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Integrated Phased-Array 1x16 Photonic Switch for WDM Optical Packet Switching Application

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Abstract: Integrated InP/InGaAsP phased-array 1x16 optical switch is fabricated and characterized for broadband WDM optical packet switching. Wavelength-insensitive operation covering the C-band and penalty-free transmission of 40-Gbps signal are demonstrated.

Keywords: Transparent optical switches, integrated photonics, optical packet switching, phased arrays.

1. Introduction

Optical packet switching (OPS) is a possible solution to the problem of power consumption and cost in the future high-capacity optical communication networks. In particular, broadband OPS using wavelength-division multiplexed (WDM) payloads is an attractive scheme to obtain low-latency high-throughput switching with relatively small number of ports [1-4]. For the WDM-OPS application, wavelength-independent large-scale switches are required and have been studied extensively [3,4].

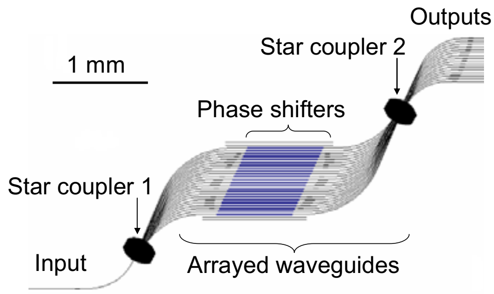
We have recently succeeded in fabricating the first monolithically integrated high-speed 1x16 optical switch based on the phased-array scheme [5], which should theoretically offer wavelength-independent operation. The initial characteristics of the switch were promising with average extinction ratio of 17.0 dB and reconfiguration time less than 6 ns.

Here, we investigate the applicability of our 1x16 switch to broadband WDM-OPS systems for the first time. We successfully demonstrate wavelength-insensitive operation with less than 0.8-dB wavelength-dependent loss across the entire C-band for all output ports. Penalty-free transmission of a 40-Gbps non-return-to-zero (NRZ) signal is also confirmed experimentally.

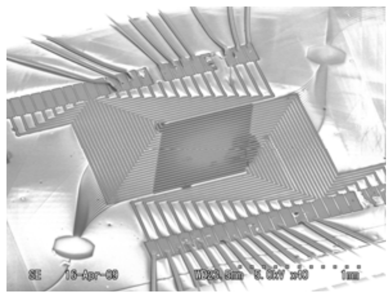
2. Design and fabrication of the switch

The integrated 1x16 optical phased-array switch consists of two star couplers, an input waveguide, 24 arrayed waveguides with phase shifters and 16 output waveguides (Figure 1a). The optical mode distribution at the output plane is engineered via constructive and destructive interference by controlling the phase shifters at the array section independently. Thus, the signal is switched to a selected output at a certain configuration of electrical signals. We calculated the optimal design parameters using the effective index approximation, beam-propagation method and Fourier optics. In order to achieve wavelength-independent operation, we designed all arrayed waveguides to have equal length, so that the path-length-difference-based perturbation to the phase distribution was eliminated [6].

The entire chip consists of shallowly etched ridge waveguide with InP/InGaAsP p-i-n double hetero-junction structure. Bulk InGaAsP Q1.3 guiding layer was employed to achieve efficient phase modulation through either the carrier-injection or electro-optical effect. The device was fabricated using single-step metal-organic vapour phase epitaxy (MOVPE) growth and standard dry-etching techniques [5]. Figure 1b shows the scanning electron microscope (SEM) image of the fabricated switch affixed and wire-bonded on a chip carrier. The total footprint of the switch is 4.1 mm x 2.6 mm. Further reduction in device size should be possible with the use of deeply etched high-mesa waveguides.



(a)

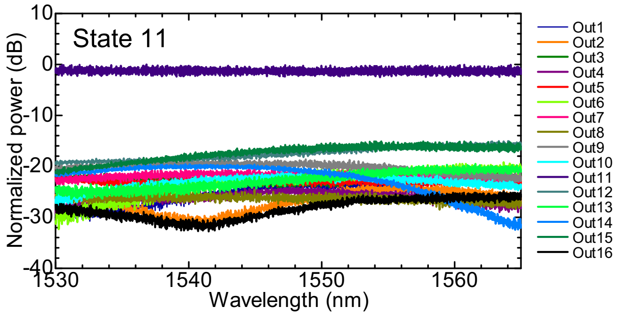


(b)

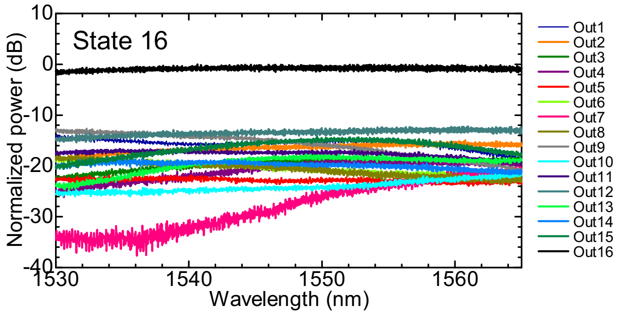
Figure 1 : Mask layout of the 1x16 optical switch (a) and the SEM image of the fabricated device after wire-bonding (b). The device size is 4.1 mm x 2.6 mm.

3. Characterization of the switch

Continuous-wave light from a wavelength-tunable laser was injected to the switch with transverse-electric (TE) polarization mode. First, the driving voltage conditions for all the 16 switching states were found iteratively by sweeping the DC voltages to the 24 phase shifters. The conditions were optimized using a 1.55-μm-wavelength signal and were not modified for other wavelengths throughout the experiment. The wavelength sensitivity of the switch was then measured by sweeping the wavelength of the laser between 1530 nm and 1565 nm. As example cases, Fig. 2 presents the optical power measured at the outputs versus the signal wavelength in State 11 and State 16. The power values are normalized to the maximum value for clear view of the crosstalk levels. We obtained similar characteristics for all the 16 states and confirmed the wavelength-dependent loss to be less than 0.8 dB for all cases. The crosstalk suppression ratio is better than 8.9 dB across the entire C-band for all cases. Since the facets were not antireflection-coated, we observed small Fabry-Perot oscillations in the output power. The peak-to-valley ratio of these oscillations is between 1.5 and 2 dB, corresponding to an estimated on-chip loss of lower than 7 dB for all switching states.



(a)



(b)

Figure 2 : Normalised optical power at the outputs when the switch is at State 11 (a) and State 16 (b).

Finally, we measured the bit-error-rate (BER) characteristics of the switch using a 40-Gb/s NRZ pseudorandom bit sequence (PRBS) optical signal at 1.55-µm wavelength. Figure 3 shows the BER curves and eye diagrams of the output signal at State 1, State 9, and State 16. Clear eye-openings and penalty-free transmission were confirmed in all cases.

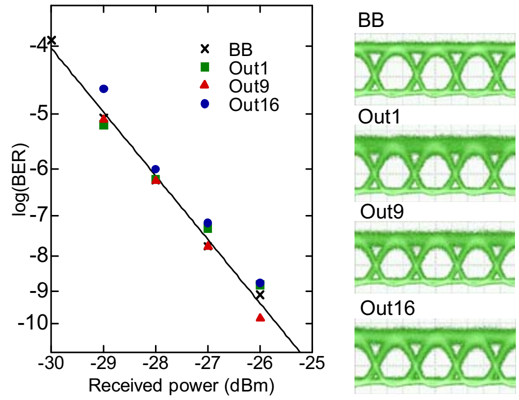


Figure 3: BER characteristics and eye-diagrams of the transmitted 40-Gbps NRZ signal in State 1, 9, and 16.

4. Conclusion

We have fabricated and experimentally investigated the wavelength sensitivity of a monolithically integrated InP/InGaAsP phased-array 1x16 optical switch. The device switches to all outputs in the entire C-band (1530-1565 nm) with the wavelength-dependent loss smaller than 0.8 dB. From the Fabry-Perot oscillations between the facets, the on-chip loss was estimated to be less than 7 dB at all outputs. Penalty-free switching of a 40-Gb/s NRZ signal was also confirmed.

5. References

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