Silicon-Photonic Integrated Circuits with Enhanced Optical Functionality for Data-Center Applications

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Abstract: Silicon photonics adds optical functionality with minimal impact on cost and yield, having become the platform of choice for coherent receivers. We discuss adding optical functionality for direct-detection, including optical equalization and polarization demultiplexing.

1. Introduction

One of the main advantages of silicon photonics [1] for fiber-optic transceivers is its ability to add significant optical functionality with minimal impact on cost and yield. This is because silicon photonics is manufactured with mature processes on large wafers with very low defect density. This has enabled silicon photonics to become the platform of choice for optically complex devices such as coherent transceivers [2]. However, for low complexity devices, such as today's intensity-modulation direct-detect (IMDD) receivers, silicon photonics struggles to compete with III-V platforms. One can see the complexity difference between coherent and IMDD by comparing Figs. 1(a) and (b) or (c).

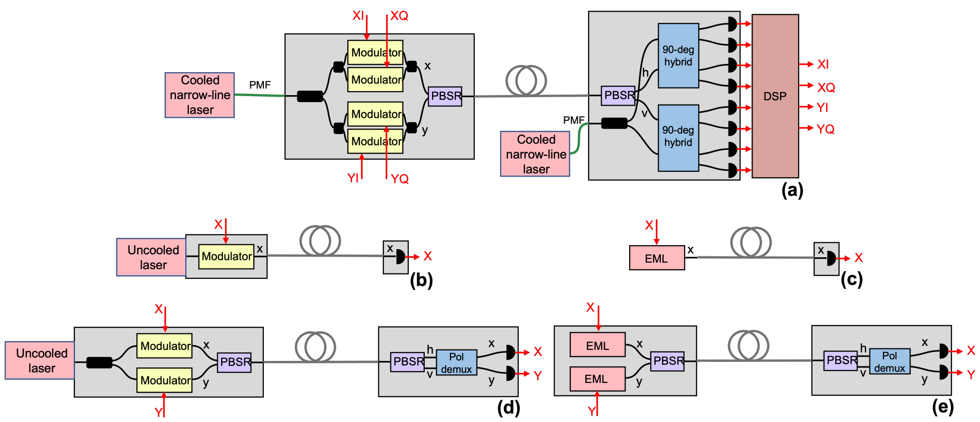

Fig. 1. Coherent and IMDD links. (a) DP-coherent, (b) IMDD with silicon photonics, (c) IMDD with EMLs, (d) DP-IMDD with silicon photonics, and (e) DP-IMDD with EMLs

IMDD is the most cost effective transmission type for short-reach links. One of the reasons is that the same digital-signal processing electronics is used for electrical cable or optical IMDD fiber links. For instance, the SERDES in an electronic switch can drive a copper or optical IMDD link. However, the relentless drive to reduce the cost per transmitted bit can no longer be sustained by simple IMDD. One cannot keep adding more wavelengths or fibers without running into chromatic dispersion, four-wave mixing, or other challenges.

What is needed is a way to take some of the features of coherent and apply them to IMDD while keeping the ability to share electronics between copper and optical. This involves taking some functions that are done in the electronic domain in coherent and moving them to the optical domain in IMDD, such as optical multiple-input multiple-output (OMIMO) (i.e., polarization demultiplexing) and optical equalization (OEQ), as shown in Fig. 2. Also, functionality that eases multiwavelength operation is needed, such as comb lasers.

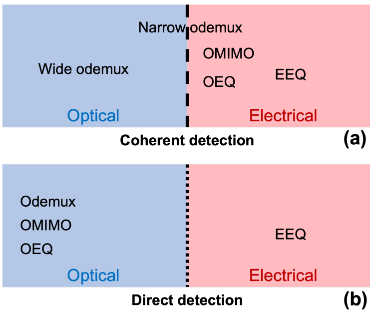

Fig. 2. Distribution of functionality in coherent and direct detect receivers.

2. Optical polarization demultiplexing

Coherent links today utilize dual polarization (DP). The two polarizations remain approximately orthogonal in the fiber, but the overall polarization drifts in time. The two polarizations are demultiplexed using a MIMO operation in the digital-signal processor (DSP). In an IMDD system, the MIMO operation must be done optically, as shown in Figs. 1(d) and (e), for silicon-photonic- and electro-absorption modulated laser (EML)-based transmitters, respectively. The operation is difficult in optics because optical elements have finite ranges yet the polarization evolution can be arbitrarily large [3]. This endless operation is typically effected by additional extra stages.

An early DP-IMDD transmitter was demonstrated in 2008 [4], and an early endless DP-DQPSK (similar to IMDD in regards to polarization demultiplexing) receiver was demonstrated in 2010. [5]. There have been recent demonstrations of non-endless [6], endless dual polarization [7], and endless single polarization polarization demultiplexing [8, 9].

Experimental results of a silicon-photonic DP receiver are shown in Fig. 3. Two 100-Gb/s PAM4 signals are polarization-combined, transmitted through optical fiber and a polarization scrambler, and demultiplexed and received in a silicon-photonic DP receiver. Tones are placed on the two channels to uniquely identify them. Fig. 3 shows the ratio of the unwanted tone to wanted tone in a given demultiplexed channel when the polarization demultiplexer tracking is turned on or off. The measured bit-error-ratio of one of the demultiplexed channels remains below 2×10^{-6} during the scrambling. No line-rate digital signal processing (DSP) is required to receive the demultiplexed channels.

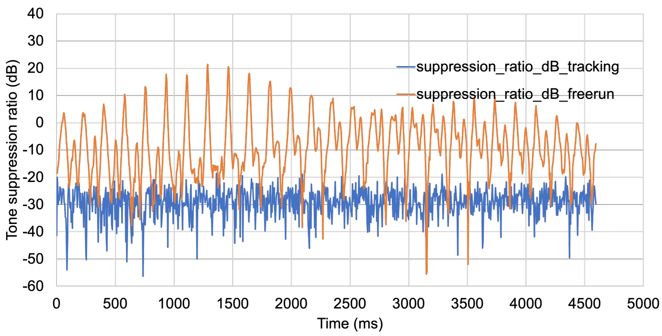

Fig. 3. Distribution of functionality between optics and electronics in coherent and direct detect receivers.

3. Optical equalization

Optical equalization can be performed using optical filters, such as finite-impulse-response fiilters constructed from length-imbalanced Mach-Zehnder interferometers, as shown in Fig. 4(a). In this old experiment, the solid symbols in Fig. 4(b) show significant equalization of chromatic dispersion, optical filtering, and polarization-mode dispersion with just one pre- and one post-cursor tap [10].

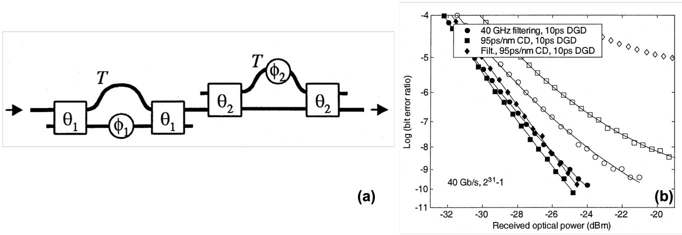

Fig. 4. Optical equalization.

4. Comb sources

Comb sources, an array of continuous-wave (cw) lines on a single fiber, are suitable as remote light sources (RLSs) powering multiwavelength IMDD transmitters, especially ring-based transmitters. InP gain chips with silicon-photonic external cavities are especially suitable for this. Fig. 5 shows a laser with a single gain chip and multiple external cavities on a single silicon photonics chip to generate two lines [11]. This concept can be extended to many lines.

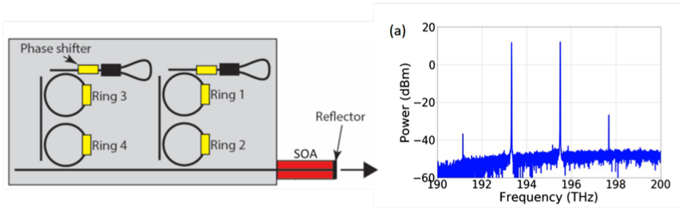

Fig. 5. Dual-channel laser using a single InP gain chip and single silicon-photonics chip.

In conclusion, significant optical functionality is deployed in today's silicon-photonic coherent transceivers. There is now a need to apply enhanced optical functionality, such polarization demultiplexing, optical equalization, and comb generation, to IMDD links. The author thanks Ying Zhao and Fred Heismann for their invaluable contributions to this work.

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