Integrated Wavelength Selective Cross-connect for Next Generation Reconfigurable Network

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The wavelength select cross-connect is an enabling component for next generation high data rate dynamic photonic networks. Application range from high performance computing to the backbone and the core network. In this work, we design and fabricate an InP based monolithically integrated 4x4 wavelength selective cross-connect prototype. It uses space as well as wavelength selective switching to achieve connectivity for routing any wavelength from a given input port to any given output port. Power penalty for simultaneous multi-path routing of up to three 40 Gb/sec input signal is evaluated. Less than 0.2dB penalty is measured for multiple and simultaneously routed channels.

Introduction

Optoelectronic wavelength selective cross-connects are important to meet the growing demands for large-bandwidth, high-speed, wavelength-agile circuits for next generation of high-port-count reconfigurable networks [1]. Switching the payload in optical domain eliminates the energy-consuming and bandwidth-limiting optical-to-electronic (and vice-versa) conversion required in conventional electronic cross-connects. The applications range from reconfigurable add-drop multiplexer functionality for providing increased transmission capacity and throughput in the photonic core node [2] to providing high speed switching with low latency for high performance computing applications [3]. Broadcast and select architectures exploiting wavelength selection have been proposed but so far only discrete implementations have been demonstrated. Although highly promising, scalability and power consumption remain the impeding factor for practical implementation. Photonic integration is promising for reducing the number of fibre-pigtails to remove excess coupling losses, decrease footprint and bring down the power consumption in large scale switching fabrics.

Arrayed waveguide grating (AWG) based architectures offer a route to highly-scalable, rich-functionality multi-wavelength cross-connect circuits. Integrated planar lightwave circuits for wavelength cross-connects have been demonstrated using AWG and Mach-Zehnder interferometer based optical switches [4]. Switch reconfiguration times of 2ms and the high power consumption for these switches makes them less attractive for dynamic reconfigurable networks. Integrated Indium Phosphide (InP) based wavelength cross-connects have been demonstrated [5] also using Mach-Zehnder interferometer switches. Alternatively, semiconductor optical amplifier (SOA) can offer on-chip signal amplification and flexibility with fast re-configurability. SOA based integrated wavelength selective switch [6] and broadcast & select space switches [7] have recently been demonstrated with multipath routing showing promising prospects for ease of control.

We demonstrate multi-path high data rate routing in an integrated 4x4 space and wavelength selective cross-connect. The switch incorporates wavelength and space division multiplexing in a broadcast and select architecture on a single monolithic InP circuit. Bi-directional routing and multi-wavelength multi-path simultaneous routing at 10 Gb/sec have been already demonstrated with power penalty less than 1dB [8]. In this work, we successfully demonstrate simultaneous routing of three 40 Gb/s wavelength channels. Data integrity for received channel is evaluated in term of measured power penalty for each co-propagating data channel.

Integrated 4x4 space and wavelength selective cross-connect

The space and wavelength switch circuit is designed to achieve full connectivity for simultaneously routing any wavelength from a given input port to any given output port. The switching is achieved with an input selection broadcast and select switch (BSS) SOA followed by a wavelength selection SOA stage at each output port as shown schematically in figure 1. Appropriate electrical biasing of the SOA gates allows multiple wavelengths to be simultaneously routed to one or more outputs.

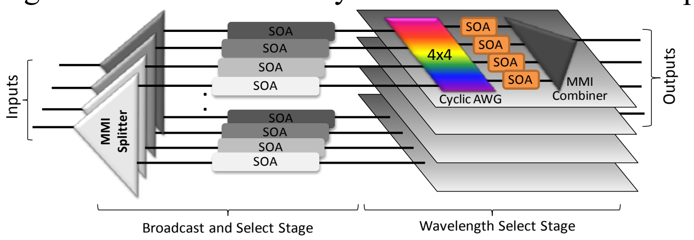

Fig. 1 Schematic of the 4x4 broadcast and select cross-connect.

The monolithically integrated 4x4 space-wavelength cross-connect is fabricated on re-grown active-passive InGaAsP/InP epitaxy in a (JePPIX) multi-project wafer run [9]. To reduce the total circuit area, deep etched waveguides are used for smaller bend radius. Pairs of 750µm long BSS SOAs share one active island. The four SOAs for each WSS are shorter at 140µm each and are accommodated on one active island. Standard 2µm wide shallow etch waveguides are used for SOAs. The total footprint of the switch is 4.2mm x 3.6mm.

Cascaded 1x2 multimode interference (MMI) splitters and shallow etched 90° waveguide crossings make the broadcast connections to the long BSS SOA gates. These input select SOAs enable the WDM data on the selected input port to the following WSS. The four WSS consists of 4 input- 4 output cyclic AWG with SOA gates at each of the four outputs. These shorter wavelength select gates pick out one or more wavelengths to be routed to the output. The BSS SOAs serve a dual purpose of selecting wavelength multiplexed inputs as well as on-chip amplification. The shorter WSS SOA gates primarily function as channel selectors and are not expected to operate with significant gain. The selected wavelength outputs are combined using cascaded 2x1 MMI couplers. All the input and output waveguides are positioned on a 250µm pitch on the same facet of the chip. This enables simultaneous access to all the ports using a single commercially available lensed fibre array. The input-output facet is antireflection coated to avoid on-chip oscillations.

The cyclic AWG is designed with a channel spacing of 3.2nm and periodicity (free spectral range) of 12.8nm. The spectral transfer function for the cyclic AWG is estimated by measuring the output amplified spontaneous emission from each of the

BSS amplifier sequentially biased at 70mA via a single WSS SOA biased at 15mA. The overlaid spectrum is shown in fig 2. A mean 3dB spectral bandwidth of 1.6nm (200GHz) is measured for the AWG pass-bands. The background level is limited by amplified spontaneous emission and is so crosstalk cannot be inferred from this measurement. A mean fibre-to-fibre loss of 24 dB with a standard deviation of 6 dB is measured for 12 functional paths with SOAs operating at current density of 5kA/cm^2. A mean chip to fibre-array coupling loss is estimated to be 7.5 dB when all waveguides are simultaneously aligned. Predicted and measured losses indicate a mean gain of ~15dB for the combination of BSS SOA and WSS SOA. For the best measured path, a net 3dB on-chip loss is measured.

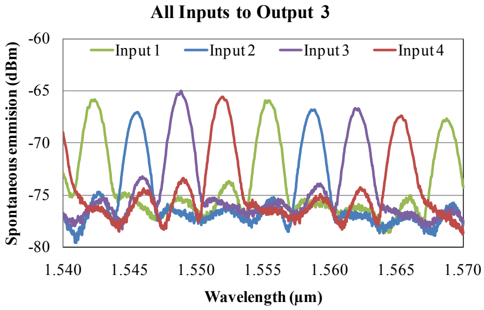

Fig 2. Overlaid spectral response of the cyclic AWG

3 x 40Gb/sec Multi-path Simultaneous Routing

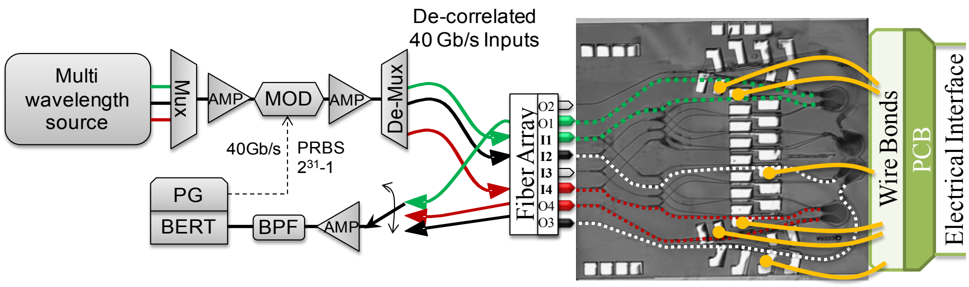

Fig 3. Experimental setup for simultaneous multi-path routing of 3x40 Gb/s data channels

For a multi-port wavelength agile cross-connect, it is desired that simultaneous routing of multiple channels is possible without impairing co-propagating channel. The experimental arrangement for assessing multi-path routing is shown in fig 3. To facilitate the complete assessment of the cross-connect, all 32 SOA contacts are wire-bonded to an electronic printed circuit board which is connected to the multi-current source. The current source provides the bias required for switching ON the required SOAs. Each path between a given input-output ports consists of two SOA gates. By biasing the appropriate SOAs in the circuit, the wavelength channels are routed from any input to any output port. Average bias currents of 92mA and 22mA are used for the long BSS and short WSS SOAs respectively. The circuit temperature was maintained at 18ºC. Polarization controllers are used before the chip to maximize SOA gain for individual channels.

The optical input consists of three tuneable laser sources multiplexed and externally modulated at 40 Gb/s with pseudo random bit sequence pattern of 2^{31}-1 bit length. The WDM data is de-multiplexed and input to port I1, I2 and I4 of the cross-connect. Data integrity for each 40 Gb/s NRZ data channel co-propagating through the cross-connect is evaluated using error rate measurements. Input I3 was not tested due to an unexpected SOA failure**.** The output of the switch is amplified, band-pass filtered (3nm full width at half maximum) and analyzed for bit error rate. Back-to-back measurements were performed by replacing the chip with a variable optical attenuator to maintain the same range of input powers to the receiver. The co-propagating 40Gb/s data at inputs I1, I2 and I4 are simultaneously routed to output ports O1, O3 and O4 respectively.

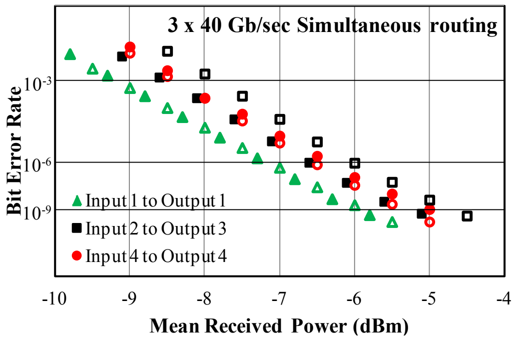

Fig 4. Bit error rate assessment for multiple simultaneous routed 40 Gb/s channels. Back-to-back data for each channel is shown with open symbols.

Bit error rate was assessed for each of the three channels. As seen from fig 4, power penalties of less than 0.2dB are measured for two paths and even negative penalty for one of the paths. Optical signal to noise ratios greater than 36 dB for 0.1nm resolution bandwidth are measured at the output of the chip for each of the three channels. Low penalty for simultaneous multichannel operation demonstrates negligible signal impairment due to crosstalk between the studied channels and bit rate scalability without signal degradation.

Conclusion

We have demonstrated simultaneous high data rate multi-path routing in a monolithic integrated 4x4 space and wavelength switch. Low excess power penalty less than 0.2dB are measured for three 40Gb/s data channels. This is highly promising for next generation reconfigurable networks.

Acknowledgement

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