

Optically Reconfigurable 1x4 Silicon-on-Insulator Remote Node Switch for Access Networks

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Abstract: Operation of an optically controlled 1x4 remote node, based on membrane InP switches and SOI waveguide circuits, is shown. Extinction ratio >25dB and penalty-free operation for 10Gb/s 2^{31} -1 PRBS data through the switch are demonstrated.

OCIS codes: (130.3120) Integrated optics devices; (060.6719) Switching, packet; (060.1155) All-optical networks

1. Introduction

The exponential increase in demand for bandwidth is forcing access networks to extend the amount of bandwidth they can support. Traditionally based on "static" allocation of time slots per user (or TDM) and passive optical splitters, these systems are struggling to keep up with the rise in line-rate as it cuts away link budget and therefore splitting ratio and network reach. One attractive alternative for passive splitting is the use of wavelength division multiplexing (WDM-PON) combined with passive splitters [1] to increase the number of subscribers and their share of the total network bandwidth while using low loss optical demultiplexers. This way some flexibility can be obtained in the allocation of bandwidth, but users linked to a certain wavelength output of the demultiplexer still have to compete with other users on the same branch for bandwidth through TDM, and physically rewiring the network to double the number of wavelengths routed to a certain sub-network is not possible.

A more radical solution is to replace passive splitters with active optical switches [2,3]. In these demonstrations, electronically controlled switches are used to choose between a simple passive splitting and a more advanced WDM based filtering. Since traditionally PON splitter boxes are located in cabinets where no electric power is present, power supply based on photo-voltaic cells was suggested. However also in these demonstrations, the emphasis was on allowing network reconfigurability rather than packet-based switching. In an attempt to implement a more dynamic packet switch, PLZT switches [4] (Lead Lanthanum Zirconate Titanate) were used. While switching speeds of 10 nanoseconds are possible, their insertion losses and power consumption are very high. Previously we have suggested the use of a membrane InP Switch (MIPS) on silicon on insulator (SOI) as an optically controlled switch with high extinction ratio and no pattern dependence [5,6] however no actual switch architecture was implemented.

In this paper, we report on the world's first bias free and optically controlled 1x4 switch. A SOI passive circuit which includes a label processing circuit as well as a data broadcast and select architecture has been monolithically realized. By replacing electrically controlled semiconductor optical amplifiers (SOAs) or InP space switches with multiple MIPS devices we obtain a 1x4 switch which offers high optical isolation between its outputs and requires no electrical bias for its operation. We further demonstrate that data sent through the different chip outputs incurs no receiver sensitivity penalty as the device itself adds no noise and demonstrates no patterning effects.

2. Device design and fabrication

The 1x4 switch is based on a silicon-on-insulator circuit fabricated using a multi-project wafer run carried out by ePIXfab. An image of the complete IC is given in figure 1.

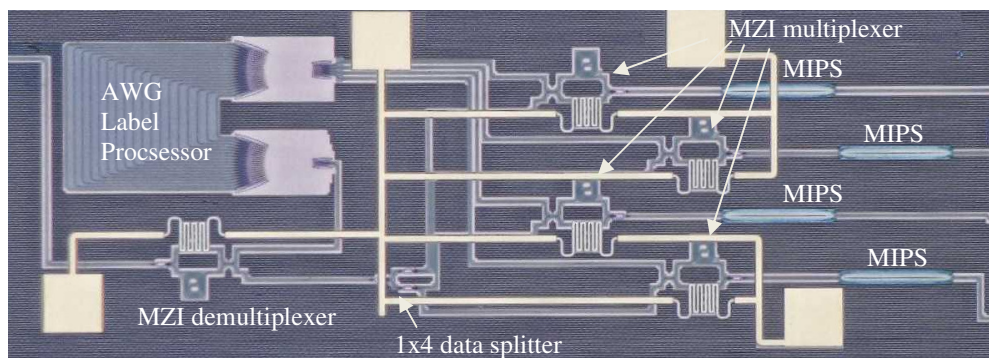


Figure 1: Microscope image of the integrated 1x4 optically controlled remote switch

This silicon chip is further post processed to include the membrane InP switches, SU-8 inverted tapers and heaters as previously described [6]. The incoming input signal which contains the data and WDM labels is first demultiplexed using a Mach Zehnder interferometer (MZI) into the data path (bottom of chip) and label path (top of the chip). The filtered out data signal is split into four by two consecutive 1x2 MMI splitter stages with each output of the splitter connecting to a separate chip output path. The WDM labels, which were de-multiplexed from the data signal, are sent to a 200 GHz channel spacing arrayed waveguide grating filter (AWG). After filtering, the four AWG outputs are multiplexed with the four copies of the data signal using an MZI multiplexer and sent to 4 separate membrane InP switches. The choice of active outputs is done by controlling which of the 4 WDM labels are active when the data packet arrives at the switches. The architecture allows for both uni-cast, multi-cast and broadcast operation as no space switching is involved.

3. Device characteristics

The different components making up the integrated 1x4 switch were tested and characterized separately. In figure 2 we show side by side the measured optical performance of the AWG filter and MZI (de)multiplexer.

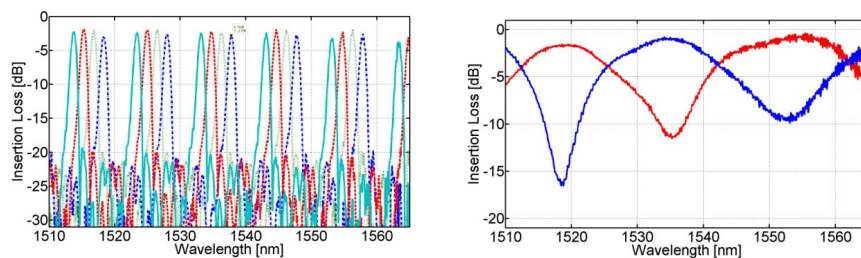


Figure 2: (Left) periodic response of 200 GHz AWG; (Right) MZI (de)multiplexer through and cross transmission response

The AWGs were designed for a 200 GHz channel spacing and a free spectral range (FSR) of 9.6 nm. Typical insertion loss measured on the AWG was 2.5 dB with a worst case channel cross talk of 17dB. While for normal operation 17dB channel cross talk may not be sufficient, the non-linear absorption response of the MIPS [7] makes 17dB more than enough. The MZI was designed with a FSR of 35nm. An extinction ratio of 10 dB and a 1dB insertion loss were obtained. The full chip was also statically characterized for the extinction ratio (ER) of each output when the labels for other channels were present. This is to check for both the intrinsic ER of the membrane switch between the on and off states and the effect of the AWG cross talk on the eventual switch cross talk. In figure 3 we show the behavior of a single output of the switch (port number 2) while alternating the label wavelength as well as the ER for the other 3 ports for the on and off states. In this these experiments the label power was set to 0 dBm and the data signal was 8.5dBm (giving a total insertion loss >35 dB).

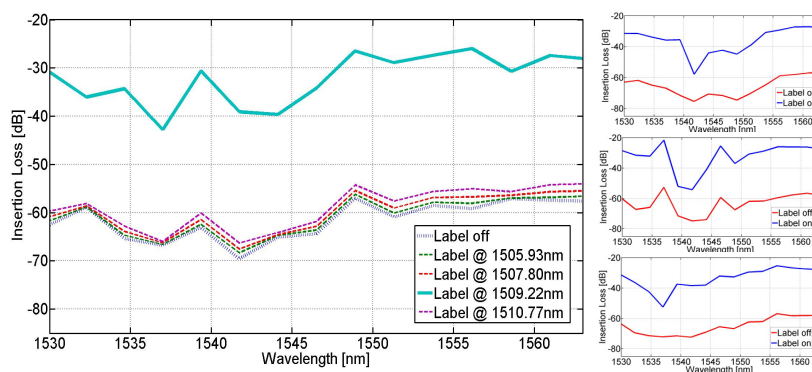


Figure 3: (Left) Port 2 extinction ratio for labels on and off and in the presence of other labels; (Right) Port 1, 3 & 4 extinction ratio with and without a label present

It can be seen that the typical on-off ER of the switch is better than 25 dB at most wavelengths and better than 30dB for the wavelength range 1550-1560 nm were the data signal is placed (see red trace on fig. 2 (right)). It can also be seen that when a different wavelength for the label is used, the ER only degrades by 2-3 dB.

4. Data transmission set-up and results

In order to test the operation of the 1x4 switch IC it was tested for data transmission through the 4 different paths for both packetized as well as continuous PRBS data transmission. The 4 labels were created by modulating the input current to a C-band semiconductor optical amplifier (SOA). Choosing an SOA instead of a Mach-Zehnder type modulator, as previously reported [6], insured an improved on/off ration of the label but limited the label on and off switching times. In addition the SOAs were designed to work in the C-band and in order to exploit to the maximum their gain, the labels were moved by 3 FSRs compared to the measurements in figure 2 to occupy the wavelengths 1535, 1536.6, 1538.2 and 1539.8 nm. The data signal was created by modulating a laser (1559.38 nm) with a 10 Gb/s pattern generator running a $2^{31}-1$ PRBS sequence. Due to the high device fiber to fiber loss in the experimental setup (>30dB), an EDFA was used to boost both data and label signals to +4.5 and +13 dBm respectively. In figure 4 we present the measured BER for a PRBS data stream routed through each one of the output ports while keeping the label operating at CW. The receiver used for these measurement was an AC coupled APD receiver housed inside an XFP module with a typical Rx sensitivity of -28dBm. Since it was AC coupled it could not be used to measure the packetized BER. For packet transmission we measured BER with an Agilent 8192A 10Gb/s receiver and obtained error free operation with a penalty of 0.8dB. In addition we show a time trace and eye patterns of the output of the port number 1 when the label is modulated to be on for only one of the 4 packets being transmitted.

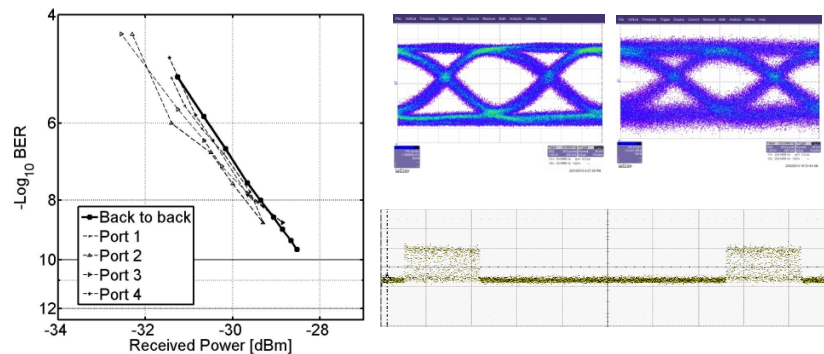


Figure 4: (Left) Measured BER for 10 Gb/s PRBS data through the 1x4 switch for all 4 outputs; (Right, top) Obtained eye patterns for packetized data before and after the switch; (Right, Bottom) Output of port 1 when switching one of 4 packets through it

The receiver sensitivity after the device shows no measureable penalty for PRBS operation and the chip output shows indeed that the high ER of the MIPS in combination with the high ER of the SOA as label generator insures no data appearing at port 1 output when no label is present. The output eye pattern has been captured with the Agilent DC coupled receiver and is dominated by the electrical noise due to considerably weaker input optical signal.

5. Discussion and conclusions

We have demonstrated the operation of an optically controlled 1x4 switch based on membrane InP switches (MIPS) co-integrated with a broadcast and select passive silicon circuit and a wavelength selective label distribution. High extinction ratio of >25 dB and penalty free operation in CW mode were presented.

The fabricated chip suffered from considerable insertion losses which are not related to the design but are the result of fabrication issues. In particular the etching of the cladding layer resulted in a 10 dB increase in insertion loss of the MIPS forcing the use of very high power label and data signal compared to previous reports [5,6]. It is expected that better devices can reduce the device insertion loss to 15dB of which 8 dB are 1x4 splitter losses and 6 dB are the input and output coupling losses. High gain in devices with in-well optical pumping has been reported [8,9] suggesting that with improved processing and epitaxy as well as improved inverted taper couplers (which have been reported with <1dB loss [10]), such MIPS based optically remote controlled switch can demonstrate better loss performance than a simple passive splitter while maintaining its dynamic configuration capability.

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