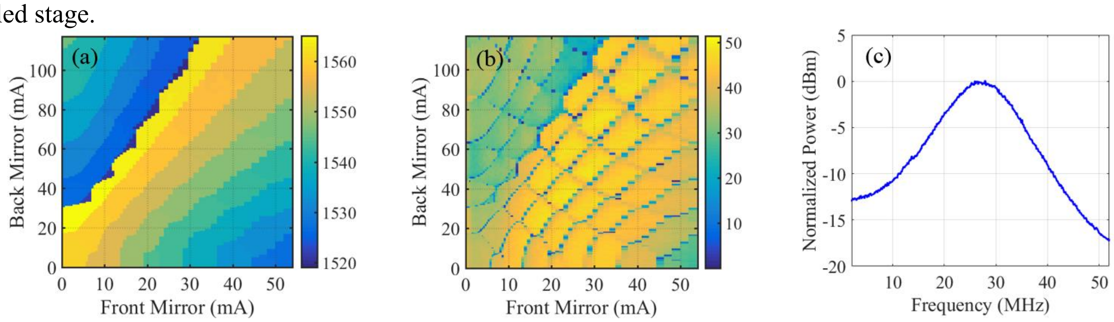

Fig. 2. DC characterization of the SGDBR laser: (a) Emission wavelengths (nm) as a function of currents applied to the front and back mirrors; (b) SMSR (dB) as a function of currents applied to the front and back mirrors; (c) Measured heterodyne laser linewidth spectrum demonstrating a 3-dB linewidth of 6.4 MHz.

As shown in Fig. 1, the multi-section SGDBR laser, consists of a back absorber, back SGDBR mirror, phase section, active gain section, and front SGDBR mirror. The emission wavelength can be tuned by adjusting the current applied to the front and back mirrors as well as the phase section. Without any tuning ($I_{front\ mirror} = I_{back\ mirror} = I_{phase} = 0$ mA), the emission wavelength is 1560 nm. Figure 2(a) shows the tuning characteristics of the SGDBR laser at a temperature of 15°C. The full tuning range is from 1521 nm to 1565 nm, covering more than the entire C band, which is most commonly used for free space laser communication. The side mode suppression ratio (SMSR) at different front and back mirror currents is demonstrated in Fig. 2 (b). As shown, greater than 45-dB SMSR was demonstrated over the entire tuning range. For the tuning maps generated (Fig. 2(a) and Fig. 2(b)), no current was applied to the phase section, however, this could be leveraged for fine tuning and optimization of the wavelength precision and SMSR. For laser linewidth characterization, the self-delayed heterodyne method was utilized and the measurement results are shown in Fig. 2(c) demonstrating a 3-dB linewidth of 6.4 MHz.

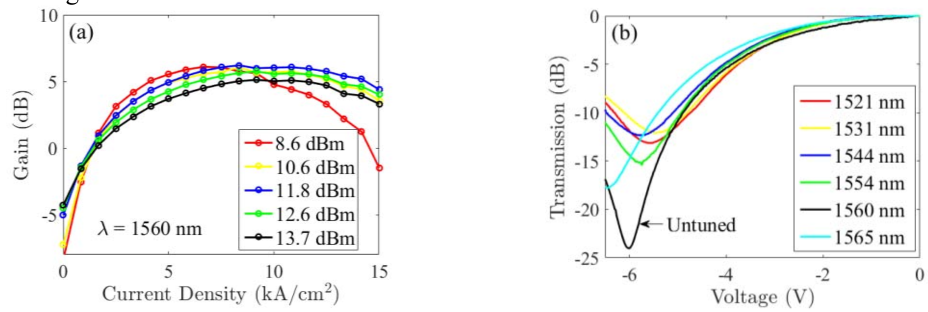

Fig. 3. (a) SOA gain as a function of current density at different input power levels; (b) MZM transfer function under reverse bias for different SGDBR laser wavelengths.

A 400-µm-long integrated high-speed SOA (SOA 1) follows the SGDBR laser. This can be used to compensate the insertion loss of the 1-mm-long MZM that follows. This SOA could also be used for modulating the SGDBR laser signal. The gain characteristics as a function of current density applied to SOA 1 are shown in Fig. 3(a). The transparency current of SOA 1 is approximately 15 mA. In conjunction with the MZM, this high-speed SOA can be utilized for pulse position modulation (PPM), which is commonly used for deep-space links [3]. Figure 3(b) shows the transfer function of the MZM under reverse bias. At a wavelength of 1560 nm, the DC extinction ratio (ER) is 24 dB with a V_π of -6.0 V.

A high-power two-section SOA (SOA 2) is used to boost the output signal. This comprises of a 350-µm-long curved waveguide section and a 500-µm-long flared waveguide. The output waveguide intersects the cleaved facet at an angle to minimize feedback to the laser cavity. The propagation loss of the curved waveguide is estimated to be 3 dB. The high-power SOA could obviate the need for an erbium-doped fiber amplifier (EDFA) especially for near-earth links. Figure 4(a) shows the output optical power of the PIC transmitter (W_{flare} = 5 µm) under conservatively low CW pumping conditions. The measured off-chip power is up to 14.5 dBm (28 mW). To characterize the RF performance of the modulator, one arm of the MZM was wire bonded to a 50-Ω RF feeding transmission line and on the other side to a 50-Ω load mounted to the ceramic carrier. Figure 4(b) shows the eye diagrams for non-return-to-zero (NRZ) on-off keying (OOK) modulation up to 7 Gbps at a bias of -2.2 V.

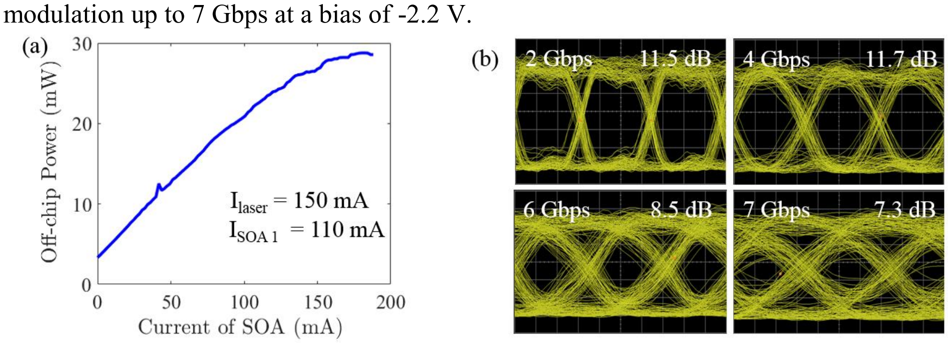

Fig. 4. (a) Output optical power of the PIC transmitter versus current in the flared-waveguide section of SOA 2 with a curved-waveguide section current of 90 mA; (b) Eye diagrams with NRZ OOK modulation.

3. Conclusion

An InP-based PIC transmitter was fabricated and characterized for free space optical communications. The SGDBR laser demonstrates a 44-nm tuning range and >45 dB SMSR across this range. The measured 3-dB linewidth is 6.4 MHz and off-chip optical power is 14.5 dBm. The high-speed MZM demonstrated up to 7 Gbps operation under reverse bias, and the transmitter can be configured for various modulation formats to adapt to link and power requirements.

Acknowledgment

The authors acknowledge support from the NASA Space Technology Mission Directorate.

References

[1] R.J. Cesarone, D.S. Abraham, S. Shambayati, and J. Rush, "Deep-space optical communications, visions, trends and prospects in Proc. Conf. Space Optical Systems and Applications, 2011, pp. 410-423.

[2] D. O. Caplan, "Laser communication transmitter and receiver design," J. Opt. Fiber Commun. vol. 4, pp. 225—362, 2007.

[3] V. Rosborough, F. Gambini, J. Snyder, L. Johansson, and J. Klamkin, "Integrated transmitter for deep space optical communications," in Conf. IEEE Avionics and Vehicle Fiber-Optics and Photonics (AVFOP), 2016, pp. 207-208.

[4] H. Zhao, S. Pinna, B. Song, L. Megalni, S. T. Šuran Brunelli, L. Coldren, and J. Klamkin, "High-power integrated indium phosphide transmitter for free space communications," in Conf. on Lasers and Electro-Optics, 2018, paper JW2A.52.

[5] H. Zhao, S. Pinna, B. Song, L. Megalni, S. T. Šuran Brunelli, L. Coldren, and J. Klamkin, "Integrated indium phosphide transmitter for free space optical link," in Advanced Photonics 2018 (IPR, NOMA, Sensors, Networks, SPPCom, SOF), paper ITu4B.6, in press.