Tb/s-Class InP-Based System-On-Chip Photonic ICs

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Abstract: State-of-the-art monolithically integrated, multi-channel InP-based system on chip (SOC) photonic ICs have been developed to implement Tb/s class coherent transmitters and receivers with extended C-band tunability. A 14-channel PIC architecture is demonstrated enabling 4.9 Tb/s total capacity using 44 Gbaud 16-QAM coherent modulation. Furthermore, multi-channel coherent transmitter PIC with hybrid integrated with SiGe drivers capable of operating up to 1.0 Tb/s per wave, utilizing 100 GBaud, 32QAM modulation are demonstrated.

OCIS codes: (250.0250) Optoelectronics; (060.0060) Fiber optics and optical communications; (250.5300) Photonic integrated circuits; (060.1660) Coherent Communications

1. Introduction

The development of fully integrated optical system-on-chip (SOC) transmitter and receiver solutions has resulted in significant benefits to the economics, power consumption, density, and reliability of high capacity DWDM systems. Traditionally, the use of photonic integrated circuits (PICs) reduces costs by minimizing electrical and optical assembly processes, test apparatus and time. Furthermore, PICs mitigate potential performance degradation due to the many optical couplings required in a discrete component system and enable efficient creation of super-channels, helping the increase of the DWDM line card capacity while reducing operational complexity.

Photonic integrated circuit technologies have contributed to more than an order of magnitude increase in capacity every decade, a trend that started with electroabsorption-modulated lasers [1] and continued through with the commercial introduction of the first fully integrated multi-channel optical SOC 100 Gb/s transmitter and receiver PICs in 2004 [2]. Several generations of commercial SOC InP-based PIC transmitters and receivers have been deployed based on a compact platform that leverages coherent modulation with unique scalability, efficiency and security. A large scale fully integrated optical SOC InP-based coherent PIC platform was demonstrated in a research setting in 2014, by monolithically integrating 40 wavelength channels and over 1700 optical functions on a single chip. The PIC platform demonstrated a 2.25 Tb/s PM-QPSK transmitter with over a 1 THz optical bandwidth [3]. A 6-channel implementation of with C-Band tunable 1.2 Tb/s transceiver modules operating at 33Gbaud, 16-QAM was also developed and transitioned into manufacturing in 2016. Each channel on the PIC comprises of an integrated widely-tunable laser capable of continuous tuning over the extended C-band (4.8 THz). The progression in performance of system-on-chip PICs has resulted in the demonstration and deployment of multiple generations of optical engines [3-7].

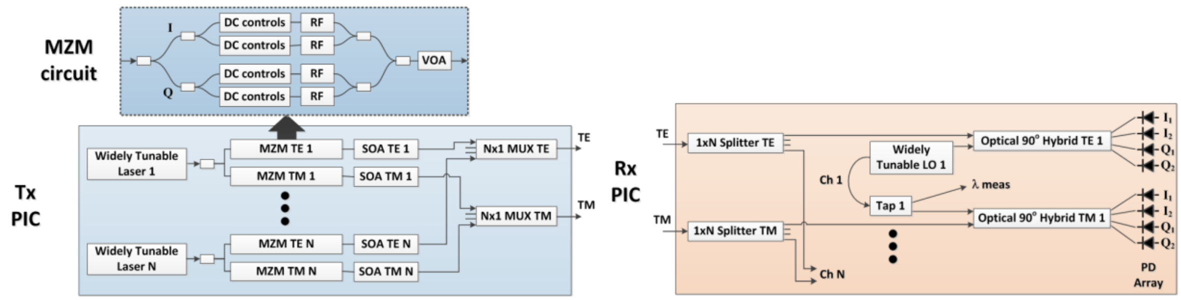
A fully integrated InP-based coherent transmitter PIC with extended C-Band tunability architecture was recently shown to support 14 channels on a single chip operating at 33 and 44 Gbaud per channel under 16-QAM dual polarization [6]. To further scale the platform beyond 44Gbaud, a 2-channel Tx PIC and Rx PIC assembly was realized with hybrid integrated SiGe drivers and amplifiers. This test vehicle was used to demonstrate transmission between TxPIC and RxPIC over a variety of distances, from 200 Km to 1400 Km and with a variety of symbol rates and modulation formats. Up to 1 Tb/s per wavelength capacity is shown by operating at 100Gbaud under 32-QAM (back-to-back). Additionally, 100Gbaud under 16-QAM signals generated with an integrated TxPIC assembly are transmitted over a distance of 1400 Km using a reference receiver. We believe this are the highest data-rate and capacity coherent PIC results to date and demonstrate the viability of 100Gbaud operation of fully integrated multi-channel InP-based PICs and SiGe electronic assemblies [7].

The ability to monolithically integrate lasers, optical amplifiers, saturable absorbers, modulators and low-loss passive waveguides on an InP-based platform enables the realization of systems on chip for a variety of applications. In this paper, we present an overview of the architecture of extended C-Band tunable coherent transmitter and receiver

PICs, representing the state-of-the-art for functional integration of InP-based transmitter technology [2-6].

2. Multi-Tbps System-on-Chip Architecture

Figure 1 (a) shows a schematic of the multi-channel Tx PIC integration, up to 14-channels were realized and reported in [5]. Each channel includes an independently controlled, widely-tunable laser (WTL) providing continuous tuning over the entire extended C-band (4.8 THz). The output from each laser is split into two nested Mach-Zehnder Modulators (IQ-MZMs). At the output of the MZM, a variable optical attenuator (VOA) and a semiconductor amplifier (SOA) is used to provide additional power balancing and amplification of the output power from the Tx PIC. DC control elements in each of the four arms of the nested MZM are used for power balancing and biasing the modulator to the required phase condition. Each MZM on these PICs is designed to run at symbol rates of up to 100 Gbaud and support modulation formats with variable spectral efficiency.



a) b)

Fig. 1 (a) Schematic of the multi-channel widely tunable coherent Tx PIC architecture. (b) Schematic of the Rx PIC architecture.

The corresponding receiver (Rx) PIC architecture is shown in Fig. 1(b). The monolithically integrated InP receiver PIC accepts two inputs polarized to be TE on chip from free space optics that rotate one signal path polarization from TM to TE. Each polarization signal path is split with a multi-mode interference coupler (MMI) based 1xN power splitter to feed N 90° optical hybrids. The optical hybrids mix the incoming signals with one of the independently controlled, integrated widely tunable local oscillator laser outputs. MMI-based optical taps on the laser output paths are used to couple light out from the chip to measure wavelength over the extended C-band (>40 nm). The PICs described herein enable each channel on the multi-channel PIC to span the entire extended C-band (40 nm), maximizing optical channel utilization and capacity as well as enabling reconfigurability on a super-channel or on a per-channel basis [5].

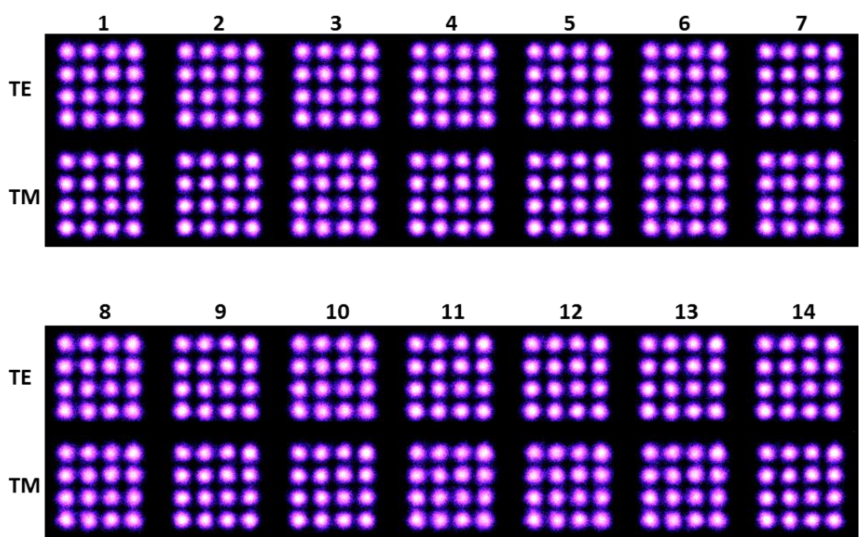


Fig. 2: Back-to-back 44 Gbaud constellations for all 14 channels on a Tx PIC as measured using an Rx PIC-based receiver. The figure shows only the outermost sub-carrier on each polarization for a dual-pol 16-QAM signal.

The 14-channel Rx and Tx PICs were mounted and wire-bonded to ceramic carriers with a multi-channel high-speed trans-impedance amplifier (TIA) ASIC and MZM driver, respectively. The RF elements on the PIC were directly probed with a custom high-speed probed card. An arbitrary waveform generator and amplifier were used to provide the RF signals to the modulator. Figure 2 shows the recovered 44 Gbaud x 16-QAM constellations for two polarizations and all 14 channels integrated on the widely tunable coherent transmitter PIC. All channels on the PIC achieved performance above the required FEC limit, demonstrating a capacity capability of 4.9 Tb/s for a single PIC operating at 44 Gbaud data rates [6].

To demonstrate transmission between TxPIC and RxPIC platforms, a 2-channel SOC test vehicle was assembled with hybrid integrated 180 nm SiGe BiCMOS electronic drivers and amplifiers. The Tx and Rx PICs were mounted on a carrier with a two-channel MZMD and TIA, respectively. Each driver and amplifier supplied 8-high-speed streams. A commercial line system was used to generate and transmit data signals at various formats and symbol rates. Utilizing the TxPIC assembly, 100 Gbaud x 32-QAM signals were transmitted to the reference receiver in a back-to-back configuration. Figure 3 shows the transmitted signals, with a total data rate capability of 1 Tb/s on a single wavelength, and a Q^2-factor above 6.2 dB, using SD-FEC[6] with 25% overhead allows for 800 Gb/s per wavelength. Furthermore, a net payload transmission in excess of 600Gb/s was obtained with three different combinations of symbol rates and modulation formats (data not shown) at 66Gbaud x 64-QAM, 88Gbaud x 16-QAM, 100Gbaud x 16-QAM. Each demonstration with successively longer distance 200, 600, 1400Km [7].

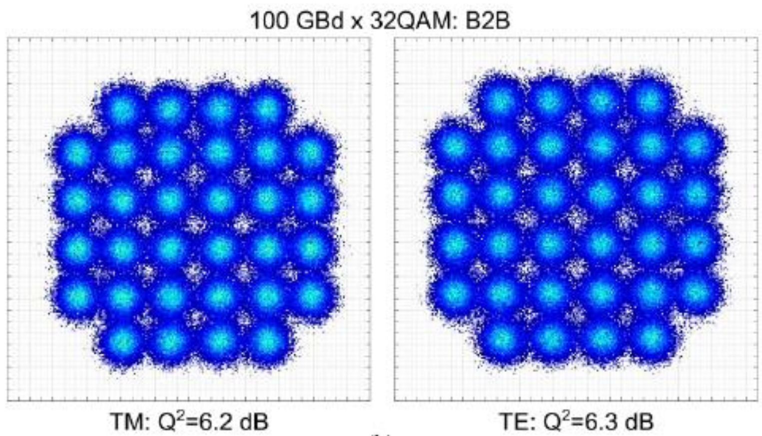


Fig. 3: Constellations of the received 100 Gbaud, 32QAM signal from the TxPIC assembly to a reference receiver in back-to-back configuration.

3. Conclusion

We have presented an overview of the state-of-the-art functional integration of system-on-chip utilizing InP-based PICs to realize multi-channel transceivers with extended C-band tunability for optical communication applications. The Tx and Rx PICs described in this paper are scalable, up to 1700 optical functions were integrated in a 40-channel PIC. A multi-channel architecture has been commercialized using a 6-channel transceiver module that integrates extended C-Band widely tunable lasers and with 1.2 Tb/s total payload capacity. Furthermore, using SOC Tx and Rx PICs we have demonstrated data rates of up to 100 Gbaud per channel under 32-QAM dual-polarization modulation, achieving up to 1 Tb/s per wavelength. The utility of integrated multi-channel InP-based PICs to achieve high-baud rates and high order modulation formats over a wide range of distances has been demonstrated. The InP-based SOC integration platform and multi-channel architecture offers commercial solutions that deliver multi-terabit scalability with security, simplicity, and operational efficiency.

4. References

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