1x8 InP Optical Phased-Array Switch with Integrated Inline Power Monitors

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Abstract: Monolithic InP 1x8 optical switch with inline power monitor array is demonstrated. On-chip optimization of the switch is achieved using the feedback signal from power monitors, paving the way to construct integrated NxN switch matrix.
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1. Introduction

Large-scale integrated optical switch with sub-nanosecond reconfiguration time and broad optical bandwidth is of particular importance in the future optical-packet switching networks and high-performance computing systems. Among several approaches, we have recently developed monolithically integrated InP 1×N switches based on optical phased array, and demonstrated their advantages in terms of relatively small footprint and optical insertion loss, even at a large port count (N) beyond ten [1-3]. By integrating 2N of these 1×N switches in the Spanke architecture [4], we can readily construct an N×N integrated switch matrix. Moreover, monolithic integration of these switches with other active components would offer versatile signal processing functionality on a single photonic integrated circuit (PIC). To cascade multiple switches on a single chip, however, power monitoring at the respective output switch ports is indispensable for optimizing the driving conditions of the switch.

In this paper, we design, fabricate, and demonstrate a monolithic InP 1x8 optical switch with low-loss inline power monitors integrated at the respective output ports. The power monitor utilizes evanescent optical coupling in the contact p-InGaAs layer, which allows simple integration without requirement of any extra fabrication step. Using the feedback signal from power monitors, we successfully achieve on-chip optimization of driving conditions for all eight switching ports with characteristics comparable to those obtained using an off-chip external power meter.

2. Device design and fabrication

The top photograph of a fabricated power-monitor-integrated 1×8 switch is shown in Fig. 1(a). The device consists of two star couplers, 12 phase shifters, and 8 power monitors at the output. By applying phase shift in the arrayed phase shifter, optical interference pattern at the output of the second star coupler is controlled dynamically. The inline power monitors enable measurement of the switched power at respective ports, which can be used in optimizing the driving conditions of the switch.

In order to ease fabrication, the power monitor is designed to have an identical epitaxial structure as phase shifter. Fig. 1(b) shows the cross-sectional structures at the phase shifter and power monitor (left) and at the passive waveguides (right). A 500-nm-thick bulk InGaAsP with an absorption edge at 1.3-μm wavelength (Q1.3) is used as the core waveguiding layer. The phase shifters are operated in forward-biasing conditions, where efficient phase modulation is achieved through band-filling effect and free-carrier plasma effect in the Q1.3 layer. On the other hand, the power monitors are reverse-biased to collect photocurrent generated at the p-InGaAs contact layer, where a propagating mode is coupled evanescently. The overlap of a TE-polarized waveguide mode in the p-InGaAs layer is calculated to be 2.1×10^{-4}, which can generate sufficient amount of photocurrent for monitoring with a moderate length of 800 μm, while keeping the insertion loss small. Since both the phase shifter and power monitor have an identical structure, conventional fabrication process can be applied directly without any extra step for integration of power monitors. Moreover, owing to the all-passive epitaxial design of the device, regrowth-free fabrication is possible, which significantly reduces the cost and yield degradation.

The device was fabricated by a metal organic vapor phase epitaxy (MOVPE) growth, followed by a single-step inductively-coupled-plasma reactive-ion etching (ICP-RIE) to form ridge waveguide structures. The SiO_2 and polyimide layers were employed for the passivation and planarization, respectively. The electrodes at the phase shifters and power monitors were then formed by deposition of Ti/Au using an electron-beam evaporator, followed by lift-off.

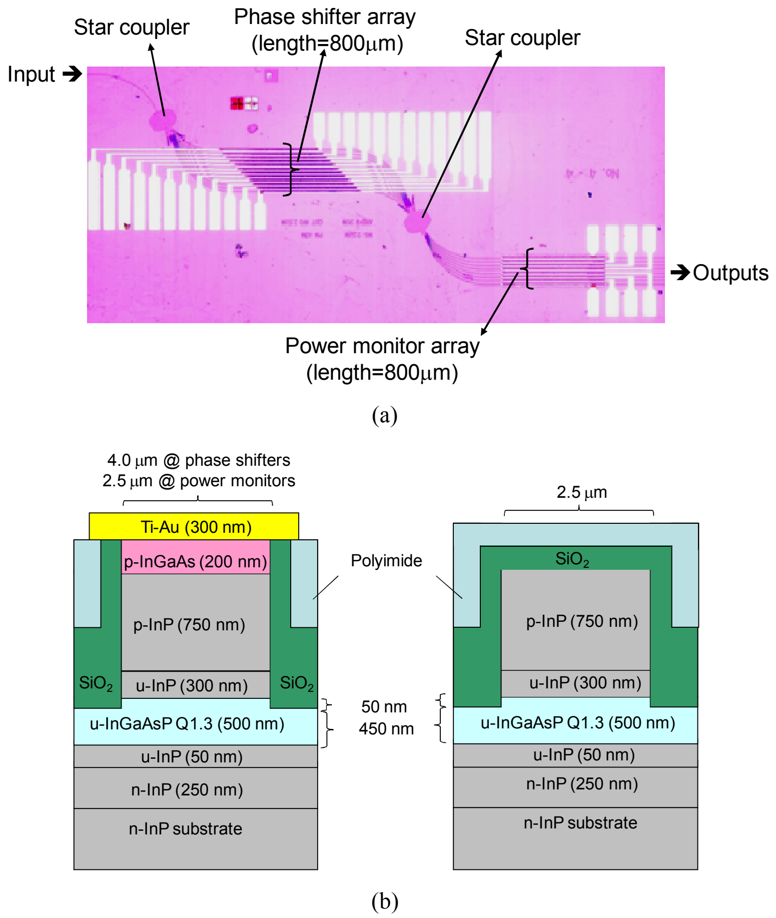


Fig. 1. (a) Top photograph of a fabricated 1×8 optical phased-array switch with integrated power monitor array (4.5 mm × 2.1 mm). (b) The cross-sectional structure at the phase shifter and power monitor (left) and at the passive waveguide (right).

3. Experiment

First, we confirmed operation of the inline power monitor using 1550-nm-wavelength TE-polarized light. Fig. 2 shows the photocurrent measured under different reverse biases (0-7 V) as a function of actual optical power. The plots are calibrated by the case without an optical input, so that the effect of dark current is subtracted. As shown in Fig. 2, under a reverse bias larger than 5V, there is a clear linear relationship between the output power and photocurrent. We thus adopt a reverse bias of 5 V in the subsequent experiment to derive the driving conditions for the switch.

Optimization of the 1×8 switch was carried out by an iterative method to maximize the optical power at respective output ports while sweeping the injection current to each phase shifter. The optical power was measured either by the on-chip power monitors or by a conventional method of coupling the light from each port with a lensed fiber and measuring the power using an external power meter [1,2]. As an example case, Fig. 3 displays the photocurrent (a) and optical power (b) at the output port #8 as a function of injection current to phase shifter #1. The photocurrent trace resembles that of the actual output power reasonably, indicating that it can indeed be used as a feedback signal in optimization. The conditions for all eight output ports were thus derived using the on-chip power monitors. Table 1 summarizes the extinction ratio of 1×8 switch under two sets of driving conditions, which were derived using the on-chip inline power monitors and external power meter, respectively. Both cases resulted in comparable performance with the averaged extinction ratio of 15.6-15.7 dB.

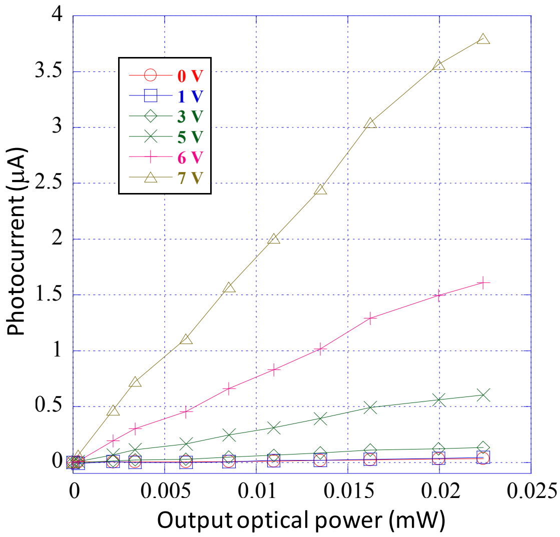
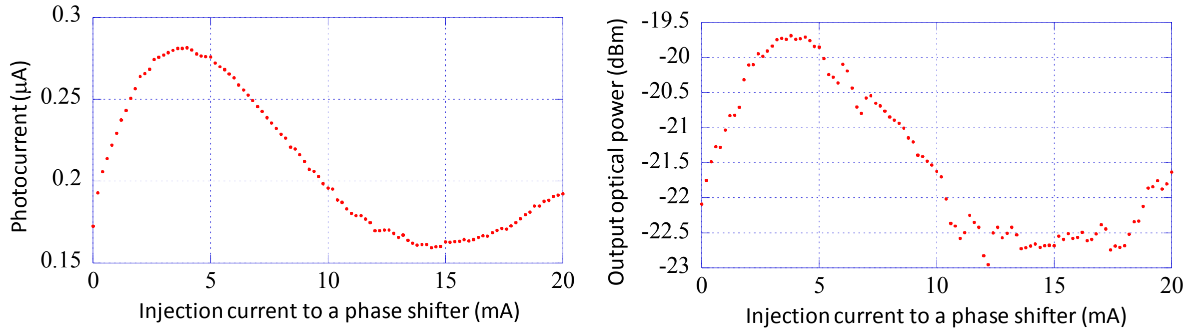


Fig. 2. Photocurrent at inline power monitor as a function of output optical power measured under a reverse bias from 0 to 7 V.



(a) (b)

Fig. 3. Measured photocurrent (a) and output optical power (b) at port #8 as a function of injection current to the phase shifter #1.

Table 1. Extinction ratio of the 1×8 switch under the current injection conditions derived by using on-chip inline power monitor and external power meter.

	Average	Maximum	Minimum
Using on-chip power monitor	15.6 dB	24.3 dB	9.4 dB
Using external power meter	15.7 dB	21.6 dB	8.8 dB

4. Conclusion

We have fabricated a monolithic InP 1x8 optical switch integrated with inline power monitors at output ports. Since the power monitor utilizes the same epitaxial structure as the phase shifter, high-yield low-cost integration is achieved without a need for any extra fabrication step. Using the feedback signal from the power monitors, driving conditions of the phase shifters for all eight switching ports have been derived successfully with the extinction ratios comparable to those obtained by the conventional method of using an external power meter. The demonstrated on-chip power monitor allows us to integrate the 1×N switches in cascades to construct N×N integrated switch matrices as well as other highly functional PICs.

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