High Performance Photonic Integrated Circuits for Coherent Fiber Communication

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Abstract: Advanced modulation format transmitters and receivers used in optical coherent systems are highly complex, containing many interconnected elements. Photonic integration can reduce the footprint, cost, and power consumption of optical coherent transceivers.

OCIS codes: (060.2330) Fiber optics communications; (130.3120) Integrated optics devices

1. Introduction

Figure 1 shows a typical link using optical coherent technology[1,2]. The transmitter is a continuous-wave (cw) laser modulated by one in-phase (I) and quadrature (Q) modulator for each polarization. The receiver consists of another cw laser, a polarization splitter, two optical mixers (also called optical 90° hybrids), four balanced pairs of photodetectors, four analog-to-digital converters, and a digital signal processor (DSP). Because both the real and imaginary part of each polarization of the signal are measured, the DSP has access to the full optical field and can correct for chromatic dispersion, polarization-mode dispersion, polarization-dependent loss, and other impairments. The DSP can also wavelength demultiplex, polarization demultipex, and track the relative phase between the transmitter and receiver lasers, so that homodyne detection is not required,.

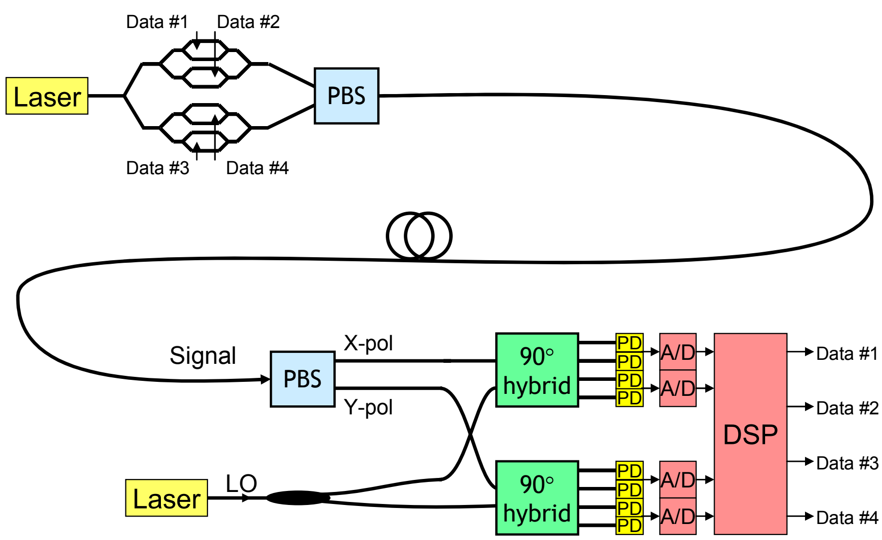

Fig. 1. Typical optical coherent system.

The transmitter has 23 optical components and 29 intra-component connections, and the receiver front-end has 13 optical components and 13 intra-component complexities. Other more complicated coherent systems have even more components and connections. This complexity is a strong driver for optical integration. This paper will review some published concepts and demonstrations of transmitter and receiver photonic integrated circuits (PICs) for coherent systems.

2. Transmitters

Because of the processing power in today's coherent receiver DSP, the transmitter in a coherent system can readily employ advanced modulation formats in order to improve spectral efficiency. Figure 2 shows quadrature phase-shift keying (DQPSK) modulators[3,4,5], Fig. 3 shows a 16-quadrature amplitude modulator (QAM) modulator[6], and Fig. 4 shows a polarization-division multiplexd (PDM) on-off keying (OOK) modulator[7].

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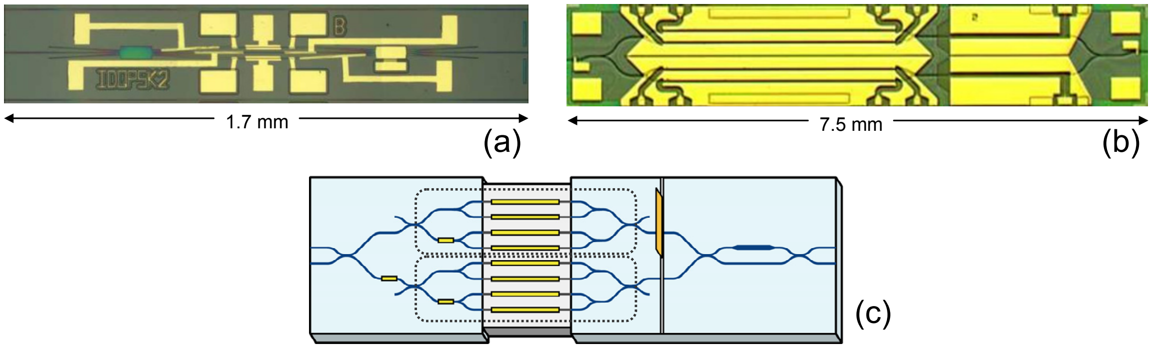

Figure 2. QPSK modulators. (a) InP using absorption modulators, (b) InP using phase modulators, and (c) silica combined with $LiNbO_3$ using phase modulators (polarization-division multiplexed).

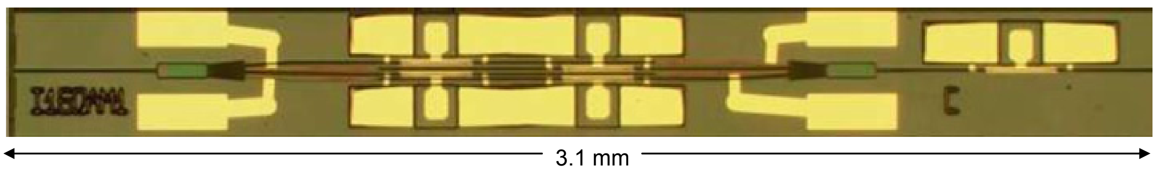

Figure 3. 16-QAM modulator in InP using absorption modulators.

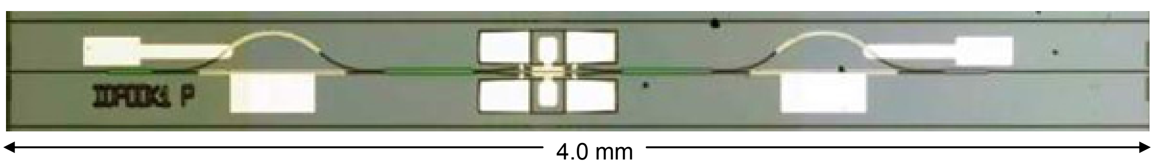

Figure 4. PDM OOK modulator in InP using absorption modulators.

Multi-channel advanced modulation format transmitter PICs have been reported, such as a 10-channel, 40-Gb/s QPSK transmitter PIC[8]. Although no multichannel transmitters have yet been reported in a coherent system, there is nothing that precludes them from doing so.

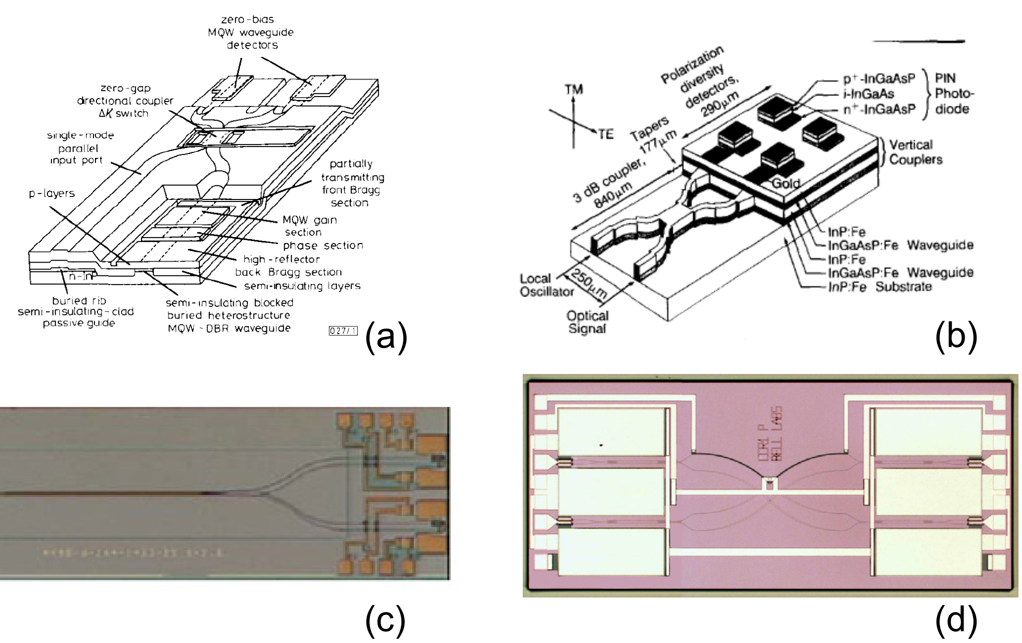

Figure 5. Some published coherent receiver front-ends. (a) single polarization, single quadrature; (b) dual polarization, single quadrature; (c) single polarization, single quadrature; and (d) dual polarization, dual quadrature.

3. Receivers

Figure 5 shows demonstrated optical coherent receiver front-end PICs, and indicates the evolution of the technology. Figure 5a shows a single-polarization, single-quadrature coherent receiver PIC in InP from 1989[9]. This demonstration was especially ground-breaking because it integrated the LO laser on the PIC. A single-quadrature coherent receiver cannot recover both the real and imaginary part of the signal and thus is limited to use in frequency-shift-keyed communication. Figure 5b shows a dual polarization, single-quadrature coherent receiver PIC, also in InP, from 1992[10]. This PIC, nor any of the following PICs, integrated the LO laser.

There was a gap in activity in coherent receiver PICs for 17 years. With the advent of powerful DSPs, dual-quadrature coherent reception resurged. Figure 5c shows a single-polarization, dual-quadrature coherent receiver PIC in InP in 2009[11]. Figure 5d shows a dual-polarization, dual-quadrature coherent receiver PIC in silicon-on-insulator, also in 2009[12]. So far, published receiver integration has been limited to single-channel PICs.

4. Conclusion

30 years after the first demonstration of photonic integration in coherent receivers, photonic integration is finally bringing significant value to optical coherent systems. The current state of integration is still quite basic, so we can expect further integration to bring even more significant changes in optical coherent systems in the future.

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