A 4×112Gbps Compact Polarization-Insensitive Silicon Photonic WDM Receiver

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Abstract: A 4×112Gbps polarization-insensitive silicon photonic WDM receiver with a two-dimensional grating coupler, cascaded dual-ring filters and bidirectional photodiodes is demonstrated. A polarization-dependent loss of 0.45dB is achieved.

OCIS codes: (130.0130) Integrated optics; (200.4650) Optical interconnects; (060.0060) Fiber optics and optical communications

1. Introduction

The escalating demands for data communication and computing in the realms of streaming media, mobile applications, and artificial intelligence (AI) have fostered an increasing requirement for hyper-scale data centers and high-performance computers (HPC). Co-packaged optics (CPO) has emerged as a crucial technology for optical interconnects due to its remarkable advantages, including high bandwidth density and low power consumption. Silicon photonics (SiPh) is an ideal solution for CPO, thanks to its compatibility with complementary metal-oxide-semiconductor (CMOS) technology and impressive integration capabilities [1]. Silicon waveguides are commonly designed to support TE polarization in a standard silicon-on-isolator (SOI) platform, and conventional wavelength demultiplexers exclusively operate at TE polarization. However, the polarization state of an optical signal becomes arbitrary at receiver inputs after traveling through fibers, leading to severe polarization-dependent losses (PDL) [2, 3]. Addressing these polarization challenges typically involves the use of a polarization splitter-rotator (PSR) to handle random polarization inputs. Nevertheless, this approach increases the number of photonic device components, doubling the required footprint, and introducing complexity into the receiver design [4, 5].

Here we demonstrate a 4×112Gbps ultra-compact polarization-insensitive four-channel wavelength division multiplexing (WDM) receiver using a two-dimensional (2D) grating coupler, cascaded dual-ring filters and bidirectional photodiodes for the first time to our knowledge. The 2D grating coupler efficiently couples and splits arbitrarily polarized light into two TE polarization states for transmission through silicon waveguides. The receiver successfully demultiplexes four wavelength signals using the cascaded dual-ring filters and subsequently directs them to respective bidirectional photodiodes for two TE polarization power summation. The proposed receiver is fabricated using a standard SiPh process through a multiple project wafer (MPW) run. Our measurements indicate that the PDL is less than 0.5dB, presenting an effective solution for low-power, ultra-compact, and polarization-insensitive WDM receivers.

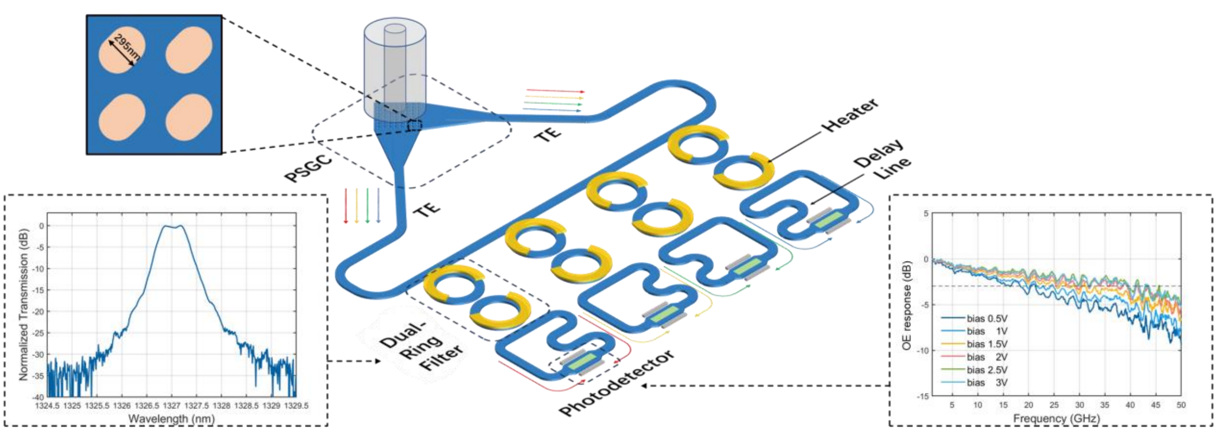

Fig. 1. Schematic of a polarization-insensitive WDM receiver with a 2D grating coupler, cascaded dual-ring filters, and bidirectional photodiodes. Insets are measured spectrum of a dual-ring filter at drop port and measured OE response of a bidirectional photodiode.

2. Receiver Design

The challenge of dealing with arbitrary incident light polarization in optical receivers is evident, whether employing edge couplers or 1D grating couplers. As shown in Fig. 1, we introduce a novel polarization-insensitive WDM receiver comprising a 2D grating coupler, cascaded dual-ring filters and bidirectional photodiodes. The 2D grating coupler effectively splits light of any polarization state, directing it into two perpendicular waveguides with both TE polarization states [6]. To optimize its performance, we employed a deep neural network (DNN) algorithm for the design of the 2D grating coupler [7]. As shown in the inset of Fig. 1 at the top left, each unit cell is a single-layer etched capsule-shaped silica dioxide pattern with a minimum width of 295nm. The 2D grating consists of 18×18 apodized capsules. Using width, length, and spacing as parameters, we forward simulated a dataset of one thousand samples and subjected them to thirty iterations of inverse design. As a result, the insertion loss was ultimately reduced to 4dB, while maintaining a PDL below 1dB within its 3dB bandwidth of 50nm. Microrings are commonly chosen for wavelength demultiplexing in DWDM systems, owing to their compact footprint and inherent wavelength filtering characteristics. Here dual-rings were implemented to effectively broaden the optical bandwidth with a flat filtering response. The dual-ring filter delivers an optical bandwidth of 85GHz, which is sufficient to support 200Gbps PAM4 signaling. Each individual microring was equipped with a titanium nitride (TiN) heater on top. This configuration enables independent tuning of the two heaters, facilitating precise adjustment of the central wavelength and filtering profile of the dual-ring filter. To simultaneously detect two TE polarization signals in bidirectional photodiodes, optical delay lines for the four channels were integrated into a single TE polarization optical path before reaching the bidirectional photodiodes. This ensures that both TE polarization optical signals accumulate an identical optical path length. The bidirectional photodiodes were designed with symmetric waveguide structures on two opposing sides for light coupling from silicon to germanium and then light absorption. This configuration efficiently converts optical signals from both directions into photocurrent for subsequent signal summation. These bidirectional photodiodes achieve an opto-electrical (OE) bandwidth of 40GHz at a reverse bias voltage of 2V. In comparison to their unidirectional counterparts with a responsivity of 0.7A/W, the bidirectional photodiodes achieve a responsivity of 0.9A/W, thanks to the more uniform distribution of the optical field.

3. Experimental Results

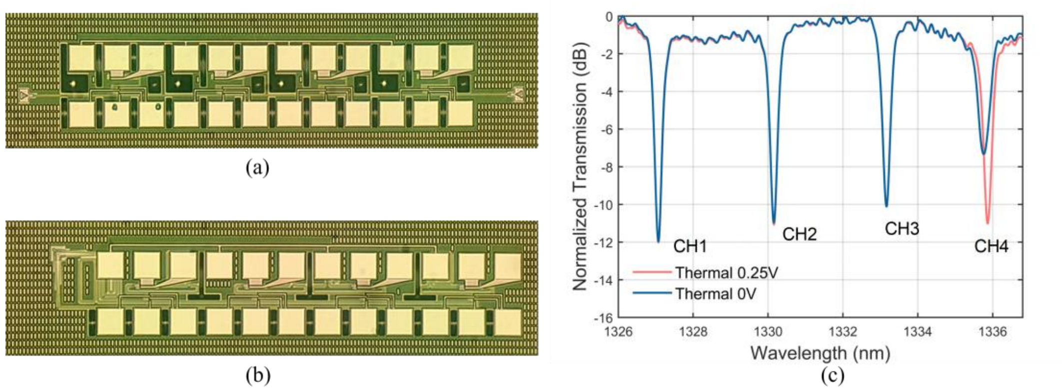

Fig. 2. Micrographs of (a) the polarization-sensitive 4-channel WDM receiver using 1D grating couplers and (b) the polarization-insensitive 4-channel WDM receiver using a 2D grating coupler; (c) Measured transmission spectrum of the four cascaded dual-ring filters.

The polarization-insensitive WDM receiver was fabricated on a standard 220nm SOI wafer through a 180nm MPW. To comprehensively assess photonic device components, a separate four-channel WDM receiver using 1D grating couplers, dual-ring filters, and conventional photodiodes was also manufactured. Micrographs of both receivers are depicted in Figures 2(a) and 2(b). The measurement of the transmission spectrum of the cascaded dual-ring filters is performed using the receiver structure with two 1D grating couplers as the optical input and output (Fig. 2(a)). As illustrated in Fig. 2(c), the nulls at 1327.1nm, 1330.2nm, 1333.2nm, and 1335.9nm corresponds to the central wavelengths of the four dual-ring filters, which have a channel spacing of ~500GHz. It is worth noting that the filter response can be finely adjusted by utilizing the integrated TiN heater on top. Fig. 2(c) provides a direct comparison between the filter responses before and after thermal tuning, demonstrating a significant improvement in the filter response for channel 4 upon activating the heater.

For conducting the eye diagram measurement, we employed a 92GS/s Keysight Arbitrary Waveform Generator (AWG) to generate a PRBS11 PAM4 data pattern. This data pattern was subsequently applied to a 30GHz $LiNbO_3$

Mach Zehnder modulator (MZM) via a 65GHz electrical amplifier. The modulated optical signal was then injected into a praseodymium-doped fiber amplifier (PDFA) and an optical filter, compensating for the signal losses introduced by the MZM and fiber connectors. Before reaching the polarization-insensitive WDM receiver, we utilized a polarization controller to establish an arbitrary polarization state. This step allowed us to assess the PDL characteristics of the receiver accurately. The photocurrents from the photodiodes were further amplified and recorded using a 65GHz Keysight sampling oscilloscope.

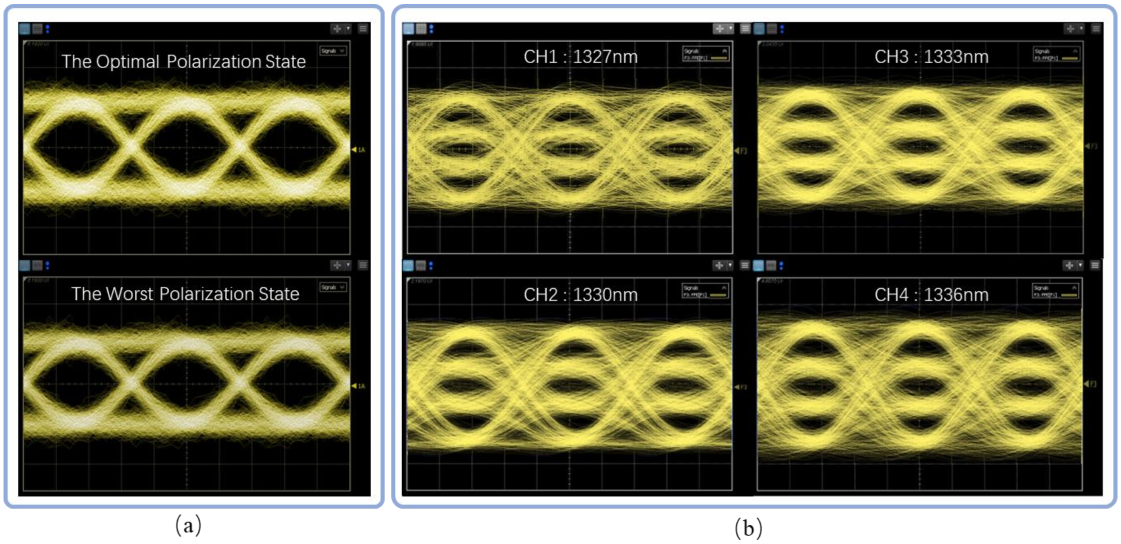

Fig. 3. (a) Measured 56Gbps NRZ eye diagrams with the optimal and the worst polarization states; (b) Measured eye diagrams of the four channels at data rates of 112Gbps PAM4 (the amplitude and time scales are the same).

To address signal distortion stemming from the bandwidth constraints of the optical transmitter in addition to the limitations introduced by the RF cables, a calibration procedure was executed using the calibration function provided by the Keysight AWG. Fig. 3(a) illustrates the optimal and the worst polarization states for a single channel at a data rate of 56Gbaud NRZ. The PDL of only 0.45dB was achieved based on the amplitude difference between the maximum and minimum eye heights. The optimum and worst polarization states were obtained by manipulating the polarization controller. Fig 3(b) shows the measured eye diagrams of the four channels at a date rate of 112Gbps PAM4. The eye heights of the four channels are approximately equal, indicating the consistency and uniformity of the device components in four channels.

4. Conclusion

We have successfully demonstrated a 4×112Gbps polarization-insensitive WDM receiver with a 2D grating coupler, cascaded dual-ring filters and bidirectional photodiodes, achieving a low PDL of only 0.45dB. Compared to traditional silicon photonic WDM receivers, the proposed receiver significantly reduces both the physical footprint and receiver complexity. The polarization-insensitive WDM receiver with a high bandwidth density offers a practical solution for CPO applications.

5. Acknowledgement

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