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Multi-path Routing at 40Gb/s in an Integrated Space and Wavelength Selective Switch

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Abstract—We demonstrate for the first time the simultaneous routing of three 40Gb/s input signals through an integrated 4x4 broadcast and select wavelength selective switch. Power penalty less than 0.2dB is measured for multiple routed channels.

I. INTRODUCTION

Large-bandwidth, high-speed, wavelength-agile circuits are increasingly important for an emerging class of high-port-count reconfigurable networks. Broadcast and select architectures exploiting wavelength selection have been proposed for high performance computing [1] and interconnection networks [2,3] but so far only discrete implementations have been demonstrated. Photonic integration provides a path to remove excess coupling losses, decrease footprint and reduce power consumption. It provides a platform for building networks of radically enhanced complexity and connectivity.

Arrayed waveguide grating (AWG) based architectures offer a route to highly-scalable, rich-functionality multi-wavelength switch circuits [4]. The combination with semiconductor optical amplifier (SOA) based wavelength selective switches gives flexibility with fast re-configurability. SOA based integrated wavelength selective switch [5] and broadcast & select space switches [6] have recently been demonstrated with multipath routing showing promising prospects for ease of control.

In this work, we demonstrate for the first time multi-path high data rate routing in an integrated 4x4 space and wavelength selective switch. The switch incorporates wavelength and space division multiplexing in a broadcast and select architecture on a single monolithic InP circuit. We successfully demonstrate simultaneous routing for up to three 40Gb/s wavelength channels. Data integrity for received channel is evaluated in term of measured power penalty for the first time.

II. INTEGRATED 4X4 SPACE AND WAVELENGTH SELECTIVE SWITCH

The space and wavelength switch circuit is designed to allow routing of WDM inputs at each of the four input ports to the desired 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. Appropriate electrical biasing of the SOA gates allows multiple wavelengths to be simultaneously routed.

Fig. 1. Schematic of the 4x4 broadcast and select switch.

The monolithically integrated 4x4 space-wavelength switch is shown in terms of eight functional blocks in figure 1. Cascaded 1x2 multimode interference (MMI) splitters and shallow etched 90° waveguide crossings make the broadcast connections to 750µm long SOA gates. These connect to each of the four WSS consisting of 4 input- 4 output cyclic AWG with 140µm long SOA gates at each of the four outputs. The AWG is designed with a channel spacing of 3.2nm and free spectral range of 12.8nm. 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. This enables simultaneous access to all the ports using a single v-groove array of eight fibre lenses. The input-output facet is antireflection coated.

The circuit was fabricated on re-grown active-passive InGaAsP/InP epitaxy [7]. To reduce the total circuit area, 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.

The spectral transfer function for the AWG is estimated by measuring the output amplified spontaneous emission from the BSS amplifier biased at 70mA. The four WSS SOAs are sequentially biased at 15mA to act as a broadband optical stimulus. A mean 3dB spectral bandwidth of 1.6nm (200GHz) is measured for the AWG pass-bands. 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/cm². A mean chip to fibre-array coupling loss is estimated to be 7.5 dB when all waveguides are simultaneously aligned. This indicates a mean 9 dB overall on-chip loss for the tested paths. For the best path, a net 3dB on-chip loss is measured. This includes the net gain of the SOA gates as well as an estimated 18dB loss for MMIs and AWG, and additional waveguide scattering losses.

III. MULTI-PATH SIMULTANEOUS ROUTING

Fig. 2. Multi-path routing experiment in an integrated 4x4 space and wavelength selective switch. Composite microscope image of the chip is shown with optical and electrical interface.

The experimental arrangement for assessing multi-path routing is shown in figure 2. The WDM source comprises of three tuneable laser sources externally modulated at 40 Gb/s with pseudo random bit sequence pattern of $2^{31}-1$ bit length. Data integrity for 40 Gb/s NRZ data is evaluated using error rate measurements for single and multiple channels simultaneously routed. Up to three ports of the 4x4 WDM switch are loaded with different wavelength de-correlated data channels at each input. Output 2 was not tested due to an unexpected SOA failure. By biasing the appropriate SOAs in the circuit, the wavelength channels are routed to any available output port. Two SOAs are biased for every selected route. Average bias currents of 92mA and 22mA are used for the long BSS and short WSS SOAs respectively. The circuit temperature was maintained at 18°C.

For single channel routing, data is input at port 2 and routed to output port 3. Polarization controllers are used before the chip to maximize SOA gain. The output of the switch is amplified, band-pass filtered (3dB bandwidth = 2.85nm) 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.

Fig. 3 Bit error rate for single 40Gb/s data channel.

As seen from figure 3, 0.2dB power penalty is observed for single channel routed from input 2 to output 3. Back-to-back data is shown with open symbols. Open eye diagrams are observed for the routed channel and for the back-to-back data.

For a multi-port wavelength agile switch, it is desired that simultaneous routing of multiple channels is possible without impairing co-propagating channel. Data at 40Gb/s is input simultaneously at three inputs (1, 2 and 4) and simultaneously

routed to output ports 1, 3 and 4 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 no-fill symbols.

Table I: Summary of routing condition

Input Port	Output Port	Wavelength (nm)	SOA Bias (mA)		Power Penalty (dB)
			BSS	WSS	
1	1	1556.75	115	25	0.1
2	3	1546.3	90	24.7	-0.6
4	4	1543.2	70	16	0.2

Bit error rate was assessed for each of the three channels. As seen from figure 4, and summarised in Table I, power penalties of less than 0.2dB are measured for two paths and even negative penalty for one of the paths. The negative penalty was attributable to misaligned filters for one wavelength channels. Comparing multi-input operation with the single input operation shows no additional penalty for simultaneous multichannel operation demonstrating no signal impairment due to crosstalk. 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.

IV. CONCLUSION

We have demonstrated for the first time 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, indicating minimal inter-path crosstalk.

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