Polarization-Insensitive 40Gb/s 4-WDM Channels Receiver on SOI Platform

Hang Guan,[1,*] Alexander Gazman,[1] Yangjin Ma,[2,3] Yang Liu,[2] Qi Li,[1] Ran Ding,[2] Yunchu Li,[3] Xiaoliang Zhu,[1] Tom Baehr-Jones,[2] Michael Hochberg,[2] and Keren Bergman[1]

[1]Department of Electrical Engineering, Columbia University, New York, NY, USA
[2]Coriant Advanced Technology Group, New York, NY, USA
[3]Department of Electrical and Computer Engineering, University of Delaware, Newark, DE, USA
* hg2388@columbia.edu

Abstract - We demonstrate a polarization-insensitive silicon photonic receiver operating with 4 × 40 Gb/s wavelength channels at 6.5 nm spacing. The integrated receiver is shown to have <1.2 dB polarization dependent loss and no measured polarization-dependent wavelength shift.

I. INTRODUCTION

Silicon-on-insulator (SOI) integrated photonics is a very promising platform for next-generation optical interconnects and telecommunication systems [1]. Silicon waveguides provide large refractive index contrast enabling small device footprints and low power consumption. In addition, the platform is compatible with complementary metal-oxide-semiconductor infrastructures to allow co-integration with microelectronics [2]. However, waveguides with strong optical confinement usually exhibit large birefringence, which poses a challenge to many applications. Particularly for receivers, large polarization-dependent wavelength shifts (PDWSs) among demultiplexed wavelength channels can lead to undesirable signal distortions. To address this issue, a polarization compensation scheme may be used to align the responses for different polarizations when the channel spacing is large, such as coarse wavelength-division multiplexing (CWDM) [3-6]. However, fabrication errors in the waveguide widths may cause additional PDWS in this scheme. Alternatively, one can use a polarization transparent or polarization diversity scheme [7-8] that separates the two orthogonal polarizations, and then utilizes two separate demultiplexers to drop off individual wavelength channels. Here we demonstrate a polarization-insensitive CWDM receiver based on a novel bi-level Y-junction that could achieve ultra-low polarization-dependent loss (PDL) [9].

II. DESIGN AND FABRICATION

Fig. 1(a) shows the layout of the receiver chip. It includes a bi-level Y-junction, two 1×4 Mach-Zehnder Interferometer (MZI) based demultiplexers, six monitoring diodes, and four gain-peaking germanium photodetectors (PDs) [10]. The input optical signal is first coupled to the chip via an inverse nano-taper, and then is split by the bi-level Y-junction to two TE modes. Each of the TE modes then enters the MZI based demultiplexer to be separated according to CWDM channel number. Finally they are combined at the gain-peaking PDs from opposite directions. Since both TE and TM components of the input signal will be converted to TE mode by the bi-level Y-junction for subsequent processing, the PDWS is eliminated. Any PDL would accumulate from the difference in the optical paths prior to the signals arrival at the inputs of demultiplexers, i.e., insertion losses of fiber coupling. Fig. 1(b) is a microscope image of a fabricated chip. The chip has a footprint of 2.4 mm × 2.4 mm, and is fabricated an 8-inch SOI wafer, consisting a 220 nm thick silicon film on top of a 2 µm thick buried oxide layer (BOX) [11].

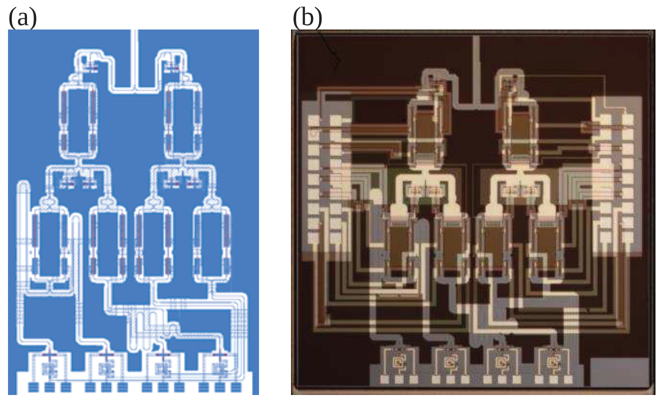

Figure 1. (a) Layout of the receiver chip without showing the metal wire and pads that are used to bias the MZIs. (b) Chip photo.

III. EXPERIMENT RESULTS

The experimental setup for performance evaluation is illustrated in Fig. 2. In our setup, a continuous-wave (CW) tunable laser (TL) signal was modulated with a pulsed-pattern generator (PPG) to generate a non-return-to-zero (NRZ) 2^{31}-1 pseudo-random bit sequence (PRBS) signal. The signal was then amplified by an erbium-doped fiber amplifier (EDFA). The amplified light further passed through a polarization controller (PC) and a polarization scrambler (PS) before edged-coupled onto the chip using tapered fiber. A digital multimeter (DMM) was used to record the photocurrent the gain-peaking PDs and a limiting amplifier (LA) was used to amplify the photocurrent. One output from the LA went to a BER tester (BERT), and the other output went to a digital communications analyzer (DCA) to record eye diagrams.

We first tuned the demultiplexers in the two branches so their pass-bands align correctly. After the alignment, the spectra of each channel should be relatively stable regardless of the state of polarization (SOP) of the input light. Fig.3 shows the measured spectra at the lowest-loss (maximum

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responsivity) and highest-loss (minimum responsivity) SOPs. The worst-case PDL is about 1.2 dB and the worst-case crosstalk level is about 9 dB.

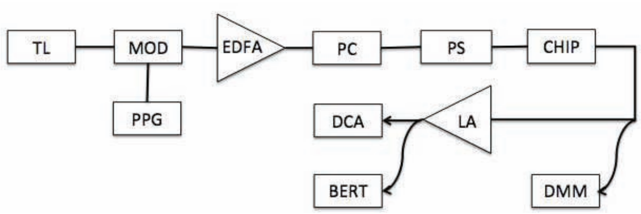

Figure 2. Experiment setup for performance evaluation.

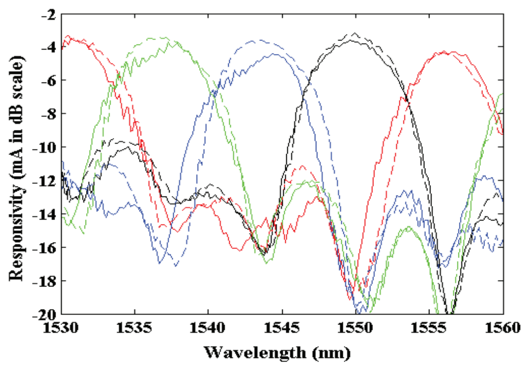

Figure 3. Spectra of four channels at (a) the lowest-loss polarization state (dashed line) (b) the highest-loss polarization state (solid line).

We next characterized the electrical eye diagram of the receiver chip at each channel with data rate of 40 Gbps. Fig. 4(a) shows the received electrical eye diagrams of all four channel when scrambling of the input polarization is turned off. Clean and open eyes are observed for all four channels. Fig. 4(b) shows the measured eye diagrams when scrambling of the input polarization is turned on.

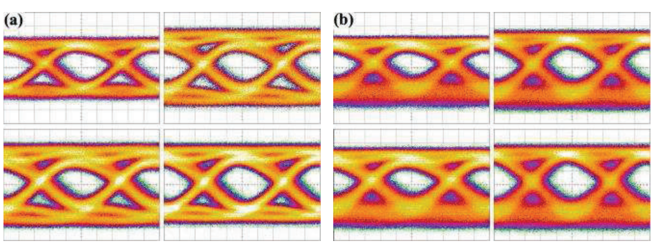

Figure 4. Received electrical eye from all channels at 40 Gbps (a) without (b) with srambled polarization (3 mV/div, 5 ps/div).

Lastly, we characterized the bit-error ratio (BER) as a function of coupling power to the chip at each channel with data rate of 10 Gbps due to the limitation on test equipment. Fig.5 shows the measured BER vs. power results of all four channels when turning on or off the scrambler. Error-free data transmission (BER < 10^{-12}) was achieved for all four channels when the polarization scrambler was off. A maximum BER power penalty of 0.9 dB was observed when opening the scrambler, measured at a BER of 10^{-9}.

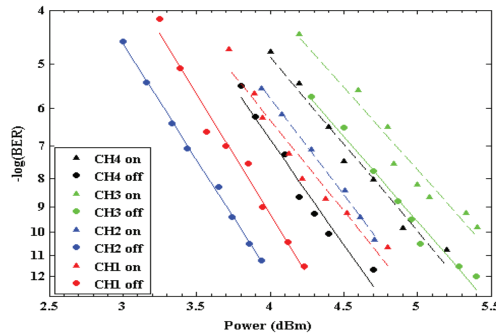

Figure 5. Experimental results of BER measurements at 10 Gbps. Dashed and solid lines represent when the scrambler is on and off, resepectively.

IV. Conclusions

We demonstrate a polarization-insensitive WDM receiver chip with 4 wavelength channels at 6.5 nm spacing. The receiver chip includes a bi-level Y-junction, four gain-peaking germanium PDs, and two MZI based multiplexers. The receiver chip is shown to have less than 1.2 dB PDL, and no PDWS. Operation at 40 Gbps with scrambled polarization is demonstrated for all four channels.

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References

[1] T. Baehr-Jones et al, “Myths and rumours of silicon photonics,” Nature Photon. **6**, 206–208 (2012).

[2] A. Narasimha et al, “An Ultra Low Power CMOS Photonics Technology Platform for H/S Optoelectronic Transceivers at less than $1 per Gbps,” OFC, OMV4 (2010).

[3] C. R. Doerr et al, “Eight-Channel SiO2/Si3 N4/Si/Ge CWDM Receiver,” IEEE Photon. Tech. Lett. **23**, 1201-1203 (2011).

[4] L. Chen et al, "Compact Integrated Polarization-Insensitive Two-Channel Receiver on Silicon," IEEE Photon. Tech. Lett. **23**, 1073-1075 (2011).

[5] L. Chen et al, “Polarization-Diversified DWDM Receiver on silicon free of polarization-dependent wavelength shift,” OFC, OWG3.7 (2012).

[6] D. Feng et al, “Terabit/s single chip WDM receiver on the SOI platform,” GFP, FA2 (2011).

[7] T. Barwicz et al, “Polarization Transparent Microphotonic Devices in the Strong Confinement Limit,” Nature Photon. **1**, 57–60 (2007).

[8] P. De Heyn et al, “Polarization-insensitive 5 × 20 Gb/s WDM Ge receiver using compact Si ring filters with collective thermal tuning,” OFC, Th4C.5 (2014).

[9] H. Guan et al, “High-efficiency low-crosstalk 1310-nm polarization splitter and rotator,” IEEE Photon. Technol. Lett. **26**, 925–928 (2014).

[10] A. Novack et al, "Germanium photodetector with 60 GHz bandwidth using inductive gain peaking," Opt. Express **21**, 28387-28393 (2013).

[11] A. Novack et al “A 30 GHz silicon photonic platform,” Proc. SPIE **8781**, 878107 (2013).