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Mach-Zelder Interferometer Switching Applications using photonic Integrated Circuits for Optical routing (A review)

A. I. Stanley[1,2], F. U. Nweke[2] and James Eke[3]

[1]*Dept. of ECE, MNIT, Jaipur, India*
[2]*Dept. of Industrial Physics, Ebonyi State University, Abakaliki, Nigeria*
[3]*Dept. of EEE, Enugu State University of Science and Technology, Enugu, Nigeria*

ABSTRACT

We report on the latest advances in implementation of integrated photonic components required for optical routing and switching: tunable wavelength converters, mode-locked lasers, active optical switches and optical buffers.

Key words: Implementation, integrated, photonic, tunable, switching, wavelenght, optical buffers.

INTRODUCTION

Optical networking allows for reconfiguration of large data bandwidth directly in the optical layer, with little electronic processing required in the data plane. Optical circuit switching (wavelength routing) is supported in the currently deployed second generation of optical networks. With further increases in traffic in optical networks, optical packet switching and routing technologies hold promise to provide the largest granularity with more efficient power and footprint scaling, relative to electronic processing [1,2]. Integration of the switching and routing function onto photonic integrated circuits has been a major contributing factor in the optical network development, and it will be required for future improvements and implementations of novel switching functions in optical networks.

Some of the key photonic functions that are of interest for optical routing and switching, and that will be covered in this paper are: widely tunable and fast wavelength-switched integrated optical transmitters and transceivers/ wavelength converters, which form the core of wavelength and packet switch fabric; mode-locked laser technologies, which can be used for optical signal regeneration; active optical switch/router cores, used as a more integrated version of the optical switch fabric; and optical buffers, needed to mitigate the contention between different packets directed to the same switch output port. The final goal of this program was a 120 Terabit optical router demonstration.

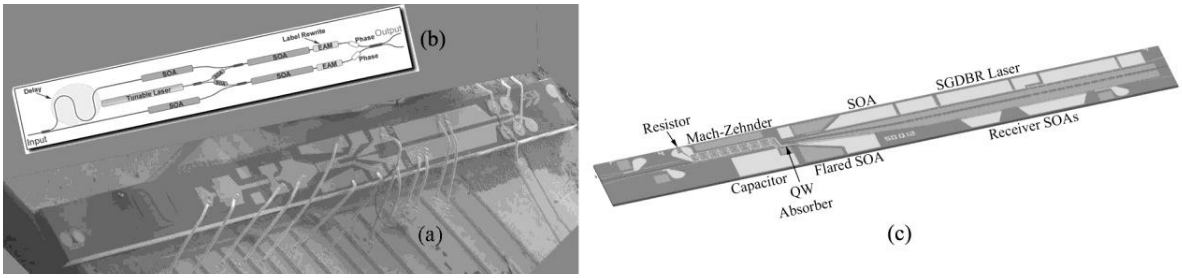

Figure 1 – (a) 40 Gbps MZI-SOA packet forwarding chip (PFC) electron micrograph (b) PFC schematic (c) 40 Gbps separate absorption and modulation (SAM) tunable wavelength converter

1. Widely Tunable and Fast Switchable Optical Transmitter and Wavelength Converter Technologies

Wide tunability in optical PICs is an attractive feature, as it allows for a single PIC to be used for wavelength and packet routing across an entire optical band. The wavelength tuning/switching speed requirement is determined by the actual application in the network: while milliseconds are adequate for optical circuit and protection switching, optical burst switching requires <120 ns speeds, and optical packet switching <5ns speeds. Carrier injection tuned lasers, with proper emphasis can achieve around 50 ns of tuning speed [3]. Dual laser implementations have been demonstrated for nanosecond speed applications [3]. Fast wavelength tuning enables packet forwarding in an optical router, where the payload is wavelength converted to a new wavelength corresponding to the desired output port. There are two main mechanisms exploited for monolithically integrated tunable wavelength converters – non-linear effects in a semiconductor optical amplifier (SOA) caused by the pump-probe signal interaction [4], and traveling wave effects of signal detection and remodulation in a photodiode-modulator based system [5,6]. 40 Gbps, error free, RZ data operation of both MZI-SOA and separate absorption and modulation (SAM) tunable device types has been achieved (Figure 2). In addition, fully integrated packet forwarding chips (PFC), operating with 40 Gbps payloads and 10 Gbps labels have been successfully demonstrated and used in optical switch demonstrations,[1].

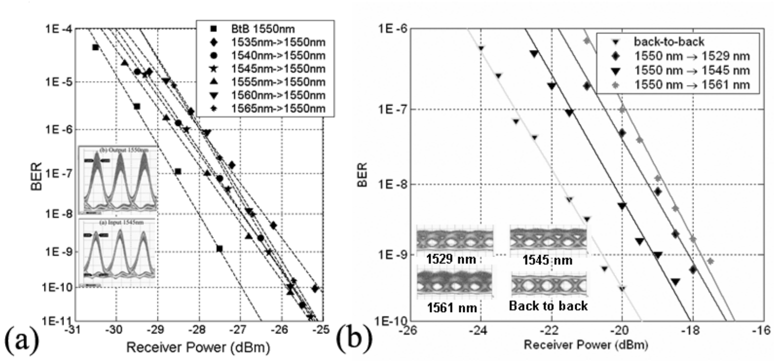

Figure 2 – (a) PFC - Bit error rate results for 40 Gbps RZ operation (b) SAM - Bit error rate results for 40 Gbps NRZ operation

In SAM devices, a transmitter and and a preamplified photodiode are monolithically integrated on a single chip. The photodiode is directly connected to the modulator through an on-chip terminated traveling wave electrode, allowing the photocurrent from an absorbed input signal to directly drive an optical modulator. Since the photodiode produces enough photocurrent to drive the optical modulator, there is no need for any electrical amplification. Due to the spatial separation of the receiver and transmitter waveguides, SAM wavelength converters have no optical filtering requirements. Additionally, bit rate transparent operation had been achieved [6].

2. Monolithic Mode-Locked Lasers

Mode locked lasers (MLLs) are key components for 3R regeneration applications in optical networks. Some qualities of MLLs utilized in optical clock recovery are their ability to perform jitter reduction, pulse reshaping, and amplification. Since the frequency of mode locking is determined by the cavity length, traditional MLLs with cleaved facets are not reproducible at a specific frequency. Thus, special MLL designs, with non-facet determined cavities and compatible with further integration into complex 3R PICs, such as [10], are of particular interest.

Previously, our team members have experimentally demonstrated optical clock recovery using a novel mode-locked laser (MLL) [8] monolithically integrated with an output semiconductor optical amplifier. The laser's distributed Bragg reflector (DBR) mirror positions are determined using lithography, allowing for mode locking and clock recovery at the exact frequency of the design (35.00 GHz), which is easily scalable to 40 GHz or higher. More recent work in this area has yielded an integrated InGaAsP/InP ring mode-locked laser with a gain flattening filter that doubles the locking bandwidth and decreases the pulse width from 940fs to 720fs [9], shown in Figure 3. The laser design and fabrication platform are compatible with other photonic integrated circuit components, enabling integrated signal processing using these MLLs in the future.

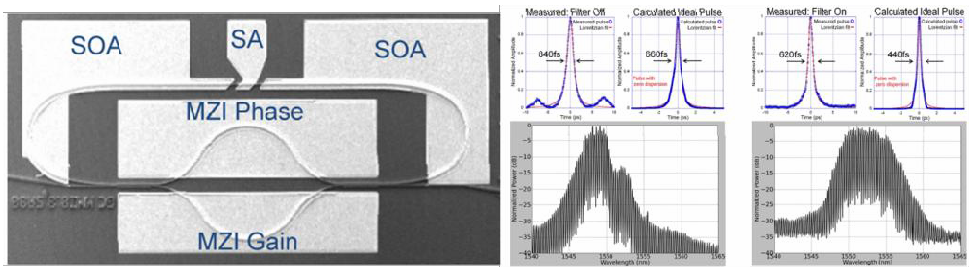

Figure 3 – (left) Electron micrograph of a mode-locked laser with an integrated Mach-Zehnder gain filter for flattening. (right) Optical spectra and pulse shapes and widths with the optical filter turned on, and off.

3. Optical Switches

Monolithic integration of a fast switch fabric for an optical router has been performed by incorporating 8 MZI-SOA tunable wavelength converters operating at 40 Gbps and an arrayed waveguide grating on a single chip [10]. The Monolithic Tunable Optical Router (MOTOR) chip contains more than 200 integrated functional elements. The device schematic, and the bit error rate measurements at 40 Gbps are shown in Figure 4. The integration platform supports both active and low-loss elements using a novel, single regrowth, quantum-well intermixing approach. This platform allowed us to reduce absorption losses in the AWGR and delay line regions by exploiting an undoped InP setback layer in the passive sections of the device while optimizing active functions. The chip has 3 different waveguide types: a surface ridge waveguide design in the wavelength converter section, a high-contrast deeply etched waveguide in the delay line for compactness, and a buried rib waveguide in the AWGR region for low scattering losses.

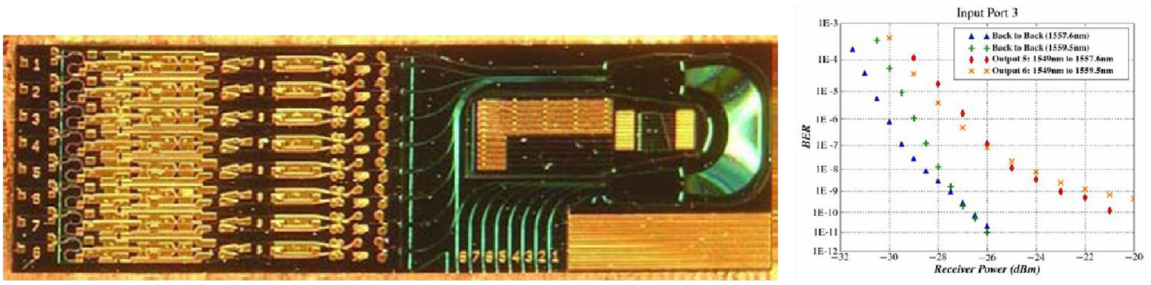

Figure 4 – Photograph of fabricated 8-channel MOTOR device; Bit error rate testing results, showing error-free operation at 40 Gbps

4. Integrated Optical Buffers

The realization of practical optical memory elements to resolve packet contention is necessary before optical routers can become viable. The most successful optical buffering demonstrations have used either feedback or feed-forward buffers, many of which implement two-by-two or one-by-two switches [7]. We have developed a simple recirculating buffer that operates without additional control components in the delay loop. Up to 190ns of storage was demonstrated with greater than 98% packet recovery for 40 Gb/s, 40-byte packets, Figure 3. To the authors' knowledge, this device has the best performance for a buffer approach amenable to integration. Further work on all photonic chip based buffers is underway.

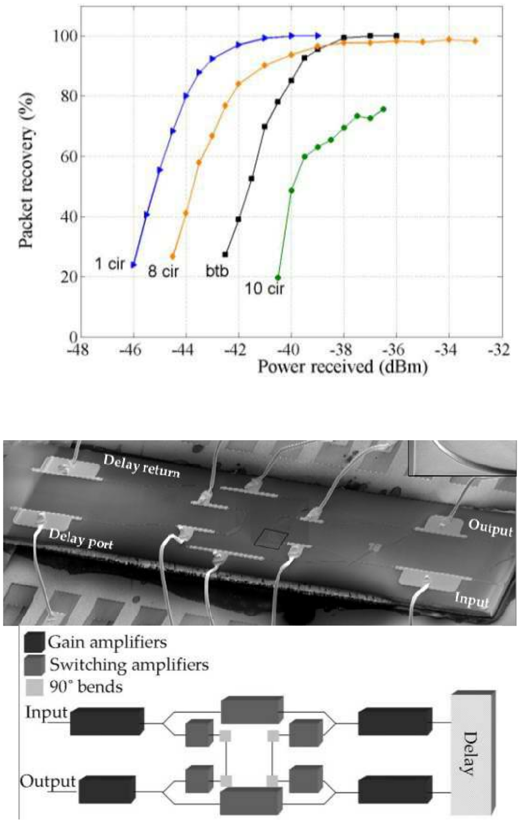

Figure 5 (top-left) Schematic of 2x2 switch with amplifiers (bottom left) SEM image of the switch affixed and wire-bonded to a submount (right) Packet recovery of 98% for up to 8 circulations (184 ns delay)

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