Passive Waveguide Circuit for BPSK Label Identification Consisting of Cascaded Asymmetric X-junction Couplers

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Abstract— **In photonic label networks, recognition of optical labels is one of the key functions. We propose a passive waveguide device to identify of BPSK labels with high scalability. The device was numerically confirmed by FD-BPM.**

Keywords- label identification; passive circuit; asymmetric X-junction coupler

I. INTRODUCTION

Optical processing is expected to be applied in routing nodes for improving the processing speed and reducing power consumption.[1,2] In label routing networks, a function to recognize optical labels is one of the key function. Various optical circuits have been proposed to realize optical label identification. Various systems distinguishing optical labels expressed by optical codes have been studied.[3,4] We have investigated passive optical circuits for recognition of optical coded labels in binary phase-shift-keying (BPSK) and quadric PSK (QPSK). [5,6] These devices have a drawback in scalability because the output signals do not have enough contrast between the destination output port and the other output ports. In this report, we propose to improve the contrast of outputs with a scalable structure for a restricted code set. The basic module device is numerically confirmed by finite-difference beam-propagation-method (FD-BPM).

II. BASIC MODULE FOR INTEGRATED CIRCUIT

Fig.1 shows the basic module for identifying optical four-bit BPSK coded label. The module consists of four asymmetric X-junction couplers. One of the asymmetric X-junction coupler is shown in Fig.2. The output depends on the incident phases. The electric fields of the output optical waves are related with the input fields by

$$\begin{pmatrix} A_{out} \\ B_{out} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix} \begin{pmatrix} A_{in} \\ B_{in} \end{pmatrix}, \qquad (1)$$

where phase terms due to the propagation along the waveguides are eliminated for simplicity. The basic module in Fig.1 consists of spatially aligned four couplers. The input to output relation of the fields is derived as

$$\begin{pmatrix} D_{out1} \\ D_{out2} \\ D_{out3} \\ D_{out4} \end{pmatrix} = \frac{1}{2} \begin{pmatrix} 1 & 1 & 1 & -1 \\ -1 & -1 & 1 & -1 \\ -1 & 1 & -1 & -1 \\ -1 & 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} A_{in1} \\ A_{in2} \\ A_{in3} \\ A_{in4} \end{pmatrix}. \qquad (2)$$

It is noted that the center crossed waveguides is ideally just the crossing without interaction. The waveguide pattern has to be carefully designed to suppress the path-length difference between the connecting waveguides, that is, between B_1-C_1 and B_3-C_2 and between B_2-C_3 and B_4-C_4.

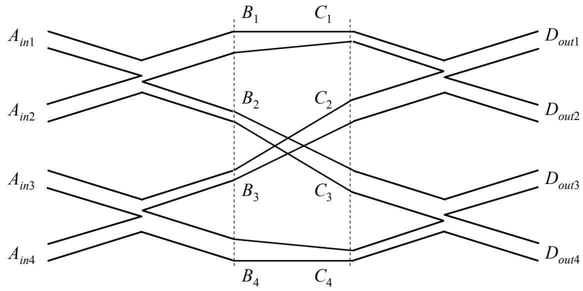

Fig.1 Basic module for four-bit coded labels.

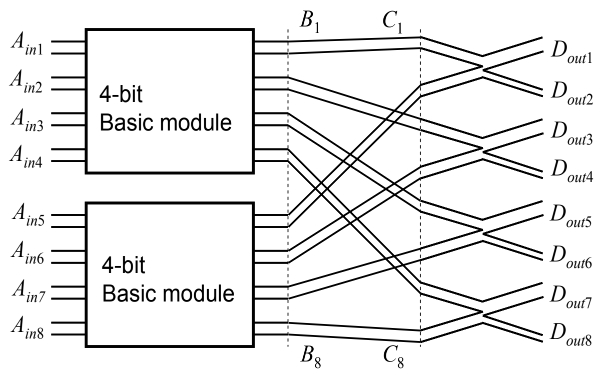

Fig.2 A scaled-up circuit for eight-bit coded labels.

We consider BPSK coded labels as given by

$$\left(\boldsymbol{A}_1^{(1)} \boldsymbol{A}_2^{(1)} \boldsymbol{A}_3^{(1)} \boldsymbol{A}_4^{(1)} \right) = \left(\boldsymbol{A}_1 \boldsymbol{A}_2 \boldsymbol{A}_3 \boldsymbol{A}_4 \right) = \begin{pmatrix} 1 & -1 & 1 & 1 \\ -1 & 1 & 1 & 1 \\ 1 & 1 & 1 & -1 \\ 1 & 1 & -1 & 1 \end{pmatrix}, \qquad (3)$$

When these labels are incident in parallel at four input ports, we obtain the output fields given by

$$\left(\boldsymbol{D}_1^{(1)} \boldsymbol{D}_2^{(1)} \boldsymbol{D}_3^{(1)} \boldsymbol{D}_4^{(1)} \right) = 2 \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}. \qquad (4)$$

This means that the incident coded labels have their own output at only one destination output port for each label.

Next, we consider scalability to eight coded labels. The identifying circuit is shown in Fig.2, where the basic module is the circuit shown in Fig.1. The output fields can be related to the input fields by

$$
\begin{pmatrix} D_{out1} \\ D_{out2} \\ D_{out3} \\ D_{out4} \\ D_{out5} \\ D_{out6} \\ D_{out7} \\ D_{out8} \end{pmatrix}
= \frac{1}{2\sqrt{2}}
\begin{pmatrix}
1 & 1 & 1 & -1 & 1 & 1 & 1 & -1 \\
-1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 \\
-1 & -1 & 1 & -1 & -1 & -1 & 1 & -1 \\
1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 \\
-1 & 1 & -1 & -1 & -1 & 1 & -1 & -1 \\
1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 \\
-1 & 1 & 1 & 1 & -1 & 1 & 1 & 1 \\
1 & -1 & -1 & -1 & -1 & 1 & 1 & 1
\end{pmatrix}
\begin{pmatrix} A_{in1} \\ A_{in2} \\ A_{in3} \\ A_{in4} \\ A_{in5} \\ A_{in6} \\ A_{in7} \\ A_{in8} \end{pmatrix} \quad (5)
$$

We consider the coded labels as given by

$$
\begin{aligned}
&\left(\boldsymbol{A}_1^{(2)} \boldsymbol{A}_2^{(2)} \boldsymbol{A}_3^{(2)} \boldsymbol{A}_4^{(2)} \boldsymbol{A}_5^{(2)} \boldsymbol{A}_6^{(2)} \boldsymbol{A}_7^{(2)} \boldsymbol{A}_8^{(2)} \right) \\
&= \begin{pmatrix} \boldsymbol{A}_1 & \boldsymbol{A}_1 & \boldsymbol{A}_2 & \boldsymbol{A}_2 & \boldsymbol{A}_3 & \boldsymbol{A}_3 & \boldsymbol{A}_4 & \boldsymbol{A}_4 \\ \boldsymbol{A}_1 & \overline{\boldsymbol{A}}_1 & \boldsymbol{A}_2 & \overline{\boldsymbol{A}}_2 & \boldsymbol{A}_3 & \overline{\boldsymbol{A}}_3 & \boldsymbol{A}_4 & \overline{\boldsymbol{A}}_4 \end{pmatrix},
\end{aligned} \quad (6)
$$

where $\overline{\boldsymbol{A}}_i$ is the complement of $\boldsymbol{A}_i$. The output for these coded labels are given by

$$
\begin{aligned}
&\left(\boldsymbol{D}_1^{(2)} \boldsymbol{D}_2^{(2)} \boldsymbol{D}_3^{(2)} \boldsymbol{D}_4^{(2)} \boldsymbol{D}_5^{(2)} \boldsymbol{D}_6^{(2)} \boldsymbol{D}_7^{(2)} \boldsymbol{D}_8^{(2)} \right) \\
&= 2\sqrt{2} \begin{pmatrix}
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
-1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -1 & 0 & 0 & 0 & 0
\end{pmatrix}.
\end{aligned} \quad (8)
$$

It is found from eq.(8) that only one different output port has the value for each code. Therefore these eight labels can be identified with this circuit.

III. BPM SIMULATION

As mentioned in the previous section, the path-length difference should be suppressed in the device designing. A two-dimensional model of the basic module for BPM simulation is shown in Fig.3. The fundamental waveguide made of Ge-doped silica waveguide has width of W=3.0µm. The core and the cladding regions have refractive indices of 1.45 and 1.461, respectively. The wider and the narrower waveguide of the asymmetric X-junction couplers have widths W_w=3.4 µm and W_n=2.6 µm, respectively.

Two curved arc waveguides at the top and the lowest waveguides around the center part are introduced to adjust the path length. The output intensities from the four output ports for input label $\boldsymbol{A}_1$ vary as a function of the offset of the arc waveguides as shown in Fig.4. When the arc offset is 26.5µm, path lengths are equally adjusted.

The fields along the circuits for four input labels are shown in Fig.5, where the intensity of the electric fields is plotted. Four input labels are found to have one output at each destination output port as shown in Fig.6. The contrast ratio of the output from the destination port to the outputs from the other ports is larger than 25dB.

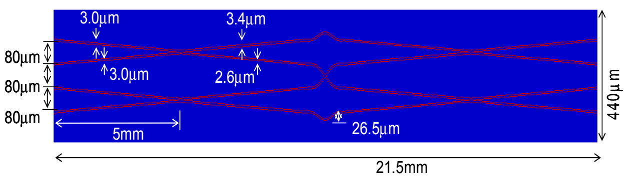

Fig.3 Two-dimensional BPM model.

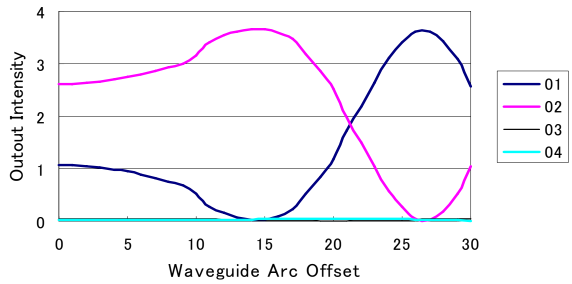

Fig.4 Output intensities for input $\boldsymbol{A}_1$ as a function of offset of arc waveguides.

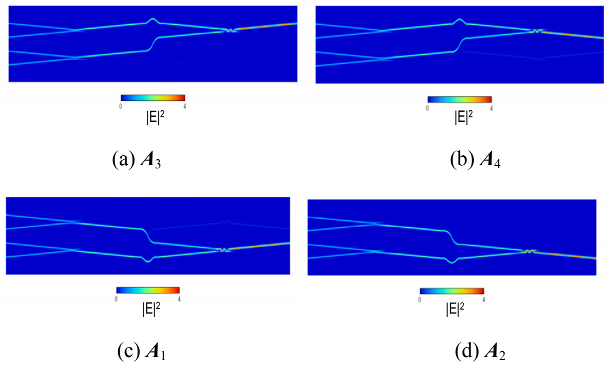

Fig.5 BPM simulation results for input labels.

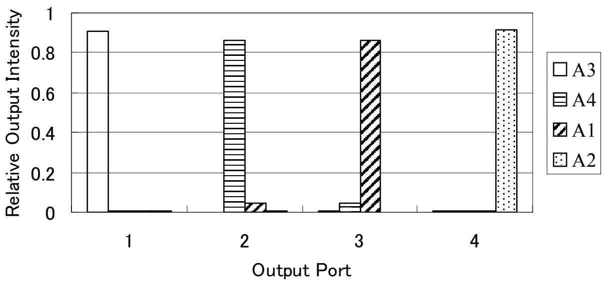

Fig.6 Relative output intensities for four input labels.

IV. CONCLUSIONS

We proposed integrated-optic passive circuits for identifying BPSK coded labels. The processing characteristics were verified by FD-BPM simulation. More refined analysis and experimental verification will be investigated.

ACKNOWLEDGEMENT

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