A 2 × 2 Electro-Optical Switch in a Thin-Film Lithium Niobate Foundry Process

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ABSTRACT

High-speed, small footprint photonic switches are crucial for data centers, telecommunications, and 5G due to handle increasing data traffic through a large number of input and output nodes. Photonic Integrated Circuit (PIC) technology, thanks to its miniaturization and performance efficiency, promises a scalable solution for the next generation of optical switches and interconnects. Among various PIC materials, thin film lithium niobate (TFLN) retains superior performance in terms of light modulation speed and power consumption. This places TFLN PICs as a versatile platform to deliver efficient solutions for the interconnects. Despite this, TFLN fabrication is less mature than silicon photonics, and foundry processes are necessary to get mature to guarantee a reliable performance and access to the manufacturing facility. Showcasing capabilities of our foundry process, we present a 2×2 Mach-Zehnder interferometer TFLN switch, operating at 1550 nm, with an average 10-90% rise time of 0.29 µs and an average 90-10% fall time of 0.28 µs.

Keywords: Photonic integrated circuits, thin-film lithium niobate, electro-optical switch, foundry

1. INTRODUCTION

Optical switches are devices that enable to selectively switch an optical signal from one channel to another. High-speed, small footprint photonic switches are in high demand due to the exponential growth of data traffic and bandwidth requirements. They play a crucial role in data centers, telecommunications networks, and 5G infrastructure[1]. Electro-optic (EO) switching, as compared to thermo-optic, acousto-optic, and magneto-optic, is usually faster and less power hungry. Silicon photonics EO switches, thanks to the maturity of this platform, are now widely employed[2]. Due to the absence of intrinsic EO properties in silicon, however, they are based on free-carrier dispersion effect, which can introduce large optical absorption loss, thus requiring high power consumption[3]. Thin-film lithium niobate (TFLN) switches, leveraging the EO properties of lithium niobate, have emerged as promising candidates for replacing silicon ones[4,5]. As the demand for efficient, scalable optical switches grows, TFLN technology holds significant promise for widespread adoption in telecommunications and data centers[6,7]. These TFLN switches offer lower power consumption and higher efficiency, making them ideal for next-generation optical networks. However, the fabrication technology for TFLN photonic integrated circuits has not yet reached the maturity level of silicon photonics. There is thus an urgent need to develop open access foundries that can offer cost-effective production and scalability, ensuring the technology meets the growing demands of modern communication networks.

Here we report a 2×2 Mach-Zender interferometer TFLN optical switch fabricated in our open-access foundry process using standard Process Design Kit (PDK) components and following design rules. The switch operates at 1550 nm wavelength and exhibits an average 10% - 90% rise time of 0.29 µs and an average 90% - 10% fall time of 0.28 µs. These results highlight the capability of our foundry to provide large-scale fast TFLN optical switches to address the growing demand.

2. DESIGN AND FABRICATION

Figure 1(a) shows an optical microscope image of the device, whereas a schematic drawing is shown in Figure 1(b). Light from either Input Port 1 or Input Port 2 is split into two arms of a Mach-Zender interferometer by a 33 µm long directional coupler, designed for 50/50 power splitting. A 7 mm long phase shifter is placed on one arm of the interferometer. The signal electrode is 14.6 µm, and the gap between the signal and ground electrode is of 4.5 µm. These dimensions were chosen to ensure 50 Ω impedance. The bends in the right part of the device are used to ensure that the two arms have equal length. Light from the two arms is then recombined by another 50/50 directional coupler and sent to Output port 1 and Output port 2.

The device is fabricated in a 150 mm wafer scale standard foundry process at CSEM[8]. Our fabrication technology is based on commercially available TFLN wafers which consist of a stack with 600 nm thick mono-crystal x-cut $LiNbO_3$ layer on top of a 4.7 µm buried thermal oxide (BOX) layer. Waveguides (800 nm wide) are patterned by etching 400 nm of $LiNbO_3$ by an optimized ion milling technology. The final chip release process yields to smooth facets which are crucial for achieving efficient light coupling at both the input and output interfaces of the device.

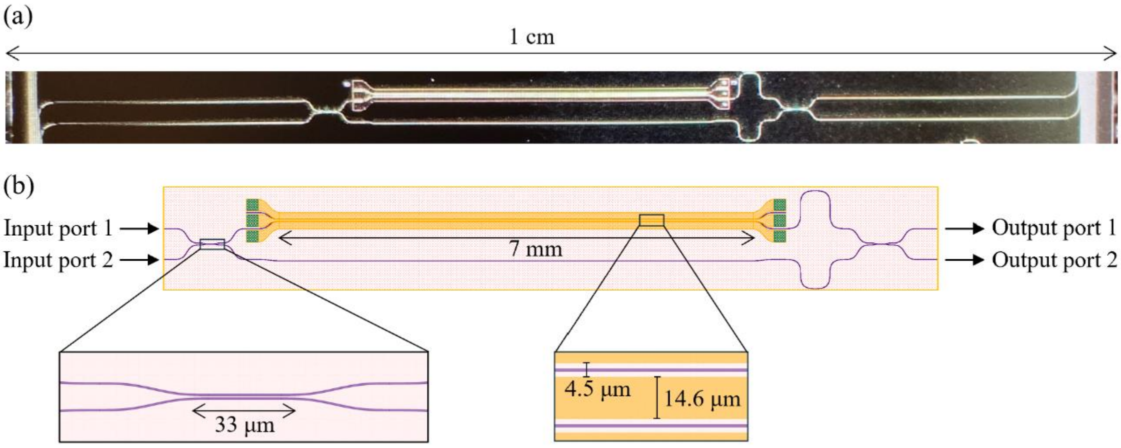

Figure 1. (a) Optical microscope image and (b) schematics of the 2x2 Mach-Zender interferometer switch.

3. RESULTS

Figure 2 shows a schematic of the setup used for the characterization of the switch. Light from a mode hop free laser emitting at 1550 nm (Toptica, CTL 1550) is sent to the chip through a polarization controller, which selects TE polarization, and a lensed fiber. A rectangular electrical signal with a frequency of 5 kHz is directly applied to the electrodes, and the optical output power is recorded by an InGaAs photodetector (Thorlabs, PDA20CS2), whose response is acquired using a 500 MHz bandwidth oscilloscope (Keysight, MXR054A).

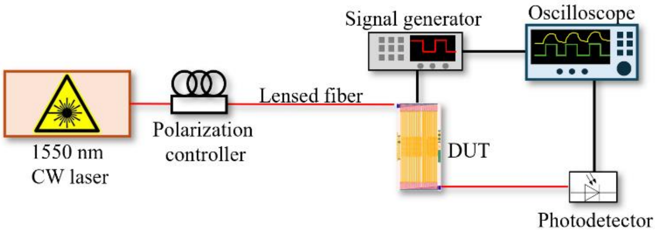

Figure 2. Sketch of the experimental setup.

The measured response of the switch for different input/output ports combinations is shown if Figure 3(a). Figure 3(b) shows close-up views in correspondence of on-off and off-on switches. For all the input/output ports combinations the response time is between 0.25 and 0.3 µs, with an average 10-90% rise time is 0.29 µs and an average 90-10% fall time of 0.28 µs. The extinction ratio of around 10 dB is likely limited by the not perfect 50/50 split in the directional couplers. The response was measured for different peak-to-peak voltages V_{pp} (ranging from 2 to 10 V) of the driving electrical signal, always giving a response time around 0.3 µs. Figure 3 shows only the response for V_{pp}= 8.5 V, which was chosen because it gives the best signal to noise ratio without signal distortions, despite V_{pp} being close the V_{π} of the phase modulator. It is important to note that we used a photodetector with a bandwidth of ~1 MHz. According to the formula BW= $0.35/t_{10\text{-}90\%}$, where BW is the bandwidth and $t_{10\text{-}90\%}$ the 10 to 90% response time of the photodetector, the latter would be ~0.35 µs. The measured response time of the switch is thus possibly limited by the one of the photodetector.

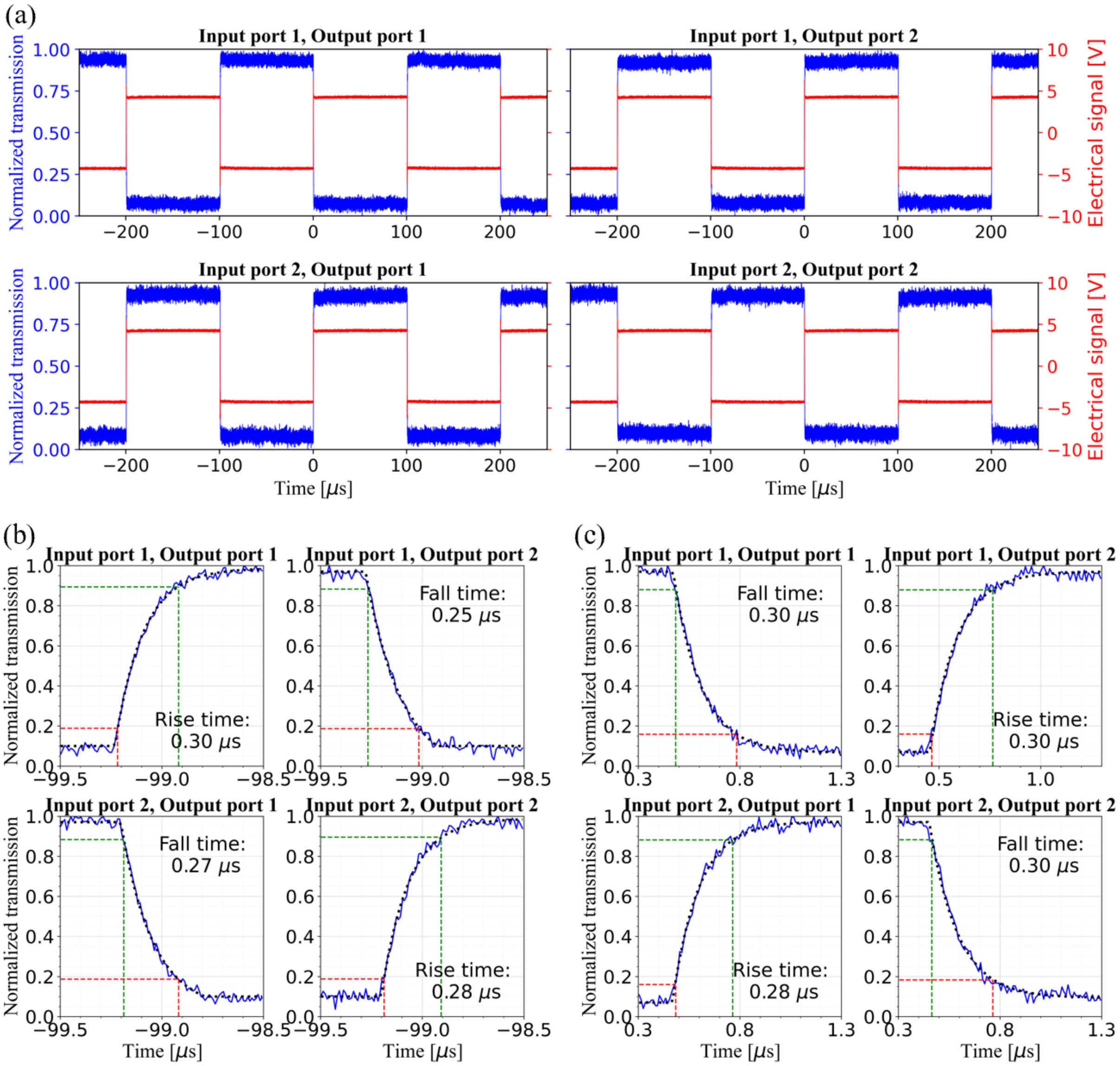

Figure 3. (a) Measured response of the switch to a square function. (b) Close-up view in correspondence of rise and fall switches for different input and output ports. The solid blue curved are the measured responses, the dotted black curves are exponential fits of the responses, the green and red lines are the 90% and 10% levels of the on and off states, respectively.

4. CONCLUSION

We reported a TFLN 2x2 EO switch with a response time of below 0.3 µs fabricated through our open-access foundry process. The successful integration of standardized TFLN technology in this switch highlights its potential for high-performance and scalable optical networks. This innovation not only paves the wave for more efficient and faster optical communication systems, but also supports the vision of widespread adoption of TFLN switches in next-generation telecommunication infrastructures.

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