# High-Power Integrated Indium Phosphide Transmitter for Free Space Optical Communications

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**Abstract:** An integrated indium phosphide transmitter is demonstrated for free space optical communications. The transmitter tunes from 1521 nm to 1565 nm, demonstrates performance up to 5 Gbps, and includes an output high-power semiconductor optical amplifier. 
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## 1. Introduction

For deployment on small spacecraft, to enable low-cost and frequent missions that include high data rate downlink capability, free space optical communication systems require photonic components with low cost, size, weight and power (CSWaP), while demonstrating high output optical power and power-efficient modulation formats [1]. Indium phosphide (InP) is the most mature and high-performance photonic integrated circuit platform (PIC), and is therefore attractive for space applications where reliability and technology readiness are critical. This platform allows for the monolithic integration of all the required active components (e.g. lasers, semiconductor optical amplifiers (SOAs), modulators/pulse carvers), and passive components (e.g. waveguide interconnects, filters, couplers), thus enabling complex single-chip implementations of advanced transmitters and receivers [1-4]. In this work, we demonstrate an InP-based PIC transmitter comprising a widely tunable 1550-nm laser, a high-speed SOA, a high-speed Mach-Zehnder modulator (MZM), and a two-section high-power output SOA. The transmitter can be configured for various modulation formats including on-off keying (OOK), pulse position modulation (PPM), differential phase shift keying (DPSK), and frequency shift keying (FSK), and the high-power SOA obviates the need for an erbium-doped fiber amplifier (EDFA) especially for near-earth links.

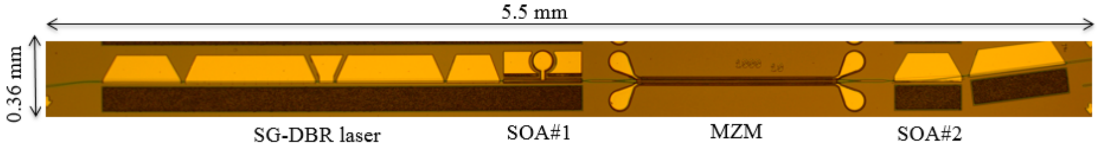
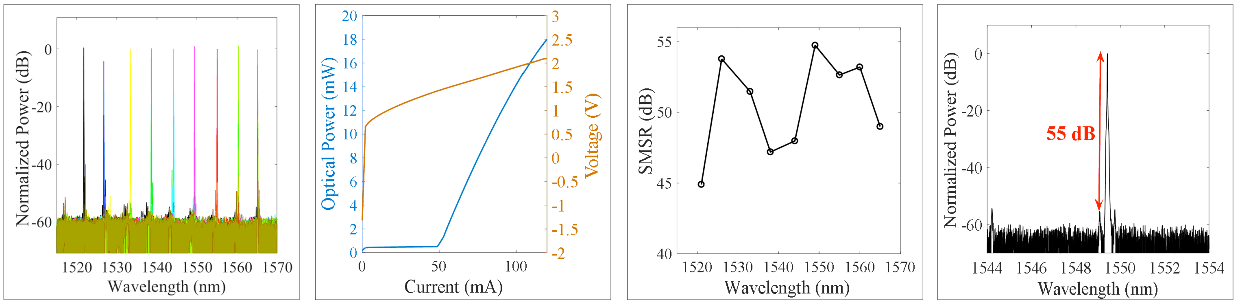



Figure 1. Microscope image of the fabricated InP-based PIC transmitter.

## 2. Transmitter fabrication and characterization

The PIC transmitter, of which the microscope image is shown in Fig. 1, consists of a widely tunable sampled grating distributed Bragg reflector (SG-DBR) laser, SOA, MZM, and high-power two-section SOA. The transmitter gain sections (used for the laser and SOAs) are based on an indium gallium arsenide phosphide (InGaAsP) multi-quantum-well structure grown on InP substrates by metalorganic chemical vapor deposition (MOCVD). The active/passive integration technique utilizes an offset structure with a single p-cladding regrowth as described in [5]. The sampled gratings in the laser section were defined by standard E-beam lithography and dry etched with chlorine-based ion beam etching. Photosensitive Benzocyclobutene (BCB) is used for its low dielectric constant to reduce parasitic pad capacitance for the high-speed SOAs and MZMs.

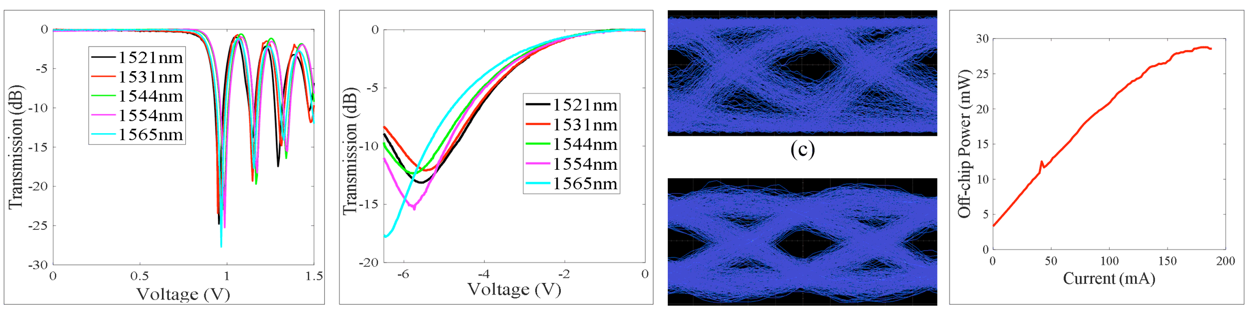
For characterization, the PIC was solder mounted to a ceramic carrier and wirebonded. The device submount was fixed to a temperature-controlled stage. Figure 2(a) shows the tuning characteristics of the SG-DBR laser. By controlling both the laser front and back SG-DBR mirror currents, the emission wavelength can be tuned from 1521 nm to 1565 nm, demonstrating a 44-nm tuning range, thus covering more than the entire C-band. The light-current-voltage (LIV) characteristics were measured by using the high-speed integrated SOA as a photodetector. As shown in Fig. 2(b), the laser exhibits a threshold current of 45 mA and an output optical power of 15 mW at a gain section current of 100 mA. The laser side mode suppression ratio (SMSR) is shown in Fig. 2(c) as a function of the laser wavelength, yielding an average value of 50.5 dB across the tuning range, with a maximum SMSR of 55 dB at wavelength near 1550 nm (see Fig. 2(d)).




(a) (b) (c) (d)

Figure 2. DC characterization of the SG-DBR laser: (a) Overlaid lasing spectra; (b) LIV characteristics; (c) SMSR versus wavelength; (d) Lasing spectrum near 1550 nm.

To characterize the performance of the high-speed MZM, a high-speed ground-signal-ground probe was contacted to a transmission line on the submount, and the transmission line was connected to the MZM through a wirebond. A bias-Tee was connected to the high-speed probe. Figure 3(a) and (b) show the modulation efficiency (transfer function) of the MZM under forward bias and reverse bias, respectively. As expected, the MZM is significantly more efficient under forward bias. This is attractive especially for applications where an MZM is used as a pulse carver (PPM configuration) for lower data rates. For higher data rates, reverse bias field-based modulation is preferable. Figure 3(c) shows the eye diagram for non-return-to-zero (NRZ) on-off keying (OOK) modulation with a forward bias of 1.22 V at 1Gbps; the measured extinction ratio (ER) was 13 dB. Figure 3(d) shows the NRZ OOK eye with a reverse bias of -5.7 V at 5Gbps. At this operating condition, the ER was measured to be 6.7 dB.




(a) (b) (d) (e)

Figure 3. (a) MZM transfer function under forward bias; (b) MZM transfer function under reverse bias; (c) 1-Gbps NRZ OOK eye diagram with forward bias of 1.22 V; (d) 5-Gbps NRZ OOK eye diagram with reverse bias of 5.7 V; (e) Output optical power of the PIC transmitter versus current in the flared-waveguide section of the booster SOA for SOA#1 current of 130 mA and first section SOA#2 current of 90 mA.

Following the MZM is a two-section SOA where the second section has a flared waveguide width to reach a high output saturation level. With this booster SOA, the PIC transmitter could be used in some near-earth free space optical links without requiring an EDFA power amplifier. Figure 3(e) shows the output optical power of the PIC transmitter under conservatively low pumping conditions. Future measurements with anti-reflection coated devices and optimized heatsinking will increase the current levels for higher power.

## 3. Conclusions

An InP-based PIC transmitter was fabricated and characterized for free space optical communications. The SG-DBR laser demonstrates a 44-nm tuning range and high SMSR (on average 50 dB) across this range. The high-speed MZM demonstrated 1-Gbps operation under forward bias, and up to 5-Gbps operation under reverse bias, and the transmitter can be configured for various modulation formats to adapt to link and power requirements.

## 4. References

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