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Novel 2x2 Photonic Switch Based on Multimode Interference Effect

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***Abstract*—We propose a 2x2 photonic switch that uses the multimode interference effect (MMI) and analyze its properties by the finite difference beam propagation method (FD-BPM). We then consider the characteristics of several well-known matrix switch architectures based on our proposed 2x2 switches.**

I. Introduction

Photonic switches using the multimode interference (MMI) effect have many potential advantages such as compactness, suitability for integration, low polarization and wavelength dependence, and good fabrication tolerance [1], [2]. However, conventional MMI photonic switches have large crosstalk and are bulky. In this paper, we have proposed a novel 2x2 MMI photonic switch with parallel electrodes in its multimode waveguide regions to improve these issues. In addition, the losses of matrix switches using the proposed 2x2 switches have been estimated.

II. Device Structure and Principle

The structure and operating principles of the proposed switch are shown in Fig. 1. It has electrodes in the MMI waveguide which cause an index reduction when a voltage is applied to them. The length of the MMI waveguide for the photonic switch is set to be $3L_\pi$. As shown in Fig. 1(a), the photonic switch guides the light from port 1 to port 4 when no voltage is applied to electrodes 1 and 2 (cross state) [3]. Here, L_π is defined as follows

$$L_\pi = \frac{4n_r W_{out}^2}{3\lambda_0}, \qquad (1)$$

where λ_0 is the wavelength, n_r is the core effective refractive index, and W_{out} is the effective width of the MMI waveguide. On the other hand, as shown in Fig. 1(b), the input light into port 1 is switched to port 3 (bar state) when a voltage is applied to electrodes 1 and 2 because the effective positions of the MMI waveguide side boundaries are formed just under electrodes 1 and 2. The distance between those electrodes, W_{in}, satisfies the following equation;

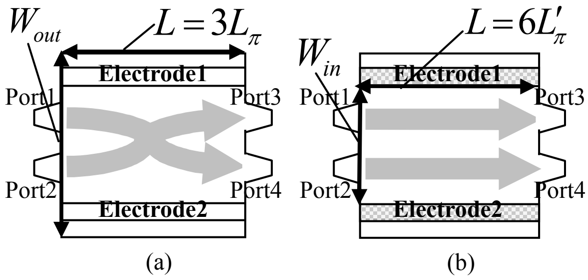

Fig. 1. Schematic and operating principles of 2×2 MMI switch; (a) the cross state (b) the bar state.

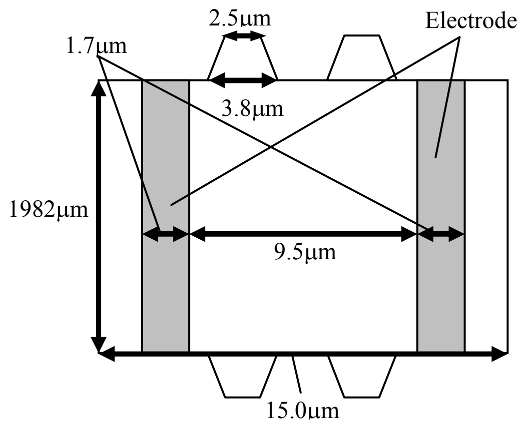

Fig. 2. Parameters of a 2x2 MMI switch used for analysis of the properties.

$$L'_\pi = \frac{4n_r W_{in}^2}{3\lambda_0}, \qquad (2)$$

where L'_π is the length of the MMI region.

III. Analysis

The fundamental switching characteristics of the MMI photonic switch were analyzed by the finite difference beam propagation method using the (3, 3) Pade approximation. The material that forms the switch is assumed to be a III/V compound semiconductor in order to attain high-speed switching and a large refractive index change. The plasma effect with carrier injection may be used. The calculation was carried out for light in TE mode, with a wavelength of 1550 nm. Figure 2 shows the parameters of the 2x2 MMI switch that was used for the analysis. Taper waveguides were used as the input and output waveguides to prevent any large-angle diffraction of the light into the multimode waveguide and to reduce light leakage at the electrodes. It was assumed that the maximum refractive index change that could be induced by applying a voltage, Δ*n*, was -0.03, and that the absorption loss was 5 cm^{-1}. The length and width of the switch were 1982 and 15.0 μm, respectively. It should be noted that the device size would be much smaller when the maximum refractive index change is large. It is because that the tapered input and output waveguides are not necessary and the width and the length of the MMI region can be reduced. Figure 3 shows the output powers from port 2 and port 3 as a function of the index change when the input power from port 1 was 0 dBm. It had insertion losses of 5.0 and 5.6 dB, and cross-talk of -45.4 and -46.6 dB for the cross state and the bar state, respectively. The insertion losses and cross-talk are largely dependent on the width of the MMI waveguide and the distance between the electrodes rather than the length of the MMI waveguide.

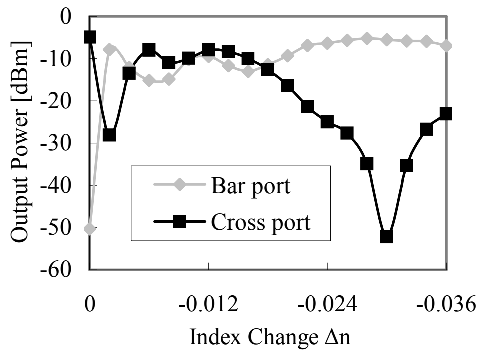

Fig. 3. Calculated output characteristics of 2x2 MMI switch.

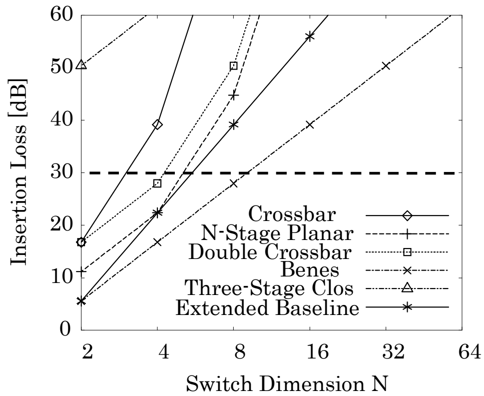

Fig. 4. Insertion loss for various optical switch architectures using the proposed 2x2 MMI switches.

IV. Matrix Switch Architecture

The characteristics of a matrix switch fabricated using our proposed 2x2 MMI photonic switches should be considered for practical applications in a photonic network. In this section, we discuss six well-known matrix switch architectures: the optical crossbar, the N-stage Planar, the double crossbar, the Benes, the three-stage Clos, and the ex tended baseline [4].

The insertion losses for the different architectures are shown in Table 1. α is the insertion loss of the 2x2 switch in dB.

TABLE I
INSERTION LOSSES FOR SEVERAL MATRIX SWITCH ARCHITECTURES

Network	Insertion Loss
Crossbar	2(N-1)α
N-Stage Planar	Nα
Double Crossbar	(N+1)α
Benes	$(2\log_2 N-1)\alpha$
Three-Stage Clos	(2n+2m+2r-3)α
Extended Baseline	$(3\log_2 N-2)\alpha$

Figure 4 shows the insertion losses when α = 5.6 dB. According to Ref. [4], the maximum attenuation allowed without amplification or regeneration was assumed to be 30 dB. The maximum matrix size should be 8x8, even with the Benes architecture, in order to satisfy that condition.

V. Conclusion

We proposed a novel 2x2 MMI photonic switch. Analysis of its properties shows that it could achieve very low cross-talk of less than -40 dB. The insertion loss characteristics of several matrix switches composed of the proposed 2x2 switches were compared, and it was shown that the maximum matrix size was 8x8 for the proposed switch without optical amplification.

Reference

[1] S. Nagai, G. Morishima, H. Inayoshi and K. Utaka, “Multimode Interference Photonic Switches (MIPS),” IEEE J Lightwave. Technol., Vol. 20, No. 4, pp. 675-681(2002).

[2] F. Wang, J. Yang, L. Chen, X. Jiang and M. Wang, “Optical Switch Based on Multimode Interference Coupler,” IEEE Photon. Technol. Lett., Vol. 18, No. 2, pp. 421-423(2006).

[3] Lucas B. Soldano and Erik C. M.Pennings, “Optical Multi-Mode Interference Devices Based on Self-Imaging: Principles and Applications,” IEEE J Lightwave. Technol., Vol. 13, No. 4, pp. 615-627(1995).

[4] R. A. Spanke, “Architectures for guided-wave optical space switching systems,” IEEE Commun. Mag., vol. 25, pp. 42–48(1987).