Recent Progress on LASOR Optical Router and Related Integrated Technologies

Jonathon S. Barton[1], Milan L. Mašanović[1], Matthew M. Dummer[1], Anna Tauke-Pedretti [1], Emily F. Burmeister[3], Brian R. Koch[4], Joseph A. Summers[1], Larry A. Coldren[1], John E. Bowers[1], Daniel J. Blumenthal[1]

1: University of California Santa Barbara, Harold Frank Hall Santa Barbara 93117
2: Sandia National Laboratories, Alburquerque, New Mexico
3: Ciena Corp. Linthicum, Maryland 21090
4: Intel Corp. Santa Clara, CA

Abstract: In this talk we review the latest progress on the DOD-N LASOR optical router project. Architectural studies including design and buffering will be discussed as well as prototype node performance. Recent results in integration in InP and Si/InP platforms will be described.

Keywords: Buffers, couplers, routers, switches, Photonic integrated circuits

Introduction

All-optical packet switching and routing technologies [1,2] hold promise to provide more efficient power and footprint scaling with increased router capacity. In this paper we cover the latest advances in photonic integrated circuit (PIC) optical packet switching and routing technologies investigated under the DARPA/MTO DOD-N program sponsored LASOR project [1]. In the LASOR architecture, 40 Gbps optical packets are routed based on the packet's wavelength and 10 Gbps optical labels. Integration of the switching and routing function onto PICs allows for advanced routing functions to be realized in the optical domain while offering advantages of integration including reduced footprint and power requirements.

The key components in the LASOR optical router [1] are a packet switching fabric, an optical buffer, a wavelength sensitive routing element, and a data regenerative element.

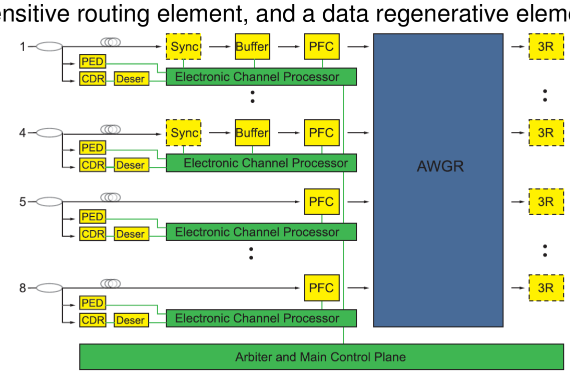

Figure 1 - LASOR Architecture with PFC, Buffers, Routing and 3R elements

The packet switch converts optical packets to new wavelengths based on information stored in a lookup table. The optical buffer is used to mitigate the contention between different packets directed to the same switch output port. A wavelength sensitive routing element is used in conjuction with an all-optical wavelength converter to forward packets from input buffers to output ports. These components include high-speed, high-performance integrated tunable wavelength converters and packet forwarding chips, integrated optical buffers, and integrated mode-locked lasers for 3R regeneration.

Widely Tunable Optical Wavelength Converters and Packet Forwarding Chips

Packet forwarding in an optical router is performed through fast wavelength tuning, wavelength conversion of the payload, and encoding of a label for the outgoing packet. A SEM of a typical device is shown in Figure 1. At the core of this functionality is a fast switching, widely tunable wavelength converter PIC. There are two main mechanisms exploited for monolithically integrated wavelength converters – non-linear effects in a semiconductor optical amplifier (SOA) caused by the pump-probe signal interaction [3], and traveling wave effects of signal detection and re-modulation in a photodiode-modulator based system [6].

Significant advances have been made in SOA-based tunable wavelength converters, utilizing both sampled grating DBR lasers [3] and Arrayed Waveguide Grating (AWG) based discretely tunable lasers [4]. Wavelength conversion with both device types at bit rates of 40 Gbps RZ has been reported. In addition, a fully integrated packet forwarding chip (PFC), operating with 40 Gbps payloads and 10 Gbps labels has been successfully demonstrated and used in an optical switch demonstration [1,3]. Finally, multistage tunable wavelength converter MZI-SOA based implementations with on chip signal filtering have been demonstrated as well [5].

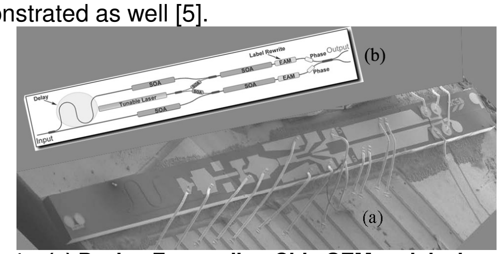

Figure 1 – (a) Packet Forwarding Chip SEM and device diagram

Recently, successful demonstration of the separate absorption and modulation (SAM) approach to wavelength conversion has been accomplished for bit rates up to 40 Gbps [6]. In this method, a transmitter and receiver are monolithically integrated on a single chip.

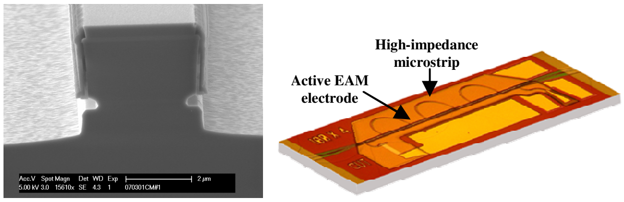

Figure 2 – (a) SEM of Undercut modulators b) Traveling wave electrode modulator used in wavelength converter

Figure 2 shows a SEM of undercut modulators employed in the latest generation of SAM devices which reduces the capacitance and enable 40G RZ wavelength conversion.

In a SAM device, 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. Due to the spatial separation of the receiver and transmitter waveguides, SAM wavelength converters have no optical filtering requirements. These devices also have the advantage of lower power consumption, and smaller footprints, with respect to comparable SOA-based devices. Operation at 40 Gbps with NRZ data shows less than a 2.5 dB power penalty across the 32 nm laser tuning range with no additional power penalty for conversion to the input wavelength. Both Mach-Zehnder and EAM based devices are being investigated [6,7].

Integrated Optical Buffers

In order to become viable, practical optical memory elements must resolve packet contention. 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 [8]. Although practical storage times have been demonstrated, integrated solutions are not currently available.

Recently a simple re-circulating buffer was demonstrated based on an InP SOA gate array two-by-two switch and an optical fiber delay loop, 450 centimeters, or 23 ns, in length.

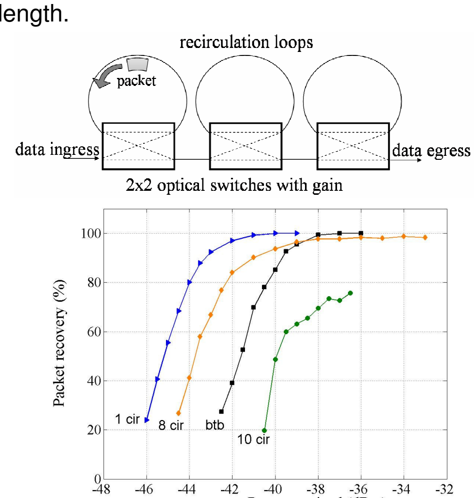

Figure 3 (top) Schematic of 3 element recirculating buffer 2x2 switch with amplifiers (bottom) Packet recovery of 98% for up to 8 circulations (184 ns delay).

The buffer exhibited greater than 40 dB extinction, sub-nanosecond switching, and fiber-to-fiber gain. Up to 184 ns of storage was demonstrated with greater than 98% packet recovery for 40 Gb/s, 40-byte packets, as shown in Figure 3.

Monolithic Mode-Locked Laser and Optical Amplifier

Mode locked lasers (MLLs) are key components for 3R regeneration applications in optical routers by providing jitter reduction, pulse reshaping, and amplification.

Recently, we have experimentally demonstrated optical clock recovery using a novel mode-locked laser (MLL) [10, 11] monolithically integrated with an output semiconductor optical amplifier. The laser design and fabrication platform are compatible with other photonic integrated circuit components, enabling integrated signal processing using these MLLs in the future.

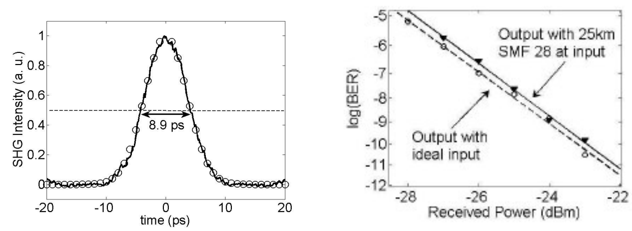

Figure 4 – (a) MLL pulseshape and (b) BER

The device was shown to generate nearly transform limited pulses at 35.0-GHz repetition rate with pulse widths tunable between 3.5 and 8.5 ps, over 12 dB extinction ratio (ER), and 8.3 dBm average output power.

6. Acknowledgment

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7. References

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