Experimental Evaluation of a Packaged SOI Hybrid All-Optical Wavelength Converter in a Meshed Network Test-bed

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Abstract *We demonstrate data transmission and switching using a packaged and pigtailed all-optical wavelength converter. The module employs a hybrid integrated SOA and two cascaded delay-interferometers on a 4μm SOI. We present wavelength routing with power penalties less than 5dB.*

Introduction

As video and media enhanced applications shape the IP next generation network (NGN), power efficiency, physical size and switching capacity are key issues for the development of the next generation telecommunication hardware [1]. Data information is being stored and exchanged currently with parallel electronic carrier routing systems that occupy hundreds of racks, employ cumbersome electrical wiring, consume a lot of electrical power and dissipate large amount of heat [2]. This however can no longer be practical since new broadband services emerge crossing the present network architecture in multiple directions. To ease the strain in central offices, efforts have now been focused in virtualization techniques in a way to minimize capital and operational expenses by sharing resources and collapsing routing interfaces [3]. Photonic integrated circuits are already being considered for employment in future scale-proof solutions and miniaturized network elements supporting multi-gigabit capacities are now being demonstrated. A promising technology path involves hybrid integration of III-V components on silicon substrates through CMOS compatible techniques [4]. With this approach a high-speed AOWC on a 4μm SOI rib photonic chip has been fabricated and characterized [5].

In this paper we demonstrate for the first time the development of a full packaged and pigtailed hybrid SOI AOWC module and its incorporation in an optical meshed network to perform 40 Gb/s data switching. The photonic chip employs a 1.25 mm prefabricated non-linear semiconductor optical amplifier (SOA) mounted on the SOI board using gold-tin bumps as small as 14 μm. Optical filtering is realized by two cascaded delay interferometers (DIs) integrated on the SOI board using 2x2 multi-mode interference (MMI) couplers. Device packaging is accomplished using a generic bath tub packaging approach which guarantees efficient electrical and optical connections to the SOI PIC. Optical wavelength switching is triggered by a generalized multiprotocol label switching (GMPLS) control plane.

Packaging process and test-bed description

The AOWC package design was based around a simple machined Gold-over-Nickel Kovar bath tub package, with associated fiber feed-through pipes and wire-bond pin headers being attached to the package via a hot epoxy wick technique. Hot-wicking at 150DegC ensures that the epoxy glass transition temperature (TG) is above the reflow temperature of the solders that would be used for TEC and fiber tube attach. After package assembly, solder attach of the TEC and optical bench was carried our using Bismuth/Tin (58Bi42Sn) solder having a reflow temperature of 138°C. Specially designed high temperature plastic formers were used inside each package to ensure that both the optical bench and TECs were held accurately in place during solder reflow. Due to the dimensions of the optical bench, three TEC units were soldered in the package and electrically connected in parallel to provide sufficient device

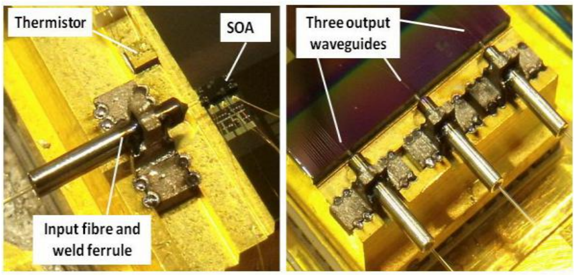

Fig. 1: Aligned and welded input and output fibres.

coverage.

Two differing bonding methods were evaluated. The first AOWC module was assembled using a uniform layer of thermally conducting Epotek H20-e epoxy. This epoxy is quite granular so to enhance even spreading. The optical bench and module were placed on a hot plate at 60DegC to reduce the epoxy viscosity and promote even flow. The waveguide was then carefully placed on top of this. The whole assembly was oven cure overnight at 60°C. The second method employed the same planar optical bench, but with the addition of an array of 100µm deep mill holes, into which a controlled amount of viscous adhesive was deposited. The waveguide was placed on the planar surface and so brought into contact with six adhesive spots. Once cured, the adhesive shrinkage would provide a mild compressive force to keep the waveguide substrate in physic al contact with the optical bench with no adhesive interface layer being present outside of the mill areas. In this way, there is a completely planar contact area between the optical bench and the SOI device and also physical contact between the tile area directly under the SOA and the optical bench for thermal transfer during operation. Comparing the thermal expansion of the optical bench material (Kovar, 5.9ppm/°C), with the PIC attach epoxy (Epotek 353ND-T, 43ppm/°C), there is a mild compressive force between bench and device wafer, after cool-down from the oven cure process, ensuring that physical contact is maintained during device operation. Epoxy dispense was regulated via an EFD pneumatic dispense unit. This allows very small and repeatable epoxy volumes to be dispensed locally in the centre of each mill feature.

Fiber align was carried out using standard sub-micron four-axis alignment system, which also incorporates a Lumonics pulsed YAG laser system for fiber fixing. Each SOI module was loaded onto the package holder stage on the alignment workstation, with sufficient electrical current supplied to generate spontaneous emission from the SOA. This emission would be available at the input of the SOA to allow alignment of the input fiber, and also available at each of the three output waveguide end-faces for alignment of each of the output fibers. Figure 1 shows the aligned and welded fibers.

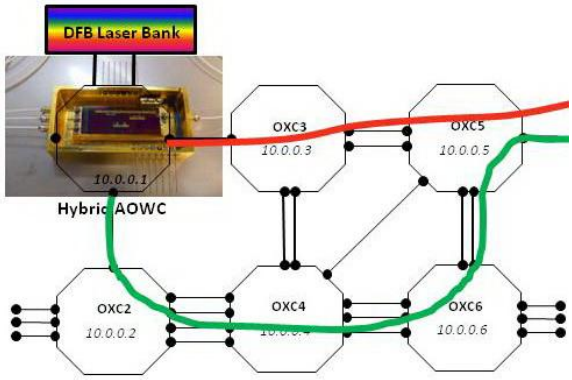

Fig. 2: Optical switching network test-bed.

Figure 2 depicts the test-bed assembled for the AOWC system testing in an environment emulating a real network. The test-bed is a GMPLS meshed network with fiber switching capabilities made around with an optical switching matrix (3D MEMS) logically partitioned to emulate five nodes (OXC2 to OXC6) interconnected by bundles of bidirectional fibres. A further emulated node (OXC1) implements the switching function via the AOWC device followed by a DWDM AWG demux to address the output ports. Every node has its own controller (Linux based PC) running a GMPLS control plane stack, interconnected with the controllers of the neighbour nodes by means of point-to-point Fast Ethernet control channels. Signalling and routing protocols are, respectively, RSVP-TE and OSPF-TE with GMPLS extensions. A distributed feedback laser (DFB) bank triggered by the control plane is used to pump cross gain and phase modulation (XGM-XPM) in the AOWC to induce the optical switching. According to the wavelength seeded, traffic is routed either to OXC3-OXC5 (red line) or to OXC2-OXC4-OXC6-OXC5 (green line).

Experimental setup and results

For testing the switching capabilities of the hybrid AOWC at 40Gb/s, the experimental setup of Figure 3 was assembled. In the transmitter, 1.6 ps optical pulses were generated by a mode-locked laser (MLL) at 1556nm and encoded with a 2^7-1 PRBS using a LiNbO3 modulator. Then the optical signal was time-multiplexed through a fiber interleaver in order to constitute a 40Gb/s data stream (pump signal). The generated data sequence was combined with the output of the laser diode pump stack

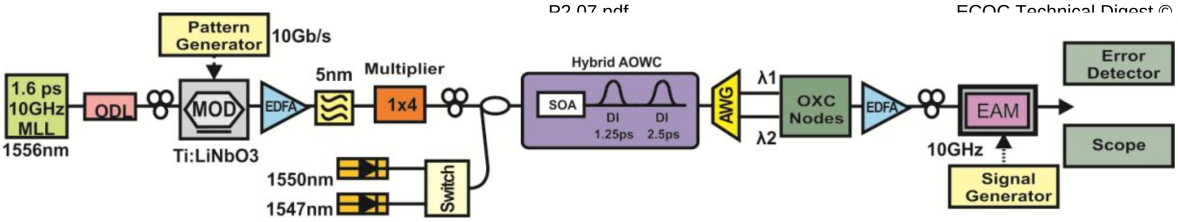

Fig. 3: Experimental setup for 40Gb/s data switching

emitting at wavelengths 1547nm and 1550nm respectively. The flip-chip mounted SOA of the AOWC was used for the non-linear processing by inducing chirp in the converted probe signal due to the refractive index modulation caused by the pulsed pump signal. The first SOI-MZI filter was detuned with respect to the probe wavelength and by filtering the blue (fast) chirp the acceleration of the effective recovery time was achieved. The second SOI-MZI filter was employed to restore the polarity of the optical pulses by suppressing the carrier of the probe signal. The free-spectral-range (FSR) of the DIs was 6nm and 3nm respectively and with proper wavelength tuning a spectral notch of ~30dB has been measured. Depending on the pump wavelength used into the AOWC, data bit stream was routed either through OXC3-OXC5 at wavelength λ1=1547nm or through OXC2-OXC4-OXC6-OXC5 at λ2=1550nm. The SOA was driven with 140mA, temperature was maintained at 20^{o}C, while the detuning of the DIs with respect to the probe wavelength carrier was ~0.3nm. The wavelength converted and routed signals were evaluated with bit-error rate measurements after performing optical demultiplexing using an electro-absorption modulator (EAM).

Figure 4 a) shows the incoming 40Gb/s return-to-zero (RZ) data signal injected into the SOA for cross gain and phase modulation. Figure 4 b) illustrates the wavelength converted signal at λ1=1547nm passing through OXC3-OXC5. The pulse broadening is mainly attributed to the narrow AWG channel filtering while the pulse asymmetry observed to the AWG spectral mismatch with the DI filter comb. Figure 4 c) depicts the wavelength converted signal at λ2=1550nm passing through the OXC3-OXC4-OXC6-OXC5. A clear and open eye has been recorded with better performance from λ1 at 1547 due to the the symmetrical filtering from both AWG and DI responses. Figure 4d) depicts the bit-error-rate measurements obtained for both wavelength converted and routed signals. Less than 5 dB penalty has been measured for the path λ1=1547nm with no evidence of error floor until 10-9. The error floor was mainly attributed to the narrow AWG filtering resulting to pulse overlapping as well as to the mismatch

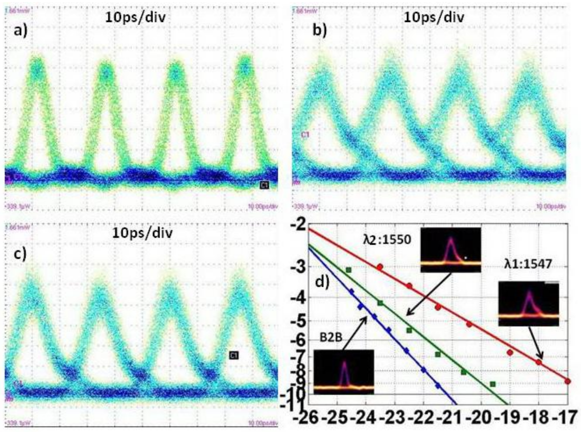

Fig. 4: Eye diagrams of a) 40Gb/s (B2B) signal, b) Wavelength converted signal after OXC3-OXC5 at λ1=1547, c) Wavelength converted after OXC2-OXC4-OXC6-OXC5 signal at λ2=1550, d) BER measurements [log (BER)- P (dBm)]

of AWG with the DI spectral responses. Error-free performance with less than 2 dB power penalty was achieved for the path λ2=1550nm.

Conclusions

We have tested a hybrid SOI all-optical wavelength converter module on a network operator test-bed. The module is fabricated using a bath tub packaging approach which can support development of hybrid PICs integrated on SOI. Data switching was successfully performed with power penalties less than 5dB.

Acknowledgements

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