

A Reconfigurable Broadband Space-Mode Router using Multiplane Light Conversion

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Abstract - We propose a reconfigurable broadband space-mode router using multiplane light conversion. For a 3-mode and 3-channel router, realizing a routing pattern similar to the AWG, insertion loss and mode dependent loss below 2dB was achieved over a 60 nm bandwidth using 7 phase plates.

Keywords—mode router, broadband, multiplane light conversion

I. INTRODUCTION AND PRINCIPLE

Spatial modes can be used as a resource for not only transport but also networking. The straightforward approach for routing of spatial modes [1] is to first demultiplex the spatial modes, followed by single-mode switching/routing, and finally mode multiplexing. A silicon-photonic space-mode switch was demonstrated in [2] using this approach. Since it is envisioned that space-division multiplexing (SDM) will be overlaid on wavelength-division multiplexing (WDM), broadband operation of space-mode switching/routing will be highly desirable [3]. In this paper, we show, via simulation, that reconfigurable space-mode routing can be realized in a single liquid crystal on silicon (LCoS) spatial light modulator (SLM) using the multiplane light conversion (MPLC) technique, without separate (de)multiplexing and single-mode switching. As an example, we demonstrate a 3-channel, 3-mode router with a routing pattern similar to the arrayed waveguide grating (AWG), and with both insertion loss (IL) and mode dependent loss (MDL) below 2 dB over a bandwidth of 60 nm.

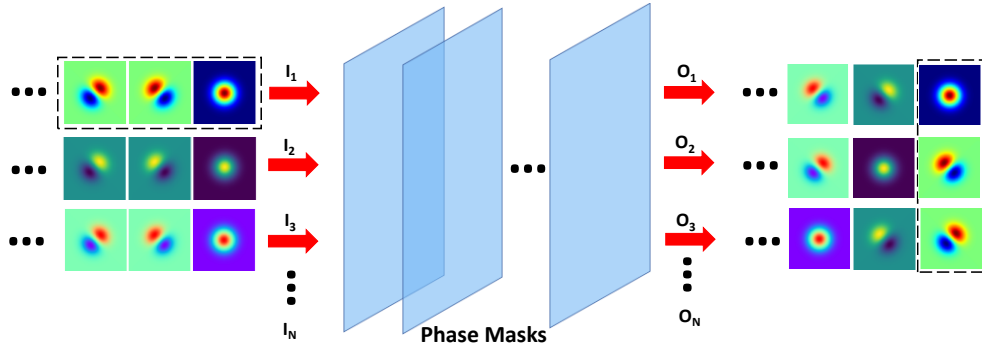


Fig. 1: Schematic of the space-mode router using MPLC. The dash boxes show modes in the first channel are routed to all output channels.

The operation of the device is schematically shown in Fig. 1. It has N input channels, denoted by $I_1, I_2, \dots, I_N$, and each channel supports N spatial modes. After propagating to the output end, all N modes in a specific spatial channel are separated to all output channels $O_1, O_2, \dots, O_N$. The degrees of freedom in the input (output) is N^2 , which is the product the number of modes and number of space channels. All input (output) degrees of freedom are orthogonal since they are either spatially separated or their spatial overlapping integrals are zero if they do overlap in space [4]. Therefore, the routing between the inputs and outputs can be realized using MPLC since it can perform any unitary transformation.

II. SIMULATION RESULTS

We use a 3-mode, 3-channel router device to demonstrate this proposal, so we have 9 inputs and 9 outputs in total, which are shown in Fig. 2(b). The input and output channels are designed to be equally spaced on a ring, as shown in Fig. 2(a), considering the symmetry in the layout, i.e., each input channel will separate all modes to all output channels. We choose Hermite-Gaussian (HG) modes because they are the eigenmodes of a few-mode fiber with a parabolic-index distribution in the Cartesian coordinate. Fig. 2(b) shows all modes at each channel for inputs (first row) and outputs (second row). The number labeled at up-left corner of each figure denotes the channel number. 7 phase masks are used to fulfill a smooth, broadband transition, which are shown in Fig. 2(c). The phase masks have 5- μm pixel pitch, 800×800 -pixel size, and 18 mm spacing. The HG_{00} mode has a mode field diameter of 300 μm . Spacing between any two channels are 1050 μm . Inputs and outputs plane are overlapped with the first and last phase plate, respectively.

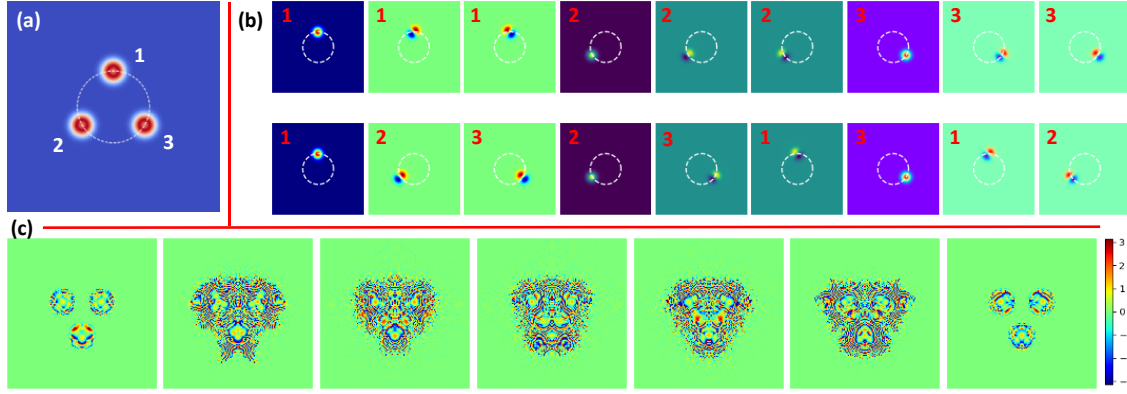


Fig. 2: (a) Layout of input and output channels. (b) First row shows all modes at each channel on the input end, and the second row shows all corresponding output modes. The number at the up-left corner denotes the channel number. (c) 7 phase masks are used for the broadband design.

Two general steps are used in the calculation. **Step 1:** We use a modified wavefront matching algorithm to calculate the mask pattern [5]. To realize a broadband design, 15 wavelengths points are calculated between 1530 ~ 1570 nm, together with the field matching of 9 inputs from forward and 9 outputs from backward direction in each iteration. The algorithm runs on a CPU (Intel Core i7-7820X) and converges in 30 iterations. **Step 2:** Once the masks updated, we digitalize the phase value to 64 levels between $-\pi$ and π , then propagate the 9 ideal inputs through the systems to get the actual outputs $E_B(x, y)$, which are then overlapped with the ideal outputs $E_b(x, y)$ to calculate the complex coupling matrix C ($C = \iint E_B(x, y) E_b^*(x, y) dx dy / \iint |E_b(x, y)|^2 dx dy$, with $*$ denotes conjugation). $|C|$ and $|C|^2$ gives the amplitude and power of the coupling matrix, respectively. In step 2 we scan 101 wavelength points from 1500 to 1600 nm and calculate matrix C at each wavelength. IL and MDL are extracted from C using the singular value decomposition, giving the overall performance of this device. Fig. 3(a) and (b) show the actual output field and amplitude coupling matrix $|C|$ at 1545 nm. Fig. 3(c) shows IL and MDL have a bandwidth of over 60 nm below 2 dB. The lowest MDL appears at 1545 nm with a value of 0.77 dB.

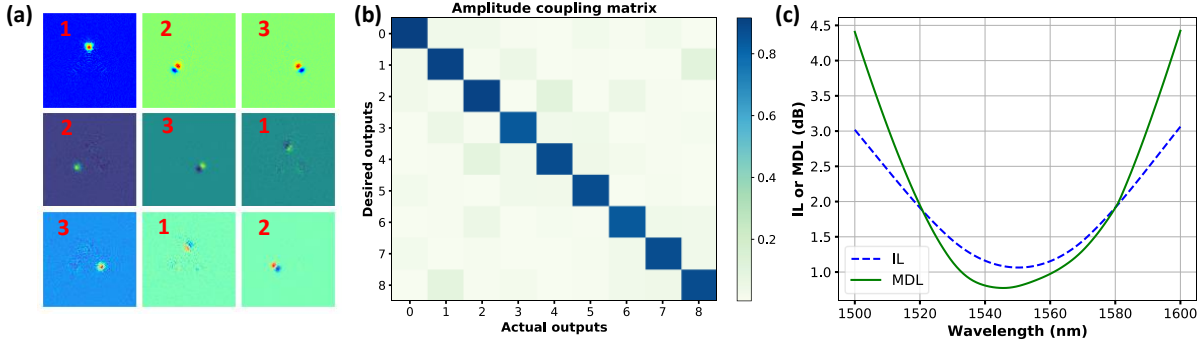


Fig. 3 (a) The actual outputs at 1545 nm. (b) The amplitude coupling matrix at 1545 nm. (c) The IL and MDL as a function of wavelength.

III. CONCLUSION

In summary, we propose a reconfigurable, broadband space-mode router using the MPLC technique on a LCoS SLM. For a 3-channel, 3-mode router with a routing pattern similar to the AWG, IL and MDL below 2 dB over a bandwidth of 60 nm was achieved via numerical simulation.

ACKNOWLEDGMENT

Funding: Army Research Office (W911NF1910385); National Science Foundation (ECCS-1808976, -1932858); Office of Naval Research (N00014-20-1-2441). Y. Zhang acknowledges the financial support from the China Scholarship Council (CSC) Scholarship No. 201606250006.

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