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Proposal of 1×N Optical Mode Switch Based on Spatial Single Dimensional Mode

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Abstract: *For a rapid increase of the recent data traffic, 1×N optical mode switch based on spatial single dimensional mode is newly proposed in this paper. Simulated results of this new switch show all 64 switching among 8 modes (0th – 7th) under low excess loss (1.6 dB) due to the precise eigen-mode realization.*

Keywords: Spatial division multiplexing (SDM) devices; SDM technologies for photonic switching and networking

1. INTRODUCTION

For a rapid increase of the recent data traffic, ROADM (Reconfigurable Optical Add/Drop Multiplexer), based on spatial single dimensional mode, has been proposed [1, 2]. We have also proposed the N×N optical mode switch which is able to switch modes as the key device of the space-mode- (SM) ROADM [3]. In this paper, the 1×N mode switch is newly proposed, regarding evolution for higher order mode: scalability. We have designed 1×8 optical mode switch and simulated all 64 switching among 8 modes (0th – 7th) under low mode switching loss (< 1.6 dB).

2. HIGHER ORDER MODE EVOLUTION OF N×N OPTICAL MODE SWITCH

In the proposing SM-ROADM system, mode information of optical signal is used as "addressing". In the SM-ROADM concept, there are no direct communication lines between transmitters and receivers. Instead, there is a whole communication channel, which is able to circulate information. For the traffic control of multiple mode signals, it is important that the mode of each signal is switched to another mode by optical mode switch.

2.1 Eigen-mode realization issue of the N×N optical mode switch

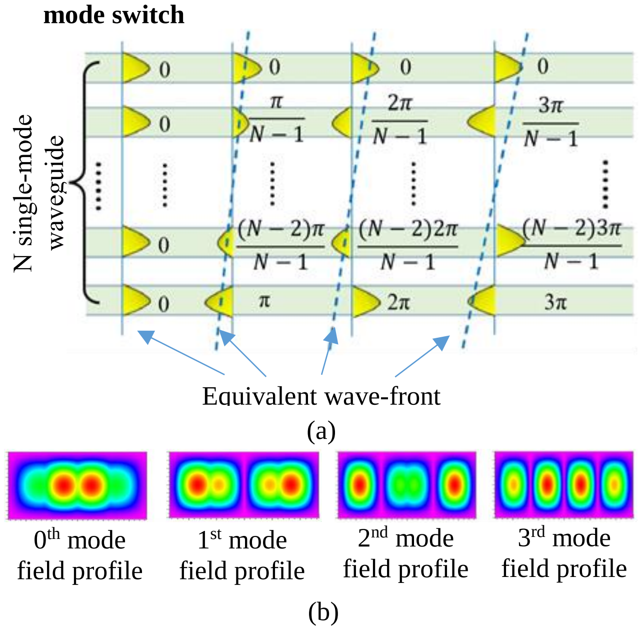

Fig. 1. (a) Phase profiles of spatial single mode in a waveguide and (b) field profiles of modes (0th – 3rd).

If only based on spatial single dimensional mode, optical mode switch is easier in the device-design rather than LP mode. Figure 1 shows the phase and field profiles of spatial single mode.

We have already reported the 4×4 optical mode switch based on the single dimensional mode [3]. Whereas the 4×4 optical mode switch can switch modes to any other different modes among 0th, 1st, 2nd and 3rd order modes, this switch configuration had a problem of precise eigen-mode realization, which is important for MIMO (multi-in / multi-out) less operation.

2.2 Operation principle of the 1×N optical mode switch

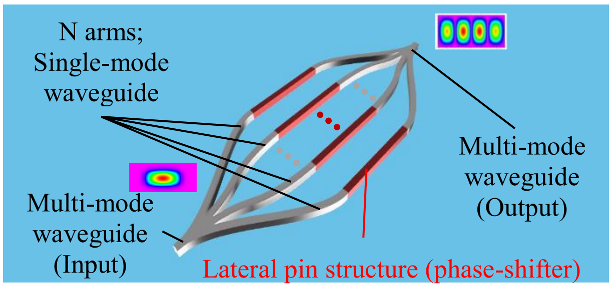

Fig. 2. Schematics of 1×N optical mode switch.

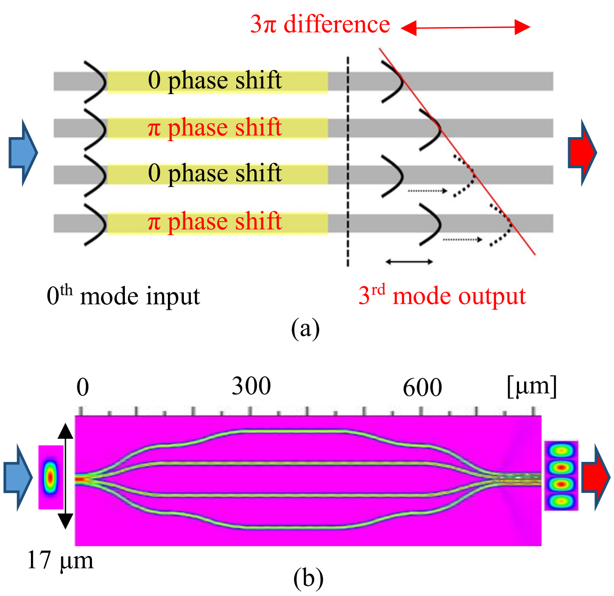

Fig. 3. (a) Switching mechanism and (b) simulation result from 0th order mode to 3rd order mode).

We propose the 1×N optical mode switch which enable precise eigen-mode realization. The schematic diagram of the 1×4 optical mode switch configuration is shown as an example in Fig. 2. Multimode input waveguide is connected to a 1×4 power splitter which separates eigen-mode into N-fold single mode in each arm. Each arm possesses mode sifting region which realizes mode conversion. Then the separated light is coupled toward output multimode waveguide. This 1×N optical mode switch secures the switching from one mode to another one. The 1×N optical mode switch is operated by electric current injection into pin phase-shifters. Lateral pin structure make π difference of phase-shift at each arm, which leads to mode-change in the output signal.
For example, when we shift π as shown in Fig.3, we get 3rd order mode output. Wave-fronts drawn in broken-lines are imaginary wave-fronts (2π difference).

3. SIMULATION RESULTS OF 1×8 OPTICAL MODE SWITCH AND DISCUSSIONS

We designed 1×8 optical mode switch and confirmed fundamental switching among 8 modes (0th – 7th order mode). Beam propagation method (BPM) was used for the simulation.
For confirmation of the switching quality, we have estimated mode switching loss. Mode switching loss Lm is defined as the ratio of output mode power Po versus input mode power Pi (see equ. (1)).

$$L_m = -10\log\frac{P_o}{P_i} \quad \text{[dB]} \qquad (1)$$

Table 1. Mode switching loss of 1×8 optical mode switch simulation. Input mode (vertical axis) vs. output mode (lateral axis).

		Output mode							
		0^{th}	1^{st}	2^{nd}	3^{rd}	4^{th}	5^{th}	6^{th}	7^{th}
Input mode	0^{th}	0.2	0.2	0.9	0.9	0.3	0.4	0.3	0.3
	1^{st}	0.2	0.01	1.6	1.4	0.4	0.4	0.2	0.2
	2^{nd}	0.4	0.4	0.2	0.3	0.3	0.3	0.3	0.2
	3^{rd}	0.8	0.7	0.5	0.1	0.2	0.1	0.2	0.1
	4^{th}	0.3	0.1	0.6	0.4	0.1	0.08	0.08	0.07
	5^{th}	0.3	0.1	0.4	0.2	0.08	0.04	0.07	0.04
	6^{th}	0.2	0.08	0.5	0.4	0.09	0.07	0.03	0.02
	7^{th}	0.2	0.3	0.4	0.2	0.07	0.04	0.02	0.004

Mode signal noise ratio (SNR_m) is also estimated. Definition of SNR_m is as follow:

$$SNR_m = 10\log\frac{P_o}{P_N} \quad \text{[dB]} \qquad (2)$$

where P_N is the power of other mode components.

Table 2. Mode signal noise ratio (S/N) of 1×8 optical mode switch simulation. Input mode (vertical axis) vs. output mode (lateral axis)

		Output mode							
		0^{th}	1^{st}	2^{nd}	3^{rd}	4^{th}	5^{th}	6^{th}	7^{th}
Input mode	0^{th}	13.5	14.4	6.3	6.3	10.9	10.6	11.2	11.4
	1^{st}	14.4	27.0	3.7	4.1	10.1	10.5	13.2	13.5
	2^{nd}	10.1	9.9	13.9	12.1	11.2	11.9	12.3	12.9
	3^{rd}	7.1	7.5	9.4	15.2	14.0	14.9	14.5	14.9
	4^{th}	12.2	15.1	8.6	10.0	14.7	17.1	17.1	18.2
	5^{th}	12.1	15.7	10.4	12.6	17.4	20.0	18.2	20.4
	6^{th}	14.2	17.4	9.1	10.4	16.7	17.9	20.9	24.0
	7^{th}	12.4	15.6	10.3	12.6	17.6	20.0	24.0	30.0

As shown in Table. I and Table II, we could successfully confirm that the configuration proposed realize relatively precise eigen-mode for all switching state. The estimated worst mode switching loss was 1.6 dB. We will plan to implement the proposed 1×N optical mode switch in the future.

4. CONCLUSIONS

We have proposed and simulated new configuration of 1×N optical mode switch. We have designed 1×8 optical mode switch and simulated all 64 switching among 8 modes (0th – 7th) by BPM simulation. Mode switching losses and mode of less than 1.6 dB has been successfully confirmed.

5. ACKNOWLEDGEMENT

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