C- and L-band low polarization sensitive nanosecond 1×2 electro-optic MZI switch on 3-µm thick silicon platform

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Abstract: We fabricated and assessed a wideband (C-/L- band) nanosecond 1×2 electro-optic switch in 3-µm thick silicon. Results show 2.5dB lowest insertion loss, 16dB averaged extinction ration, 2.5dB polarization dependent loss and 6-ns switching time.

1. Introduction

Wideband optical transmission is a realistic and efficient solution to increase the existing fiber capacity up to tenfold of C-band transmission by exploring the O-band to L-band region of single mode fiber (ITU-T G.652.D) [1]. To efficiently manage the heterogeneous and dynamic data traffic of wideband optical network (WON) without electro-optical conversion, wavelength selective switches (WSSs) are required to have low polarization sensitivity, fast switching, high contrast ratio, low cost and high stability. Commercial wideband WSSs are based on free-space optics and micro-electro-mechanical system technology, but they have bulky size and high price for mass production due to complex assembly. The other attractive option, the photonic integrated WSS, usually consists of demultiplexer/multiplexer for wavelength separation/combining and the switching component for pass/block the wavelength channels. Many different types of photonic switching components are realized on different photonic platforms: silica 1×2 Mach Zehnder Interferometer (MZI) switch with thermo-optic phase shifter is used for 1×2 WSS in [2], but it has high polarization sensitivity, slow switching speed and large chip size; polymer 1×2 thermo-optic digital optical switch using total internal reflection effect provides low polarization/wavelength sensitivity, but several milliseconds switching time [3]. Polarization diversity scheme using two MZI switches (one for TE and the other for TM) are employed in [4] to achieve polarization insensitive (PI) operation on Lithium Niobate platform, but at the cost of components (polarization beam splitter and combiner) and high drive voltage. Silicon MZI electro-optic switch using 220-nm thick waveguide has compact size and nanosecond switching time, but it works only for TE polarization [5]. Thick 3-µm silicon platform can provide wideband and PI operation due to the waveguide's low polarization dependency (down-to-zero birefringence) and ultra-wide band single-mode propagation [6]. Therefore, investigation and fabrication of 1×2 MZI switch using nanosecond electro-optic phase shifter based on wideband PI 3-µm silicon waveguide is an attractive proposition as it can be co-integrated with PI AWGs as demultiplexer/multiplexer [7] to realize a photonic integrated PI WSS as the one shown in Fig. 1 (a).

In this paper, we fabricate and demonstrate, for the first time to the best of our knowledge, a wideband, nanosecond switching, and low polarization sensitive 1×2 electro-optic MZI switch on 3-µm silicon platform. The experimental results show wide wavelength range (1520 nm to 1625 nm) operation with insertion losses ranging from 2.5 dB to 5.0 dB for TE (from 2.7 dB to 5.1 dB for TM), polarization dependent loss (PDL) < 2.5 dB, an average extinction ratio of 16 dB, and 6 ns and 8 ns switching time for rising and falling, respectively. It requires 0.34V RF switching voltage that results in 50 mW power consumption. Transmission experiments have been performed and results show error free operation with < 0.1 dB power penalty at 10^-9 BER for 10 Gbit/s optical signals and < 0.9 dB for 50 Gbit/s.

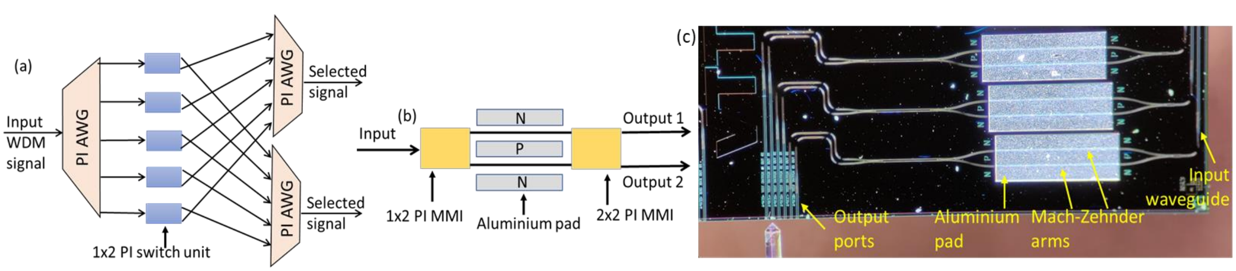

Fig. 1: (a) Configuration of 1×2 wideband PI WSS; (b) Schematic of 1×2 electro-optic switch; (c) Microscope image of fabricated chip.

2. Design and fabrication of the 1×2 electro-optic switch

The configuration schematic of the 1×2 electro-optic switch is shown in Fig. 1 (b), which is based on a balanced MZI switch with a 1×2 multi-mode interferometer (MMI) as the input power splitter, two PIN phase shifters and a 2×2 MMI as the output power coupler. The device is designed and fabricated on the 3-µm silicon on insulator (SOI) platform which provides low optical losses (~ 0.1 dB/cm) and dense integration with µm-scale bends. The wideband PI 1×2 MMI is employed as a 50:50 power splitter, and its output ports are connected to 1 mm long PIN phase shifters that use the 3 µm × 3 µm strip waveguide (with zero birefringence) for achieving PI phase tuning. The silicon pedestal is implanted with p-type on one side and n-type on the other side of the phase shifter. Aluminum pads (~ 100 µm × 1000 µm) contacting the implanted regions are used for driving the voltage. The phase tuning is based on free-carrier injection, and when forward biased (only one arm is driven during switching), carriers are injected into the waveguide that affect the mode's refractive index within the silicon waveguide. A PI 2×2 MMI is connected to two phase shifters to complete the MZI layout. By adjusting the biasing voltage and the phase difference between two MZI arms, optical power can be switched between the two output ports within nanoseconds, which benefits from the highly efficient electro-optic effect. Also, an adiabatic rib-strip converter is placed in front of the strip waveguide to connect with the single-mode rib waveguide for avoiding higher mode excitation.

The fabricated chip is based on the VTT 3-µm enhanced SOI (3-µm top silicon on 3-µm buried oxide) wafers, and the chip's microscope image is shown in Fig. 1(c). The waveguide fabrication technology uses an i-line stepper on the 150-mm wafer, and a double-step Si etching process with SiO_2 hard mask is employed to form the rib/strip waveguide structure. To smoothen the etched Si surfaces, wet thermal oxide growth and removal with buffered oxide etch (BOE) is implemented. Contacts are made by sputtering aluminium. Single layer silicon nitride is deposited on input/output waveguide facets as antireflection coating to reduce the coupling loss between the chip and fibers. Finally, a 500-nm cladding SiO_2 is deposited on the chip for protection.

3. Experimental results

Fig. 2 (a) illustrates the experimental set-up employed to assess the operation and performance of the 1×2 electro-optic switch with multiband optical signals at different NRZ-OOK data rates. Firstly, the static characterization of the wideband switching on/off spectra at two output ports for the TE and TM polarizations were characterized. A broadband tunable laser source (from S- to L- band) was employed and a polarization controller was used to set and measure the PDL. DC driving voltage was provided through the aluminium pads (one for negative and the other for positive) via probes to the electro-optic switch, and the DC forward-bias voltage was applied on one arm of the switch. Fig. 2 (b) shows the measured switching transmission characteristics for 1550 nm's TE/TM modes as a function of applied bias voltage. In the switching-off state, a low insertion loss at output 1 of 2.5 dB for TE (3.4 dB for TM) with a PDL< 0.9 dB and the extinction ratio between output 1 and 2 of 15.5 dB for TE (15.2 dB for TM) were measured. For the switching-on state, the insertion loss of output 2 was around 4.5 dB for TE (4.8 dB for TM), the PDL was < 1.2 dB, and the extinction ratio was around 14.6 dB for TE (15.4 dB for TM). The switching-on requires 0.34 V (with 0.86 V DC bias) which results in a power consumption of about 50 mW. To verify the wideband operation of the device, the on/off switching performance were record from 1520 nm to 1625 nm for TE/TM modes. The transmission of the two output ports is shown in Fig. 2 (c). The insertion losses of output 1 (no

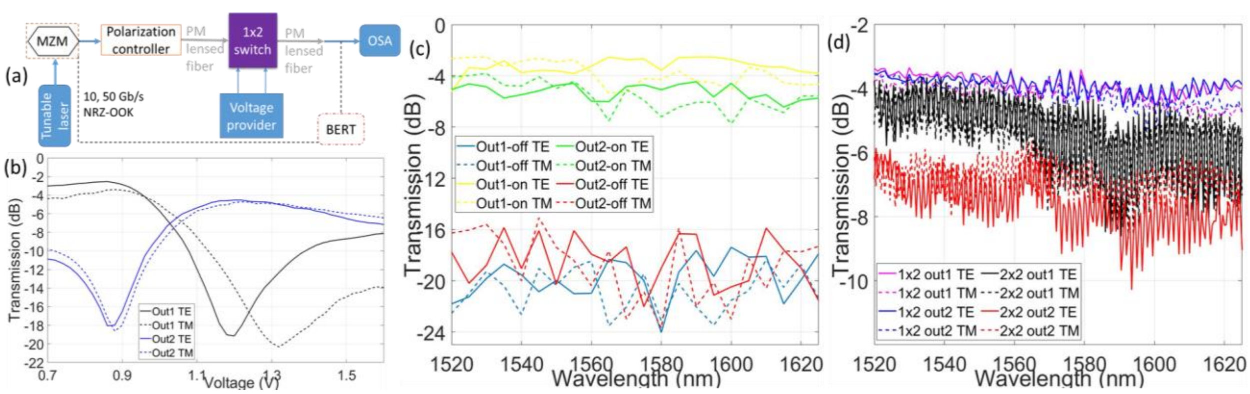

Fig. 2: (a) Experiment set-up; (b) Transmission versus voltage curves at 1550 nm; (c) Transmission for switching on/off from 1520 nm to 1625 nm at TE/TM; (d) Transmission of 1×2 MMI and 2×2 MMI at TE/TM.

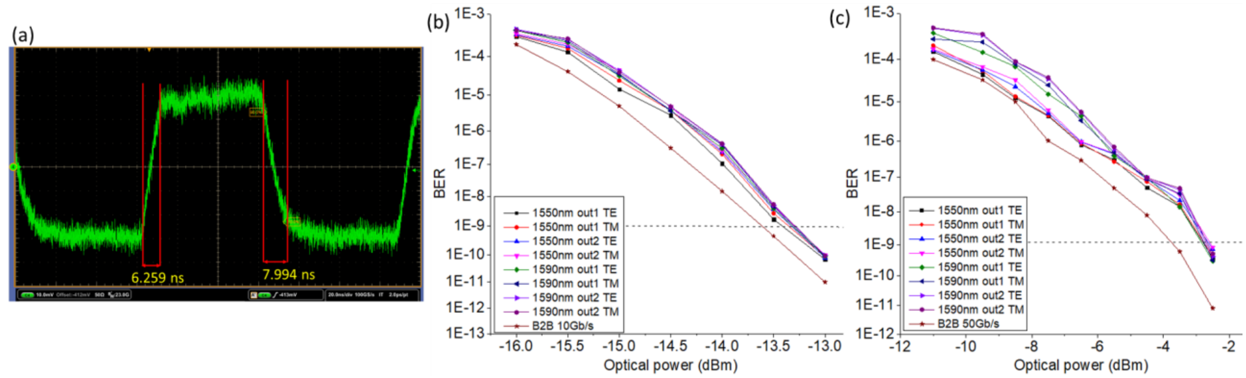

Fig. 3: (a) Switching rising/falling time; (b) BER curves at 10 Gbit/s; (c) BER curves at 50 Gbit/s.

switching) range from 2.5 dB to 5.0 dB for TE and from 2.7 dB to 5.1 dB for TM. The losses are from 4.3 dB to 6.3 dB for TE (from 4 dB to 7.4 dB for TM) at output 2 (switching on). The switching on/off extinction ratios of output 1/2 range from 12.5 dB to 19.5 dB for TE (from 12.0 dB to 18.5 dB for TM), from 12.3 dB to 19.4 dB at TE (12.2 dB to 19.4 dB at TM), respectively. To analyze the variations of the extinction ratios at different wavelengths and polarizations, the transmission performance of the individual 1×2 MMI and 2×2 MMI test structures were measured and reported in Fig. 2 (d). The results confirm that the 1×2 MMI has uniform performance with ~ 50:50 power splitter ratio for both TE and TM in the wideband wavelength range. However, the 2×2 MMI coupler has not equal splitting ratio between the two outputs with large variation at different polarizations and wavelengths. This explains the limited extinction ratios measured in Fig. 2 (c). The performance of the 1×2 switch can be improved by optimizing the fabrication of the 2×2 MMI coupler. The switching rising and falling time (90% to 10%) is also recorded by the oscilloscope and shown in Fig. 3 (a). The rising time is ~ 6 ns and the falling time is ~ 8 ns.

To quantify the switch's performance with data transmission, BER measurements of multiband modulated signals at different data rates have been performed. Firstly, BER curves were measured for 10 Gbit/s NRZ-OOK signal (PRBS 2^31-1). The back-to-back (B2B) BER curve is reported as reference. Results show error free operation with < 0.1 dB power penalty at 10^-9 BER for switched on/off 10 Gbit/s signal at 1550 nm and 1590 nm to output 1 and 2 (see Fig. 3 (b)). For 50 Gbit/s data, the power penalty at 10^-9 BER is < 0.9 dB (see Fig.3 (c)).

4. Conclusion

We experimentally demonstrated a 1×2 electro-optic MZI switch with wideband nanosecond operation and low power consumption. The experimental results show that from 1520 nm to 1625 nm the device has the lowest insertion losses of 2.5 dB for TE and 2.7 dB for TM, a PDL of 2.5 dB, 16 dB average extinction ratio, 6 ns switching rising time and 8 ns falling time, 0.34 V RF driving voltage, and 50 mW power consumption. The power penalty with 10 Gbit/s and 50 Gbit/s data at 10^-9 BER is <0.1 dB and < 0.9 dB, respectively.

5. Acknowledge

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6. References

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