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First O-band Silicon Coherent Transmitter With Integrated Hybrid Tunable Laser and SOAs

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ABSTRACT

Scaling data centers to 200 Gbps/lane with direct detection may not provide sufficient link budget for optical switches. Analog coherent detection leverages phase and polarization of optical signals to scale efficiently without requiring digital signal processing and employs integrated lasers to maximize link budgets for optical switches. We report the first O-band silicon photonics coherent transmitter integrated with hybrid semiconductor optical amplifiers and tunable lasers. The laser demonstrated >6 dBm output power with ∼700 kHz linewidths across its 14 nm tuning spectrum. 64 Gbaud QPSK transmission was demonstrated with BER ∼4e-4 and ∼6.6 pJ/bit energy-efficiency when utilizing SiGe BiCMOS drivers.

Keywords: analog coherent detection, integrated hybrid lasers, O-band 1310 nm, Mach-Zehnder modulators, dual-polarization QPSK, silicon photonics, short-reach intra-datacenter connections, polarization multiplexed carrier

1. INTRODUCTION

To meet the demand of future data center networks, energy-efficient optical links that scale to higher data rates will be required. Coherent detection offers significant advantages over the intensity-modulation direct-detection (IMDD) links that are deployed today. By leveraging phase and polarization of optical signals, coherent detection can achieve increased data rates while also enabling a higher optical link budget by mixing the modulated signal with a local oscillator (LO) laser. Analog coherent detection schemes such as optical phase locked loops (OPLL) can be utilized to minimize power consumption by performing carrier and polarization recovery without high-speed analog-to-digital converters (ADCs) and digital signal processing (DSP). By using DP-QPSK modulation, power-efficient NRZ transmitter (TX) and receiver (RX) electronics can be utilized while maximizing link budget, which can enable optical switching.[1]

Presented in this work is a silicon coherent transmitter with integrated hybrid laser meant for data center networks. This dual-polarization transmitter demonstrated 64 Gbaud QPSK constellations with bit-error ratios (BER) as low as 4e-4 while consuming ∼6.6 pJ/bit per channel. Photonic integrated circuits (PIC) were fabricated on Intel's silicon photonics platform while custom electronics were made in GlobalFoundries 9HP 90 nm SiGe BiCMOS process. Intel's platform that previously demonstrated 800G link applications[2] also includes integrated lasers and semiconductor optical amplifiers (SOA) which reduce packaging complexity and optical loss to further improve link budgets for future optical networks.

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2. TRANSMITTER DESIGN

The transmitter PIC consists of an integrated hybrid laser utilizing back reflectors based on 1 x 3 multimode interferometers (MMI) with each arm leading to tunable optical delay lines of different lengths.[3] Its front output is connected to a 1 x 2 splitter leading to 4 differential travelling wave Mach-Zehnder modulators (MZMs) — two for each polarization channel. Outputs of the two channels are boosted by semiconductor optical amplifiers (SOA) then merge in a polarization beam-combiner rotator (PBCR) where half the signals are rotated to transverse magnetic (TM) polarization while the others are left in the original transverse electric (TE) orientation. Biasing of lasers and MZMs is done with thermo-optic phase shifters.

The driver utilized in this work was previously demonstrated interfacing with a similar dual polarization MZM also fabricated by Intel but without integrated lasers or SOAs.[4] The MZM is terminated with an integrated resistor slightly less than its line impedance to peak the electro-optic response. Both driver and modulator are assembled on a custom Isola Tachyon PCB as shown in Fig. 1.

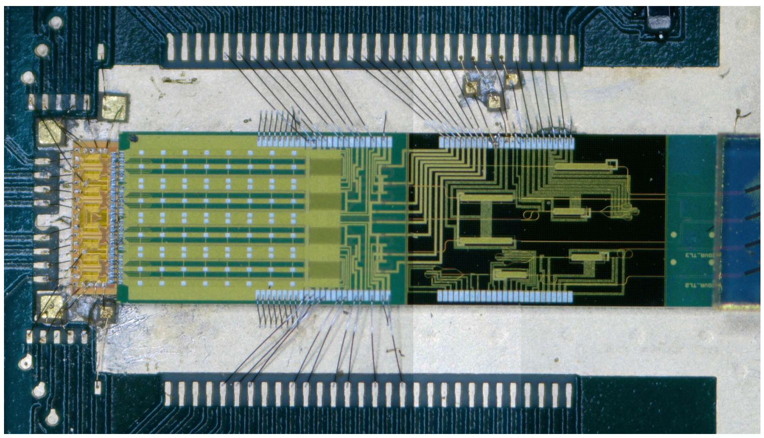


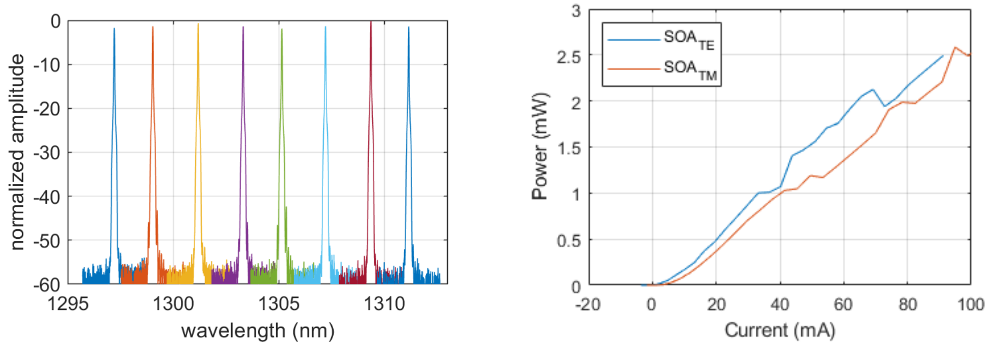
Figure 1: Micrograph of the 1.3 mm long driver on the left and 12.5 mm long PIC on the right. Both chips are 3 mm wide and had several DC traces bonded to small decoupling capacitors.

3. MEASUREMENTS AND DISCUSSION

The transmitter laser was first characterized alone without modulation. Once it was shown to have satisfactory performance, the assembly was biased and driven for QPSK transmission which was demodulated by a commercial receiver. No temperature controller was used while collecting any data so the measurement environment is assumed to be room temperature.

3.1 Integrated Hybrid III/V-Si Laser and SOAs

Laser measurements were performed with a battery box powering the gain section to minimize phase noise from AC power supplies. Lensed fiber was aligned to the edge facet with a power monitor displaying >6 dBm of output power when all MZM branches and active regions are biased for maximum transmission. The laser showed a threshold current of ∼8 mA. A self-heterodyne setup was used to monitor 3 dB apparent linewidths which were consistently <700 kHz when optimized for single mode operation. An output tap leading to an optical spectrum analyzer (OSA) also recorded tunable wavelength ranges of 14 nm and side-mode suppression ratios >40 dB seen in Fig. 2(a) which are consistent with previously reported results.[5] Additional sweeps were performed on each individual polarization channel's SOAs to verify channel output power symmetry in Fig. 2(b).



a) b)

Figure 2: a) Normalized laser frequency spectrum on the OSA showing wavelength tunability across 2 nm spaced wavelength channels. b) Polarization channel SOA injection current versus output facet power. The SOA not being swept was biased at absorption in both LI measurements.

3.2 QPSK Coherent Data Link

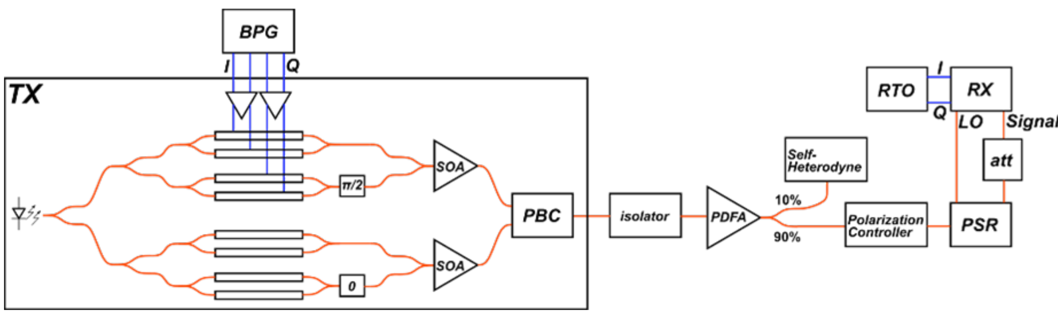


Figure 3: Block diagram of the transmitter with on-chip laser and self-homodyne test setup. Polarization carrier multiplexing was achieved by biasing the LO branch to the peak and the QPSK signal to null output power.

Intended modulation format for this transmitter is dual polarization QPSK which requires a LO laser at the receiver. To demodulate data without a reciever LO, the transmitter was biased to generate a polarization multiplexed carrier with the LO on the unmodulated polarization and the QPSK modulated signal on the other. Then the on-chip PBCR output was fiber coupled to a commercial polarization splitter rotator with linear polarizers before being fed into the reference 90-degree hybrid (Kylia COH28X-FCAPC-1300nm) connected to a pair of balanced photodetectors (Finisar BPDV3320R). Therefore only one polarization can be tested at a time with this configuration shown by Fig. 3 despite the symmetric IC design. A praseodymium-doped fiber amplifier was also introduced to compensate for additional losses introduced by using an off-chip LO for the receiver. LO path length was matched to that of the attenuator and signal to improve signal phase stability. Total output power from the facet was also reduced to <5 dBm to maintain laser stability while under additional heating when drivers were on. Overall contributions in approximate power consumption for each channel were 4.25 pJ/bit from drivers and 2.35 pJ/bit from the PIC.

RF signals from photodetectors output to a 256 GSa/s real-time oscilloscope collecting 256 kpts for BER sensitivity curves in Fig. 4 and 1.28 Mpts for constellations at the lowest BER bounds in Fig. 5. All BER sensitivity curves use a PRBS15 bit sequence while transmitted with the same LO power of 310 μW and unattenuated signal power of 110 μW per photodetector. QPSK constellations were sampled and rotated with no additional post-processing to modify measured points. Curves in Fig. 4 agree well with previously demonstrated results using similar platforms.[4]

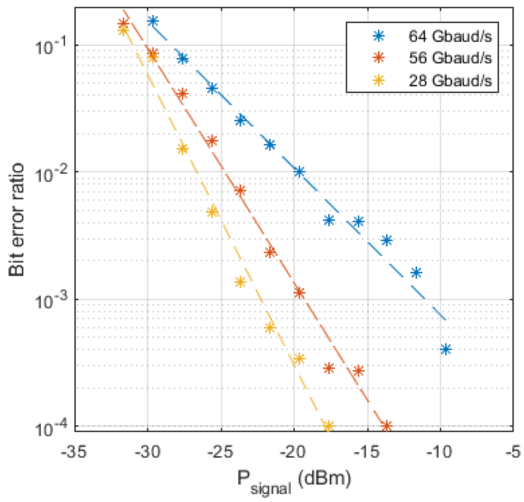


Figure 4: Sensitivity curves at 64, 56, and 28 Gbaud for received signal power per photodetector versus BER.

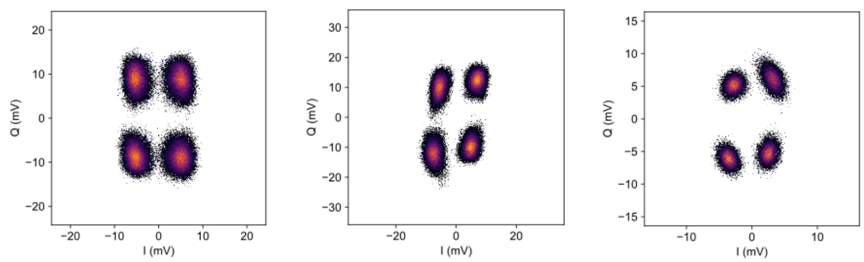


Figure 5: QPSK constellations at 64, 56, and 28 Gbaud for lowest BER of each baudrate.

4. CONCLUSION

Reported here, to the best of the authors' knowledge, is the first silicon coherent transmitter with an integrated hybrid laser operating at O-band. 64 Gbaud QPSK transmission was shown with a polarization-multiplexed carrier scheme while achieving BERs down to 4e-4 and total power consumption of ∼6.6 pJ/bit per channel. Future works will involve measuring both polarizations simultaneously with OPLL based optical receivers.

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