First demonstration of active plasmonic device in true data traffic conditions: ON/OFF thermo-optic modulation using a hybrid silicon-plasmonic asymmetric MZI

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Abstract: We demonstrate the first system-level evaluation of an active plasmonic device in 10Gb/s data traffic conditions. Thermo-optic ON/OFF modulation with 3μs response time and 10mW power consumption is presented using an asymmetric MZI silicon-plasmonic gate.

OCIS codes: (250.5403) Plasmonics; (200.4650) Optical interconnects; (250.5300) Photonic integrated circuits;

1. Introduction

Optical interconnect technology has been put forward as a much promising candidate for ensuring low-energy and high-bandwidth gateways in datacom and computercom applications, taking also advantage of the remarkable progress witnessed in the area of photonic integration [1]. This roadmap extends not only along passive optical waveguiding and active transceiver circuitry but also aims at the employment of optics in photonic Network-on-Chip implementations [2]. Hybrid on-chip opto-electronic routing fabrics with optical switching elements controlled by electronic signals have been already shown to provide significant power consumption and performance advantages [2], utilizing the broadband data carrying properties of light for routing high-capacity traffic streams and the simplicity of electronic driving schemes for the controlling operations.

In this perspective, the field of plasmonics has raised a great promise due to the inherent capabilities of Surface Plasmon Polariton (SPP) waveguides to support light propagation along metallic stripes, offering in this way a natural and energy effective interface for electronic and optical signal interaction [3]. A suitable mechanism for transforming the electronic control signal into switched light-paths is via the utilization of the thermo-optic effect, which has been heavily researched in the area of silicon photonics for chip-scale data interconnect purposes during the last years [4-7]. Most of the work has been devoted to the Mach-Zehnder Interferometric (MZI) type of thermo-optic Silicon-on-Insulator (SOI)-based switch arrangements due to their insensitivity to wavelength for broadband operation, demonstrating switching powers in the order of tens of mWs and switching times in the order of μsec [4,6] that can be simultaneously reduced at the expense of enhanced fabrication complexity [7]. In the area of plasmonics, however, only a limited number of thermo-optic control demonstrations [8-10] have been reported so far, all of them exploiting the Dielectric Loaded SPP waveguide platform. Dynamic ON/OFF switching operation has been presented only through the heterointegration of DLSPP structures on a MgF_2 substrate, with energy consumption and time response metrics being in the order of hundreds of mWs and a few ms, respectively [8].

In this article we report, for the first time to our knowledge, on a plasmonic thermo-optic switch module with 10mW consumed power and 3μs response time and on its performance evaluation as ON/OFF modulating element with true 10Gb/s data traffic. The switch configuration relies on an asymmetric MZI layout with 90-μm-long active poly-methyl-methacrylate (PMMA)-loaded plasmonic waveguides as the MZI branches heterointegrated on a SOI rib waveguide platform and located in-between two SOI-based coupler stages. The thermo-optic response of the device is experimentally characterized in dynamic operational conditions, showing a 62% modulation depth with 3μs rise- and 4.9μs fall-time. The BER performance of the device has been also addressed, showing error-free performance in both ON and OFF states with less than 1.5dB power penalty. Finally, its system-level credentials are demonstrated in an ON/OFF modulation experiment of 10Gb/s optical input data streams yielding an extinction ratio of 6dB.

2. Experimental Setup

Fig.1 illustrates the experimental setup. A CW signal at 1542nm was launched into a Ti:LiNbO3 MZ modulator driven by a Pseudo-Random-Bit-Sequence (PRBS) pattern generator, yielding a 10Gb/s 2^{31}-1 (and 2^{7}-1) NRZ data

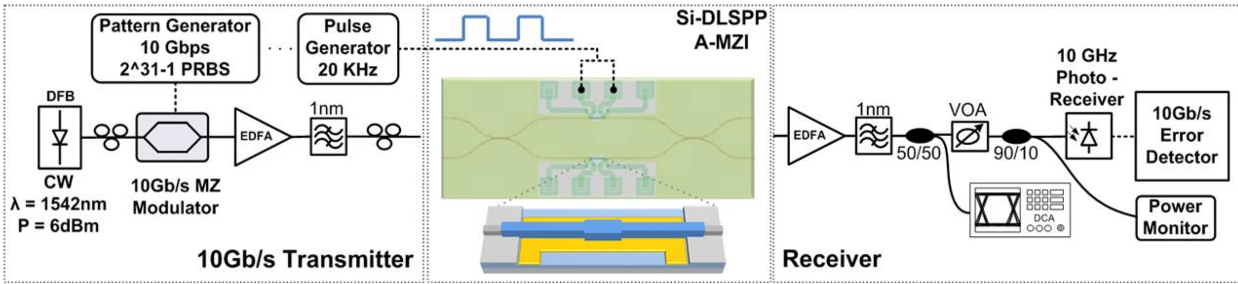

Fig. 1. Experimental setup with inset showing mask layout of the A-MZI chip and widened DLSPPW

sequence at its output. The modulated signal was then amplified, using a high-power Erbium-Doped-Fiber-Amplifier (EDFA) providing 26 dBm output power, filtered and launched into the hybrid silicon-plasmonic A-MZI.

The A-MZI comprised two 90-μm-long PMMA-loaded SPP waveguides of 500x600nm^2 cross-section serving as the active MZI branches and heterointegrated on a SOI rib waveguide platform. The interferometric layout was completed by two Si coupler stages at the MZI input and output, interfaced with the plasmonic waveguide arms through a butt-coupling approach. A detailed description of the heterointegration process and the 400x340nm^2 SOI rib waveguide platform hosting the plasmonic elements is described in [10]. The lower A-MZI arm plasmonic waveguide was modified in order to induce a default asymmetry of a close to π/2 differential phase shift between the two A-MZI optical paths providing natural biasing at the quadrature point. The π/2 phase asymmetry was achieved by widening a 7μm long DLSPP waveguide section from 500nm to 700nm, as shown in the inset of Fig.1, exploiting the resulting effective index reduction for the plasmonic propagation mode. Biasing at the quadrature point enables higher quality modulation depths within the limited phase tuning range of the 90μm long PMMA-loaded plasmonic sections, which is determined by PMMA's thermo-optic coefficient (TOC) in combination with its maximum service temperature and the requirement for reasonable total plasmonic propagation losses. The Si couplers placed at the A-MZI input/output stages had a coupling ratio of 95:5, due to an unfortunate design miscalculation, that restricted the device operation from high quality 2x2 switching, which could be in principle the case in case of perfect 3dB couplers. This issue however can be easily tackled in future fabrication runs**.** The total fiber-to-fiber losses of the device were found to be 46dB, 29dB of them coming from the SOI in- and out-grating coupler circuitry, 3dB owing to propagation losses in the silicon parts, 9dB owing to plasmonic propagation losses and 5dB stemming from the Si-to-DLSPP coupling interfaces.

The output of the chip was amplified in a low-noise EDFA, filtered, split and then fed simultaneously into a 30GHz sampling Oscilloscope and a 10GHz Photo-Receiver that was connected to an Error Detector. The control signal of the A-MZI was provided by a pulse generator operating at 20KHz that was directly connected to the electrical pads of the upper DLSPP waveguide.

3. Results and Discussion

Fig. 2 presents experimental results obtained from the characterization of the A-MZI in both static and dynamic operation. For static characterization purposes, a CW at 1542nm was used as input signal while a DC current, connected to the metal pads of the structure, was used to change the switch's state. Fig. 2(a) depicts the variation of the output power at the BAR and CROSS ports plotted against the applied current. The graph reveals that for an applied current range starting from 0 to 30 mA, the static extinction ratio of the BAR and CROSS ports was found to be 1 and 6dB respectively. The poor performance of the BAR port is due to the 95:5, instead of 50:50, directional couplers in the MZI.

Fig. 2(b)-(c) illustrate the response of the device when operating in dynamic conditions driven by 20KHz

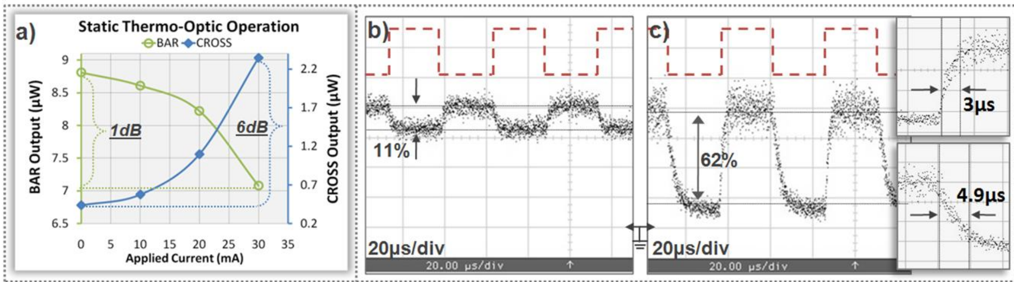

Fig. 2. (a) Static Thermo-Optic Characterization of the A-MZI, (b) BAR output TO modulation, (c) CROSS output TO modulation and rise-fall times (inset)

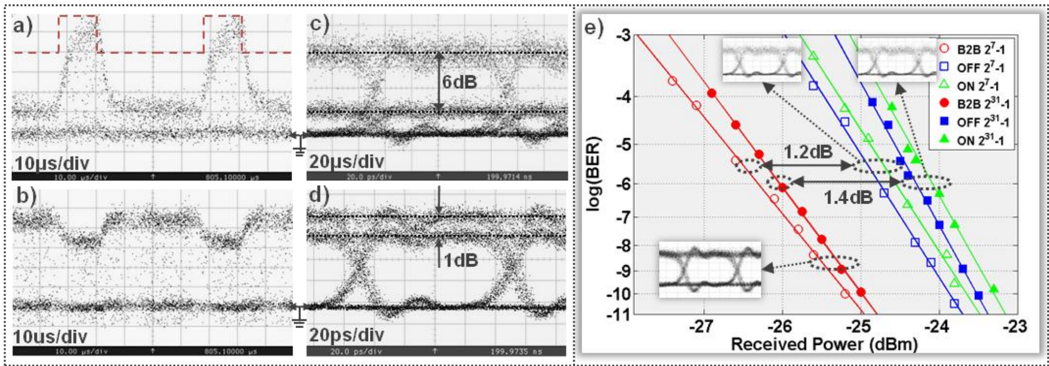

Fig. 3. (a) 10Gb/s data trace at the CROSS port, (b) 10Gb/s data trace at the BAR port, (c) 10Gb/s eye diagram at the CROSS port, (d) 10Gb/s eye diagram at the BAR port, (e) (2^{31}-1) and (2^7-1) BER measurements for B2B, ON and OFF state

rectangular pulses of 25μs duration and a Vpp level of 1.36V, corresponding to 30mA current. This, however, does not represent the true power requirements of the device, since the resistance of the A-MZI was found to be 9Ω prior wire-bonding but increased to approximately 45Ω after getting wire-bonded. This implies that the real power consumption characteristics of the device for a 30mA current are about 9mWs. The oscilloscope traces, shown in Fig. 2(b) and 2(c) indicate complementary operation as well as 11% and 62% modulation depth for the BAR and CROSS ports respectively. The insets in Fig.2 depict the rising and falling edge of the pulses at the CROSS port, revealing a 3μs rise and 4.9μs fall time.

The performance of the switch in a realistic data switching scenario with 10Gb/s NRZ optical input signals and 15μs electrical pulses at 20KHz repetition rate controlling the device are shown in Fig. 3(a)-(d). Fig. 3(a) presents a snapshot of the signal's trace exiting the CROSS port compared to the applied control pulses –red dashed line-, while Fig. 3(b) shows the corresponding trace for the BAR port. The eye diagrams of the CROSS and BAR output signals are shown in Fig. 3(c) and 3(d), respectively, clearly illustrating an extinction ratio of 6dB for the CROSS port and 1dB for the BAR port, inline with the values derived from the initial static characterization.

The transmission quality properties of the A-MZI when being in both ON and OFF states have been evaluated through BER measurements performed both for 10Gb/s 2^7-1 and 2^{31}-1 PRBS data streams, as shown in Fig. 3(e). During ON-state characterization, the A-MZI was driven by a DC current of 30mA. Both the CROSS-port during ON and the BAR-port during OFF-state operation exhibit similar BER performance with lower than 1.5dB power penalty compared to the B2B measurements.

4. Conclusions

We have demonstrated a thermo-optic hybrid silicon-plasmonic A-MZI device performing as ON/OFF modulating element with true 10Gb/s optical signals. Device operation with 3μm response time and 6dB extinction ratio was achieved, requiring 10mW of electrical power. Complete 2x2 switch operation with high-quality performance at both CROSS and BAR output ports should be feasible by improving the design through the use of 3dB Si couplers at the MZI input/output stages and by employing a dual-driving scheme with electrical current applied to both A-MZI arms.

5. Acknowledgment

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4. References

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