Polarization-diverse silicon photonics WDM receiver with a reduced number of OADMs and balanced group delays

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Abstract: We experimentally validate a 10-channel polarization diverse WDM receiver with only one ring based add-drop multiplexer per channel and on-chip optical delay lines balancing the two polarization paths for speeds up to 28 Gb/s. © 2020 The Authors

1. Introduction

Data transmission over inexpensive standard single mode fibers (SMFs) results in randomization of polarization at the receiver (Rx). To prevent loss of data, Rx systems must therefore exhibit a high degree of polarization insensitivity. One approach consists in coherently recombining the two polarizations inside the Rx [1], a method that has been extended to also handle an arbitrary number of spatial modes [2]. However, these and similar methods rely on dynamic phase shifters to coherently recombine the light. While a 2π phase shifting range is sufficient to reach any operating point required at system start-up, limited phase shifting ranges result in temporary loss of service during reset if systems drift under operation to the point of reaching their compliance limits. Thus, incoherent signal recombination in the electrical domain is much easier to handle from a control perspective, even though it typically requires partial duplication of electronics unless photocurrents are added before amplification.

In this work, we focus on a silicon photonics (SiP) wavelength division demultiplexing (WDM) approach which utilizes a dual-sided optical add-drop multiplexer (OADM) array combined with high-speed germanium photodiodes (GePD) for simultaneous filtering and detection of both polarizations [Fig. 1(a)] [3].

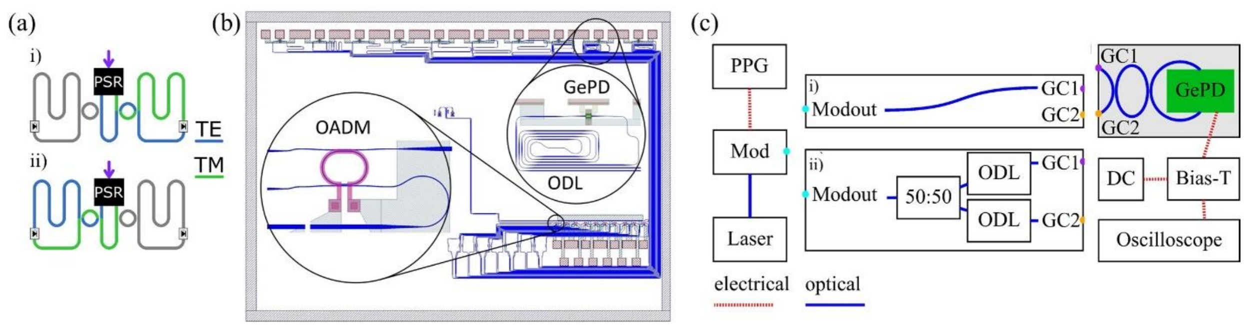

Fig. 1: (a) Schematic of balanced, polarization diverse Rx. Two orthogonal polarizations propagate in opposite directions in the same waveguide loop: i) and ii) represent the waveguide paths for the TE and TM polarizations, respectively represented in blue and green, for two channels. (b) Rx chip layout. Insets show a double-sided OADM and a high-speed GePD, with a channel-specific on-chip ODL balancing the group delays. (c) Measurement setup for i) the single-polarization and ii) the polarization-diverse configuration. Identically colored dots show interconnectivity.

In a single channel Rx, polarization diversity can be gracefully handled by routing the two polarizations to opposite ports of a waveguide photodetector, where they incoherently add up as part of the opto-electrical conversion [4]. Here, this concept is extended by applying it to both an OADM and a GePD connected to the latter, as initially conceptually proposed in [3] and illustrated in Fig. 1(a). Light from the two polarizations enters the OADM from opposite input ports, is dropped to opposite output ports, and is further routed to the GePD. A waveguide loop is connected to a polarization splitter rotator (PSR), to which several such OADM-GePD pairs can be coupled in order to drop independent channels. A first implementation of this scheme resulted in imbalanced group delays for the two polarizations, limiting the data rate to 10 Gb/s [5]. Such group delay imbalancing is further worsened in complex routing configurations as shown in the system chip layout in Fig. 1(b), particularly as the channel count is being scaled up. Differential group delay mismatch due to the placement of the OADM along the waveguide loop can however be compensated in the waveguide routing after the OADM, as illustrated in Fig. 1(a).

In the following, we report on the implementation of a 10-channel, polarization diverse Rx relying on this scheme with optical delay lines (ODLs) balancing out the optical paths. Characterization up to 28 Gb/s shows no significant difference between operation as either a single-polarization or polarization-diverse Rx.

2. Receiver characteristics

The Rx chip layout is shown in Fig. 1(b). This chip is intended to be operated with external, molded, polarization-splitting micro-optics, so that here the on-chip polarization splitting element was replaced by a pair of single-polarization grating couplers (GCs) connected to both ends of the waveguide loop, that are intended to each receive light corresponding to one of the polarizations in the fiber. The GCs have insertion losses (ILs) of ~4.5 dB. The waveguide loop is further coupled to ten OADMs with a free spectral range (FSR) of 9.3 nm, IL ~1 dB and an electro-optical bandwidth (EO BW) of ~17 GHz when the optical carrier coincides with the OADM resonance [6]. The OADMs are thermally tuned using on-chip TiN heaters [7] to compensate for fabrication tolerances.

After filtering, the signals are routed to double-sided high-speed GePDs, with responsivities ranging from 0.5 to 0.7 A/W, an average dark current of 0.28 µA and an EO BW ~20 GHz (at 2 V reverse bias). For balancing the paths leading to the two sides of the photodiodes, on-chip ODLs in the form of waveguide loops are added, mostly consisting of multi-mode waveguides in straight sections to minimize the effects of fabrication variations. The structures were fabricated at A*STAR Institute of Microelectronics, Singapore, in a standard multi-project wafer (MPW) run.

3. Measurement setup and results

The schematic of the measurement setup is shown in Fig. 1(c). For all experiments, a 12.8 dBm optical carrier is supplied by an Agilent tunable laser module 81960A. Light is further modulated by a 30 GHz commercial Mach-Zehnder modulator driven with a 2 V_{pp} signal, with 8 dB IL (measured at the maximum transfer point) and an extinction ratio of 7.7 dB. A non-return-to-zero (NRZ) pseudo-random bit sequence (PRBS) is generated by an Anritsu MU183020A pulse pattern generator (PPG). The OADMs are tuned to resonance to extract maximum optical power. After detection, the signal is analysed with an Agilent DSA-X-92004A real-time oscilloscope with a 20 GHz analog bandwidth. We performed three sets of measurements, described in the following.

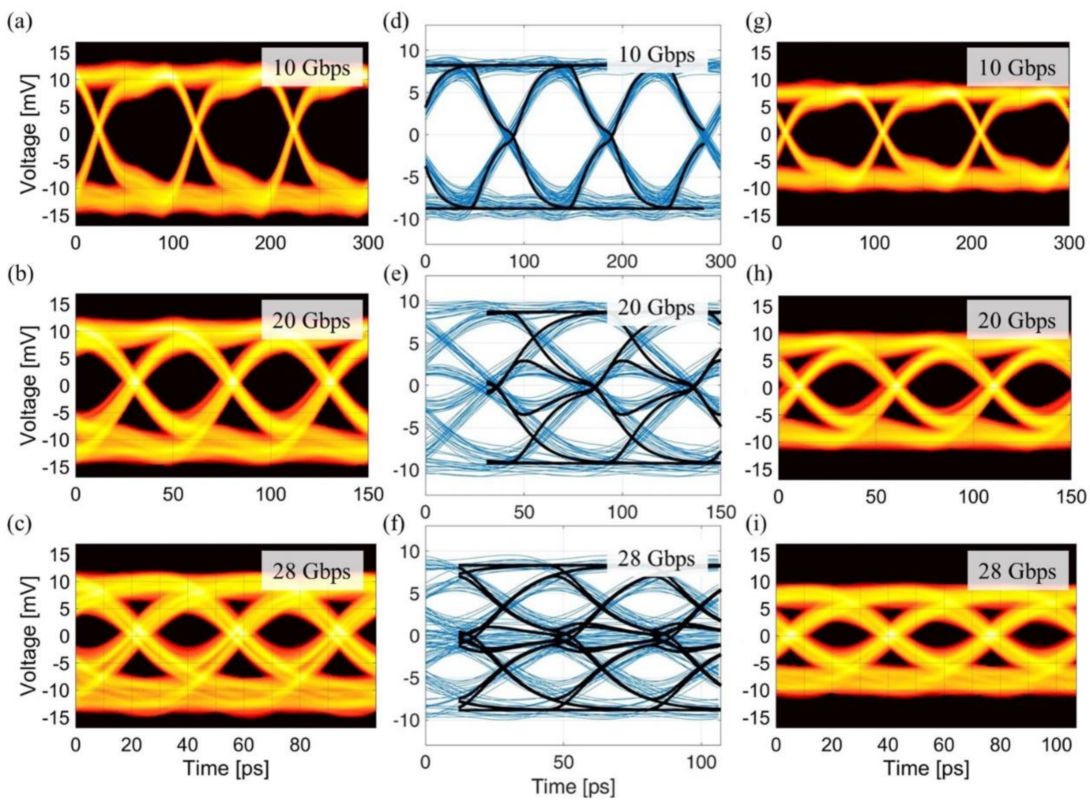

Fig. 2: Real-time reference (single-polarization) eye diagrams of C4 at (a) 10 Gb/s, (b) 20 Gb/s and (c) 28 Gb/s. Averaged polarization-diverse eye diagrams of C4 (in blue) with 40 ps group delay imbalancing at (d) 10 Gb/s, (e) 20 Gb/s and (f) 28 Gb/s overlaid by modeled traces (in black). Real-time polarization-diverse eye diagrams of C4 with balancing at (g) 10 Gb/s, (h) 20 Gb/s and (i) 28 Gb/s.

The first measurements done in single-polarization configuration serve as a baseline performance reference in the following. They are performed by injecting the modulated optical signal only through one of the GCs [Fig. 1(c), i)]. Eye diagrams of channel 4 (C4) are shown in Fig. 2 for (a) 10, (b) 20 and (c) 28 Gb/s. All other channels show similar performance.

In the second experiment, the modulated optical signal is split using a 50/50 splitter to supply equal power to the two input ports, corresponding to the worst case of equal power in the two polarization channels [Fig. 1(c), ii)]. The signals at the splitter outputs are each routed to one of the GCs at the Rx input. Additional off-chip ODLs inserted between splitter and input GCs allow to either balance or imbalance the two outside paths that are common to all channels. To exemplify the critical importance of group delay imbalancing, eye diagrams are shown for C4 in presence of 35-40 ps off-chip imbalancing that is externally applied in the test setup [Figs. 2(d)-2(f)]. As expected from modeling (black traces overlaying the experimentally recorded eye diagrams), the eye opening reduces fast with increasing transmission speed. While here it was generated off chip, it is on the same order as the imbalancing reported in [5] for a 4-channel system (44 ps for the worst case channel). To put this in context, for the system geometry reported in [5], the worst case group delay mismatch in a 10-channel system would scale up to 116 ps, which would lead to a large distortion even at very low speeds. For a complex routing constrained by further chip integration as shown in Fig. 1(b) (other subsystems are blanked out), the situation would be even further worsened if on-chip rebalancing was not implemented after each OADM on a channel-by-channel basis.

In the third set of measurements, further denoted as the final polarization-diverse measurements, the off-chip imbalancing (corresponding to ~1 cm of fiber) was canceled, reverting to the configuration expected with micro-optics packaging. Since all the on-chip optical paths are balanced, this is expected to remove the signal distortion seen in Figs. 2(d)-2(f). The resulting eye diagrams of C4 are shown in Figs. 2(g)-2(i). They indeed feature the same low level of signal distortion as in the single-polarization case. The extracted signal quality factors (Fig. 3) show good agreement with the single-polarization case for all the channels. The slight reduction in Q-factor in the final measurements is due to an overall attenuation of approx. 0.3 dB resulting from the reconfiguration of the test setup. Reduction of eye diagram openings at increased datarates is fully accounted for by the bandwidth of the OADMs and GePDs and does not constitute a limitation of the architecture reported here.

4. Conclusions

We demonstrate a 10-channel polarization diverse Rx using half the number of OADMs without the need to adaptively combine polarizations. At speeds above 20 Gb/s, balancing of the group delays in the OADM-GePD structures becomes critical. The good agreement between the signal quality factors of the single-polarization reference and of the polarization-diverse measurements for all channels validates the effectiveness of the on-chip ODL balancing scheme up to the maximum 28 Gb/s supported by the on-chip GePDs and OADMs utilized here.

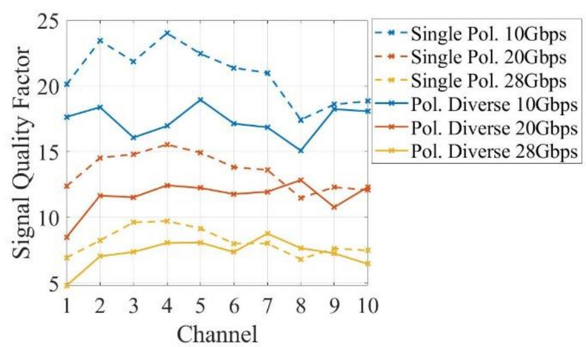

Fig. 3: Signal quality factors of all channels for the single-polarization and polarization-diverse cases at 10 Gb/s, 20 Gb/s and 28 Gb/s.

5. Acknowledgements

The authors would like to acknowledge funding from the German Federal Ministry of Research and Education (BMBF) for project EFFICIENTlight.

6. References

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