Monolithically Integrated InGaAsP/InP Active-Passive 8×8 Cross-Connect

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The increasing bandwidth and connectivity requirements in data- and tele-communications have led to a considerable interest in space and wavelength switching. Optoelectronic switching has been proposed for scalable optical switching systems but these approaches so far have used hundreds of discrete components. We present the first monolithically integrated InP active-passive 8×8 cross-connect which provides 8×8×8λ capacity within a 14.6×6.7mm² area. 432 unique optical connected paths are characterized. Data routing studies are performed for a representative range of paths to show optical signal-to-noise ratios of greater than 30dB/0.1nm. Switch rise and fall times are measured to be 3.8 and 3.2ns respectively.

Introduction

Increasingly sophisticated optical signal routing offers the possibility to define connectivity in terms of the product of physical inputs and wavelength channel numbers per port, allowing order of magnitude scaling with respect to space switches and wavelength routed switches only. This has motivated large scale experimental switch fabric demonstrations for tele- and computer-communications [1,2]. The largest fully implemented fabric has used multiplexes of eight wavelengths on each of eight input ports to enable 64×64 connectivity [3]. The use of discrete photonic components in these proof of principle implementations is however restrictive in terms of scalability and power consumption.

Extensive photonic integration can provide synchronized switch states, allowing considerable reductions in control complexity, calibration, and an improved control of optical losses, as well as decreased footprint and power consumption. Recently we have reported the first 8×8 space- and wavelength-selective cross-connect [4,5]. Arrayed waveguide grating (AWG) based architectures are chosen to offer a high scalability route to rich functionality optical cross-connect circuits. The combination of wavelength selective switches with semiconductor optical amplifier (SOA) switches is implemented to offer flexible control and re-configurability with fast switching speeds.

In this work we present the first monolithically integrated 8×8 WDM cross-connect. The combination of both space- and wavelength-selective routing is exploited on a single monolithic InP circuit. Dynamic multi-path provisioning is performed in time and wavelength. Data integrity for received channel is evaluated in term of measured power penalty.

8×8 Integrated Cross-Connect

The monolithically integrated 8×8 space and wavelength selection switch consists of a broadcast port selection or photonic switch stage (PSS) and a color selection or wavelength selective stage (WSS), as shown in the architecture in Fig. 1*a*. In the first stage, eight colorless inputs are broadcast to 64 broadband SOA gates for input port select through a shuffle network. Eight parallel 8 input-8 output cyclic AWGs map each of the input ports to a second stage of 64 SOAs gates which perform the color selection. The selected wavelength channels are combined and sent to the eight colorless outputs. The grey-scale layers in Fig. 1*a* are the seven identical layers implemented in the integrated circuit for both stages.

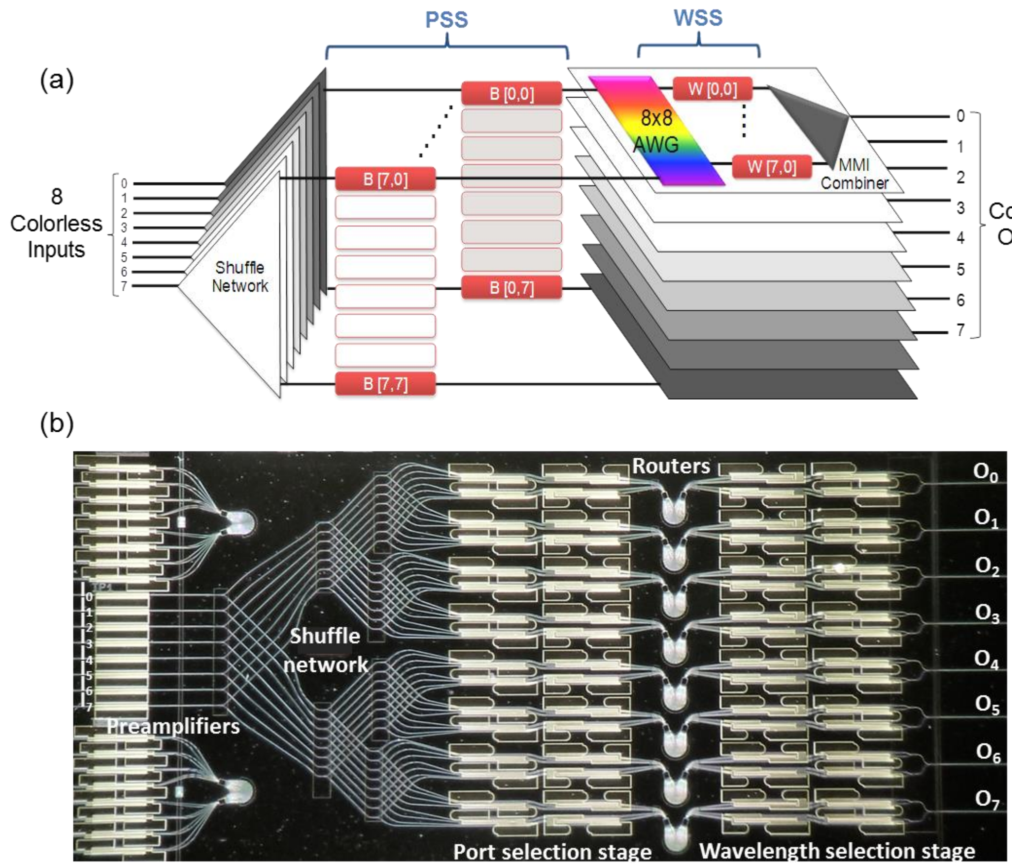

Fig. 1 – Architecture (a) and microscope image (b) of the 16.4×6.7mm^2 8×8 cross-connect.

The device is realized on a re-grown active-passive InGaAsP/InP epitaxy. An optical image of the chip is shown in Fig. 1*b*. The eight pre-amplified colorless inputs are broadcast through a shuffle network made of cascaded 1×2 multimode interferometer (MMI) splitters. After port and color selection, the selected channels are combined with broadcast cascaded 2×1 MMI couplers. The active islands in the InP wafer are used for SOAs gates and preamplifiers, while the passive regions are used for waveguide wiring, splitters and cyclic routers. Shallow waveguides allow low leakage amplifiers and low divergence 90° waveguide crossings. Deep etch waveguides are used for splitters and low-radius micro-bends for a more compact chip size. To reduce further the total circuit area, pairs of 1mm long BSS and WSS SOAs share one active island. The cyclic AWG used in the WSS is designed with a channel spacing of 3.2 nm (400GHz) and a free spectral range of 25.6 nm. All inputs and output waveguides are positioned on a 250µm pitch to enable simultaneous access to all the ports using a commercially sourced lensed fibre array. The 136 SOA contacts are wire-bonded to an electronic printed circuit board (not shown). The chip is attached with conductive epoxy to a water-cooled block. The total footprint of the switch is 16.4×6.7mm^2.

WDM and Multi-Path Dynamic Routing Assessment

The chip connectivity is evaluated by using the SOA amplified spontaneous emission as a source and measuring AWG transfer functions at both chip sides. The SOAs on the selected path are biased with 40 mA current. Sixty paths out of sixty-four connections are verified from the wavelength selection SOAs to the input side. From the photonic switching stage to the output side, 432 paths out of 512 paths connections are verified. In total 84% of the paths from the input to the output side of the chip are electrically and optically connected.

Data integrity for multiple simultaneously routed 10 Gb/s wavelength channels is evaluated by optical spectra and bit error rate assessment. The experimental control plane to demonstrate multi-path WDM data routing is schematically shown in Fig. 2.

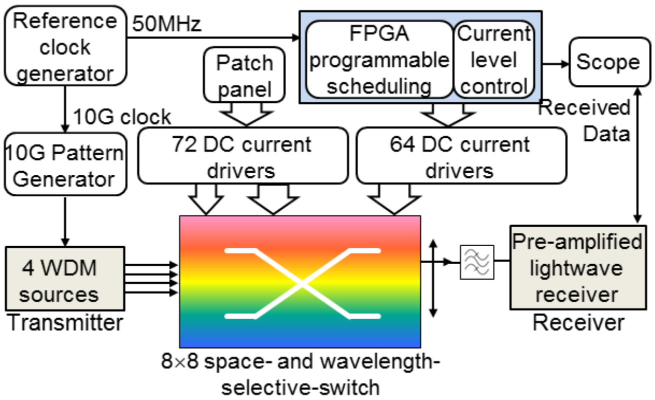

Fig. 2 – Setup for WDM single and multi-port simultaneous routing.

An Altera Stratix III FPGA provides control signals to the high speed current drivers for optical path selection using a round-robin schedule. A common reference clock generator for the FPGA and the bit error rate test equipment allows synchronization between the routed data and the switch controller. Four different wavelength channels, λ_0=1543.1 nm, λ_1=1546.3 nm, λ_2=1549.8 nm and λ_3=1552.7 nm, with a nominal channel separation of 400GHz are multiplexed and modulated using a single Mach-Zehnder modulator with a pseudo random bit sequence (PRBS) of 2^{13}-1 bit length. The WDM signal is then amplified, de-multiplexed, de-correlated and used as input to the device. The chip output is connected to a pre-amplified optical receiver after a 0.95 nm bandwidth filter for broadband noise rejection.

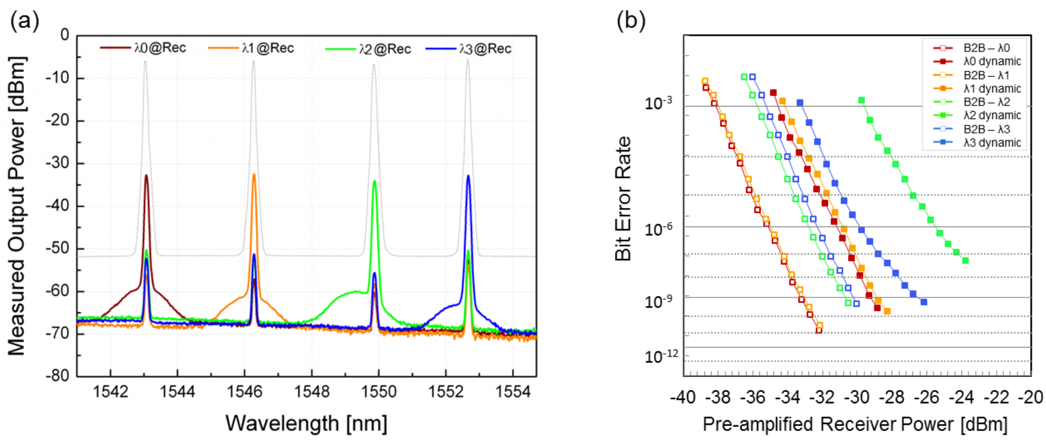

Fig. 3 – Optical spectra (a) and bit error rate measurements (b) for WDM routing through path 0 to 0.

Each path include three SOAs. An average total current per path in the range from 120 to 160 mA is used. The optical spectra of multiplexed channel at input 0 are evaluated at output 0. Optical signal to noise ratios greater than 27.0 dB for 0.1 nm resolution bandwidth are measured for each of the channels in Fig. 3*a*. A mean chip to fibre-array coupling loss is estimated to be 13.5 dB when all waveguides are simultaneously aligned indicating a mean 13.3 dB on-chip loss. Moderate power penalties in the range from 3.6 to 4 dB for three of the four filtered output wavelength data signals are measured (Fig. 3*b*). The third channel is compromised by the pass-band misalignment imposed by the WDM source multiplexer.

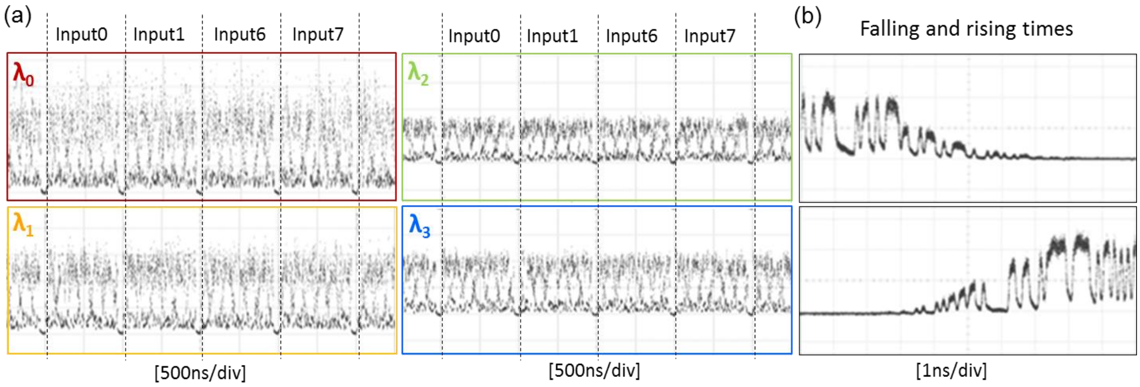

Fig. 4 – Time traces (a), rise and fall time (b) for dynamic multi-port WDM routing at output 0.

To demonstrated simultaneous WDM multi-path data routing the wavelength multiplexed data is split into four copies using broadband splitters and launched into four input ports: 0, 1, 6 and 7 of the chip. Sixteen channels are routed within the 8×8 cross-connect to output port 0. All four input paths are sequentially enabled with a round-robin scheduling and loaded with WDM input signals for dynamic multi-path WDM reconfigurability studies. The color-select SOAs are enabled with fixed current levels of order of 35 mA. The correspondent SOAs are biased with order of 60 mA current and are driven by periodic 1μs pulses with 60 ns guard-bands programmed via the FPGA. Fig. 4*a* shows the time traces of the output WDM signals. Along the x-axis the selected input port changes at each time slot as for the round-robin scheduling. The four sets of wavelengths are selected using external optical filters and are displayed as four separate graphs. Fig. 4*b* also shows fall and rise time for the output signal taken for λ_0 when moving from one time slot to the next one: The switching occurs within 5 ns.

Conclusions

Simultaneous colourless multipath routing for sixteen 10Gb/s data channels is demonstrated through the first integrated 8×8 broadcast and select WDM cross-connect, with low excess power penalties and OSNR values higher than 27 dB/0.01nm.

References

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