Silicon Microring Modulator with Polarization Insensitivity

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Abstract *We propose a polarization-insensitive silicon IQ microring modulator. We show theoretically and experimentally that the symmetric circular paths from the polarization splitter-rotator achieve polarization independence. We demonstrate our modulator is effective for single sideband modulation.*

Introduction

Silicon photonics (SiP) will play an important role in optical communication due to its low cost, high compactness, low power consumption, and compatibility with complementary metal-oxide-semiconductor (CMOS) [1]. It has gained increasing implementations in various optical communication subsystems, for example, SiP transmitter [2] and SiP integrated coherent receiver [3].

Silicon photonic technology is polarization sensitive due to the mode confinement, requiring special architectures to produce polarization diversity or polarization insensitivity in SiP. At the receiver side, researchers have demonstrated all-silicon polarization-insensitive receivers based on polarization splitter-rotator (PSR), which splits the TE and TM polarization modes of the input laser, and treats both modes in a loop-back structure [4]. Polarization-insensitive all-silicon transmitters are also desirable, not only to reduce cost by eliminating polarization-maintaining components, but also to enable modulation of distributed carrier with variable polarization. The Fabulous project studied reflective polarization-insensitive SiP modulators in a passive optical network [5,6]. However, the proposed polarization-insensitive modulator based on Mach Zehnder modulator (MZM) is inherently limited in the electrical bandwidth, owing to its travelling-wave electrodes.

In this paper, we propose a polarization-insensitive SiP modulator based on microring modulators. The proposed modulator uses lumped electrodes thus avoiding the bandwidth limitation in [5,6]. We also construct an I/Q configuration to generate single side-band (SSB) modulation, as an efficiently way to improve the transmission length.

Principle and Modulator design

The proposed modulator is based on the principle depicted in Fig. 1, in which (a) and (b) depict the different process of two polarization stations within the same structure. The input laser is degenerated into two polarizations with regard to the SiP plane, that are, transverse electric (TE) and transverse magnetic (TM) modes. The two polarization modes are coupled into the chip by an edge coupler, and passes a polarization splitter-rotator (PSR). For the TE mode in the clockwise direction as depicted in Fig. 1(a), it passes the PSR without polarization rotation, propagates to the two branches of MRM to be modulated. Upon returning to the PSR, it is rotated to TM mode and output. The TM mode propagates in the counter-clockwise direction as depicted in Fig. 1(b). It is converted to TE mode at injection into the PSR, gets modulated, and returns to the PSR. The PSR does not change its polarization at the output, so it outputs from the edge coupler

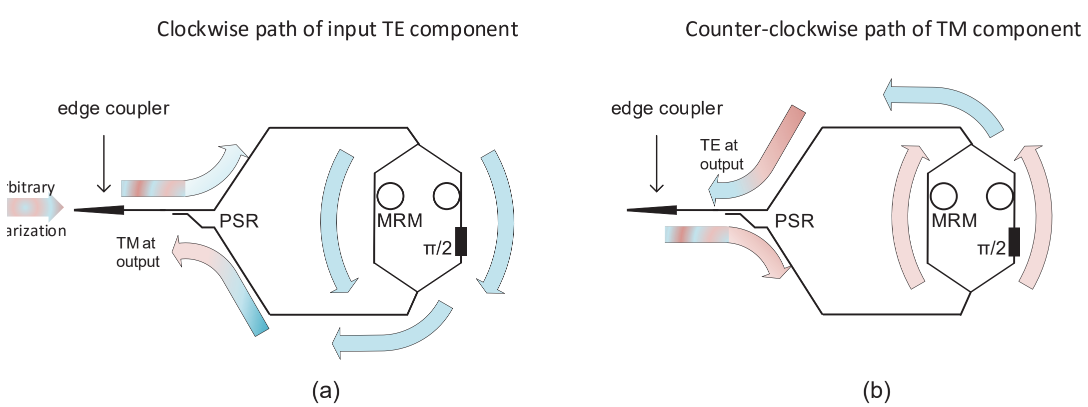

Fig. 1. Polarization-insensitive modulator, (a) TE mode input, clockwise; (b) TM mode input, counter-clockwise.

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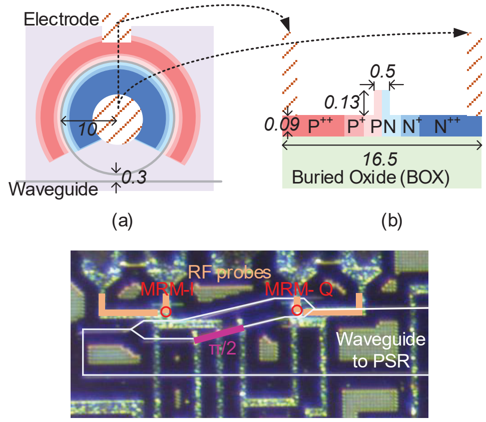
in TE mode.



(c)

Fig. 2. (a) Layout top view; (b) layout cross-section view; (c) fabricated chip photo

The two MRM have identical designs; fabrication errors could be compensated by thermal heating. One branch has a heated waveguide as a phase shifter to generates π/2 phase shift, for I/Q modulation. The two MRM are modulated by a Hilbert pair for SSB modulation [7].

The proposed silicon microring modulator is designed with the layout depicted in top view in Fig. 2(a) and intersectional view in Fig. 2 (b). The design is fabricated at AMF Singapore with a 10 µm radius and a 300 nm gap between the straight and ring waveguide. A picture of the chip is shown in Fig. 2(c). The PSR, not included in the photo, has the design suggested in [8].

Experimental setup

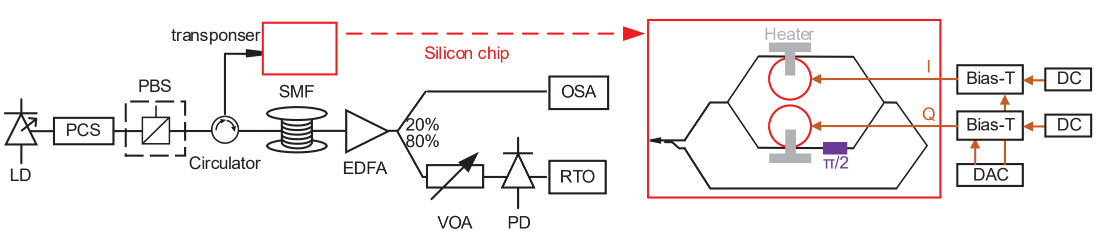
We use the experimental setup in Fig. 3 to test our chip. In no point do we use a polarization maintaining fiber. A laser diode (Cobrite DX1, 1550 nm) generates a laser, whose polarization state is controlled with an electrical driven polarization controller (Keysight N7786B). We emulate the polarization sensitive situation a polarization beam splitter, allowing only TE to enter the chip. When we test polarization-insensitive modulation we set the polarization state with a polarization controller. A circulator directs the laser into and out of the chip, followed by a reel of single mode fiber (SMF) for transmission. After power amplification with an erbium-doped fiber amplifier, 20% of the optical power is fed into a high resolution optical spectrum analyzer (HR-OSA, APEX Technologies AP2043B, spectral resolution of 100 MHz) to monitor the optical signal. The residual 80% is power controlled with a variable optical attenuator (VOA, Keysight N7761A), and received with a photo receiver with trans-impedance amplifier (Agilent 11982A, 3-dB bandwidth at 11 GHz). The converted electrical signal is captured with a real-time oscilloscope (Agilent Infinium 90000 X-series, 80 GSa/s, 3-dB bandwidth at 33 GHz) for offline processing.

The microring modulators drive configuration is shown in Fig. 3(b). Two direct current sources (DC) reverse-bias the MRM at -2 V; they are combined with the electrical modulating signals generated by a digital-to-analog-converter (DAC, Fujitsu Leia, 64 GSa/s, 3-dB bandwidth at 13 GHz) and amplified to 5 Vpp via two bias-Ts. On-chip heaters control and align the MRM resonances.

We use orthogonal frequency division multiplexing (OFDM) with quadrature phase shift keying (QPSK). A fast Fourier transform size of 1024 is used with 10 samples as cyclic prefix; subcarriers between 1 and 13 GHz are used for modulation. The 1-GHz baseband provides a guard band for single-to-signal beating interference (SSBI); beyond 13 GHz our DAC has a deteriorated response. Pre-distortion is applied for an equalized signal-to-noise ratio over the signal bandwidth. The bit-error rate (BER) is evaluated by error counting over ten OFDM frames, each of which consist 10 symbols for channel estimation, and 230 payload symbols. With all overhead counted, the final net bit rate is 22.8 Gbps.

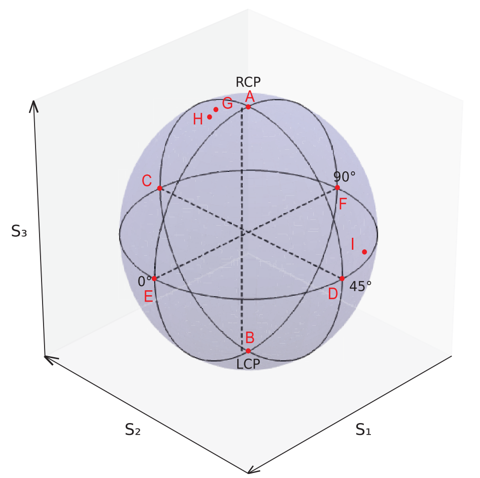
Experimental results

The polarization insensitivity of the fabricated modulator is examine first. We then compare polarization diverse case (PBS disconnected) and the polarization sensitive situation (PBS present). With the help of the polarization controller, we set

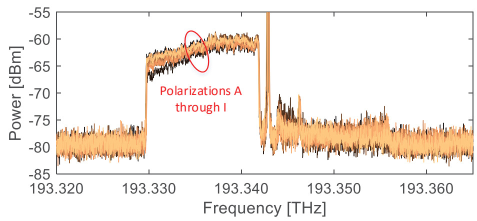


(a) (b)

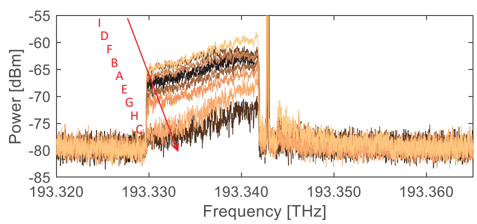
Fig. 3. Experimental setup. Abbreviations explained in the text.



(a)



(b)



(c)

Fig. 4. (a) Points examined on Poincaré sphere; modulation spectra (b) with polarization diversity; (c) without polarization diversity

the laser polarization to several polarized states as depicted in Fig. 4(a). Points A and B are circularly polarized, C through F are linear polarized, and G through I are elliptical polarizations. We trace the modulated spectra in Fig. 4(b) for polarization diversity and (c) for the polarization sensitive case; A to I varies from darkest to lightest.

In Fig. 4(b) the modulated optical spectra are almost identical, indicating the good modulation at all polarizations. In Fig. 4(c), the modulation is highly sensitive to polarization, with disparate spectra. For G, H and C, the modulations are greatly diminished. As expected, the modulation depth is very much affected by the S_2 Stokes parameter, a linear polarization dimension.

We conduct another series of experiments to compare the modulator performance for SSB and DSB signals, in back-to-back (B2B), 20-km SMF, and 40-km SMF. The experimental bit error rate (BER) results are given in Fig. 5. For DSB, to reach the hard-decision forward error correction threshold (HD-FEC) of 7% overhead at a BER at 3.8×10^{-3}, a received optical received power (RP) of -8.3 dBm is required. With a 20-km SMF transmission, the required RP increases to -6.5 dBm. If the DSB optical signal is transmitted over a reel of 40-km SMF, we cannot reach the HD-FEC threshold. When SSB modulation is adopted, the BER reaches HD-FEC threshold at -9.5 dBm. Transmissions of 20 km and 40 km incur RP penalties of only 0.5 and 1.5 dB, respectively. These experiments have shown good modulator performance for SSB, enabling stronger resistance to chromatic dispersion induced power fading.

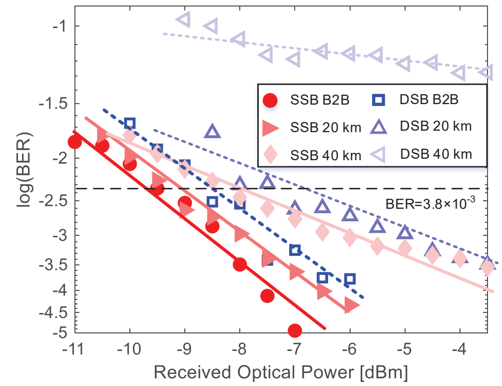


Fig. 5. Experimental SSB-OFDM transmission results.

Conclusion

We have proposed a polarization-insensitive modulator based on silicon microring modulators (MRM). The silicon chip consists of a polarization splitter-rotator (PSR), two MRM, and a phase shifter. Because of the I/Q configuration, the proposed modulator can generate single side-band (SSB) modulation which show strong robustness to chromatic dispersion induced power fading. The MRM use lumped electrodes, thus outperforming Mach-Zehnder modulator (MZM) based on travelling-wave electrodes when polarization-insensitive configuration is used [5]. We design and fabricated a chip, which we experimentally tested to validate its polarization insensitivity and compatibility with SSB modulation. This modulator could play an important role in carrier-distributed networks requiring polarization insensitivity, e.g., passive optical networks [6].

References

[1] P. Dong, "Silicon photonic integrated circuits for wavelength-division multiplexing applications," *IEEE J. Sel. Top. Quantum Electron.,* vol. 22, no. 6, pp. 370–8, Jun. 2016.

[2] C. H. Chen *et al.*, "A comb laser-driven DWDM silicon photonic transmitter based on microring modulators," *Optics Express*, vol. 23, no. 16, pp. 21541-8, Aug. 2015.

[3] C. R. Doerr *et al.*, "Monolithic silicon coherent receiver," in *Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference (OFC/NFOEC'09)*, Mar. 2009, pp. 1-3.

[4] A. H. Park et al., "Ring resonator based polarization diversity WDM receiver," *Optics Express*, vol. 27, no. 5, pp. 6147–57, Mar. 2019.

[5] S. Menezo *et al.*, "Reflective silicon Mach Zehnder modulator with Faraday rotator mirror effect for self-coherent transmission," in *Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference* (OFC/NFOEC'13), Mar. 2013, pp. 1–3.

[6] S. Menezo *et al.*, "Transmitter made up of a silicon photonic IC and its flip-chipped CMOS IC driver targeting implementation in FDMA-PON," *Journal of Lightwave Technology*, vol. 34, no. 10, pp. 2391-2397, May 2016.

[7] M. Lyu *et al.*, "Single-Sideband OFDM transmission via a silicon microring IQ modulator," *IEEE Photonics Technology Letters*, vol. 31, no. 2, pp. 145-148, Dec. 2018.

[8] W. D. Sacher, T. Barwicz, and J. K. Poon, "Silicon-on-insulator polarization splitter-rotator based on TM0-TE1 mode conversion in a bi-level taper," in *CLEO: Science and Innovations*, May 2013, pp. CTu3F–3.