Multimode demultiplexer for space division multiplexing by using nano-pixel

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***Abstract*—Multimode demultiplexer is proposed by using nano-pixel configuration in a square of 3.0 × 3.0 μm^2. The simulated results demonstrate mode XT of 13.6 dB and 11.4 dB for 0th and 1st order modes, respectively.**

Keywords— nano-pixel, multimode demultiplexer

I. Introduction

Space division multiplexing (SDM) using spatial mode has been widely researched and high capacity transmission has been demonstrated so far [1-2]. One technical issue is mode-demultiplexing and normally MIMO (multi-in/multi-out) is introduced in the system. This is, however, not a cost-effective approach especially in short-distance applications including inter-connection, and PIC (photonic integrated circuits)-based physical demultiplexing scheme is one of the future ways for SDM-based inter-connections. In this paper, we newly propose a mode-demultiplexer [3-4] using nano-pixel [5]. The proposed device secured space-mode in each output in a very compact area of 3.0 × 3.0 μm^2 for 0th and 1st order modes. As a result, mode XT of 13.6 dB and 11.4 dB were achieved for 0th and 1st order modes, respectively.

II. Concept of Demultiplexer Design

Figure 1 shows the schematic of nano-pixel waveguide. 3.0 × 3.0 μm^2 square region is divided into 150 × 150 nm^2 square nano-pixels, that corresponds to 20 × 20 pixels in the waveguide. 130 nm nano-hole may be arranged in each pixel according to the designed-layout which is explained below. We use 220 nm Si-core on top of SiO_2 cladding.

As to the design, we used deep learning (supervised learning) [6] for phase matching in initial layout before taking DBS (direct binary search) [7] to avoid local-minimum decision. The parameters we used are summarized into Tab. 1 [8]. Vgg16 is a widely used neural network for pattern recognition in the field of computer vision [9]. To deal with single-dimensional mode set in this work, 2D convolutional kernel is used. The kernel size is 3 × 3. It determines the size of feature maps in the processing of an image [10].

For the both process of deep learning and DBS, one of the important points in the design process is how to set the design-criteria, especially for higher order modes as it is not appropriate with single criteria (normally it is excess loss). In this work we used vector criteria of excess loss and phase-profile matching so as to secure each mode-profile at the output. Then, we exploited DBS algorithm for final optimization. As to the waveguide widths of input, TE_0 output and TE_1 output, are 1 μm, 0.4 μm, and 0.8 μm, respectively.

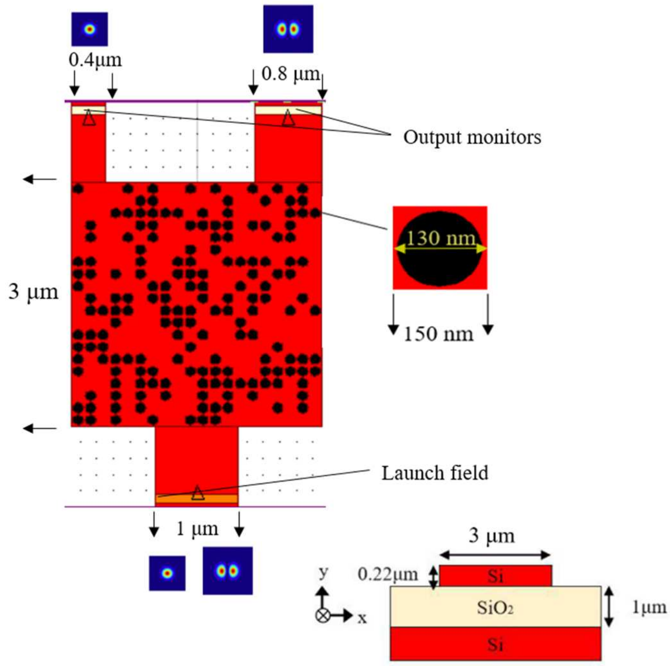

Fig.1 nano-pixel pattern design of demultiplexer in simulation

TABLE I. Deep-Learning Network Parameters

Neural Network	Vgg16
Convolution	2D
Class number	3
Activation function	ReLU
Batch size	16
Learning rate	0.0001
Training set : Validation set	9 : 1
Library(environment)	PyTorch
Validation accuracy	95.7%

III. Results and Discussion

We used FDTD (finite-difference time-domain) method for the simulation.

Figure 2 shows the simulated results of the optimally designed nano-pixel demultiplexer. Figure 2 (a) corresponds to 0th order mode and (b) corresponds to 1st order mode

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propagation. As shown in these figures, the injected 0th order mode (TE_0 mode) propagates toward left output whereas the injected 1st order mode (TE_1 mode) propagates toward right output waveguide. Figure 2 (c) and (d) indicate the monitored normalized output power at left and right ports, respectively. In the figures, blue line corresponds to TE_0 mode whereas green line corresponds to TE_1 mode. The estimated excess loss from these results were 1.03 dB and 1.15 dB for TE_0 and TE_1 modes, respectively. And the estimated mode XT were 13.6 dB and 11.4 dB for TE_0 and TE_1 modes, respectively.

To evaluate the mode quality in each output, we verify the intensity profile of the output. Figure 3 shows the results. As illustrated in the figure, the intensity profiles well matches with each mode. Much important thing is to secure phase profile, therefore, we also verify the phase profile (see Fig. 4). As is indicated in the figures, proper phase profile for TE_0 and TE_1 modes were confirmed successfully, therefore, we conclude that mode demultiplexing using nano-pixel has potential to be realized by using nano-pixel. As the device size is very compact, therefore, we believe that much more higher-order mode evolution (like 100 modes) will be possible to be realized in the near future.

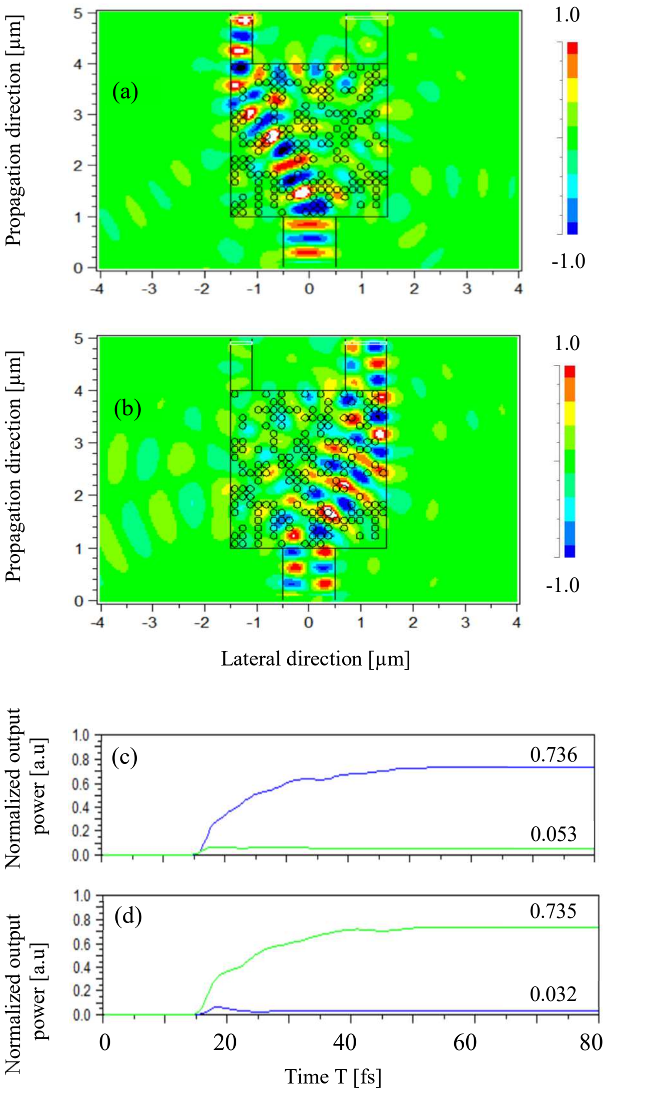

Fig. 2 The electromagnetic field of light and normalized Ey (electric field in vertical direction) of optimized demultiplexer. (a)(c) TE_0 input (b)(d) TE_1 input.

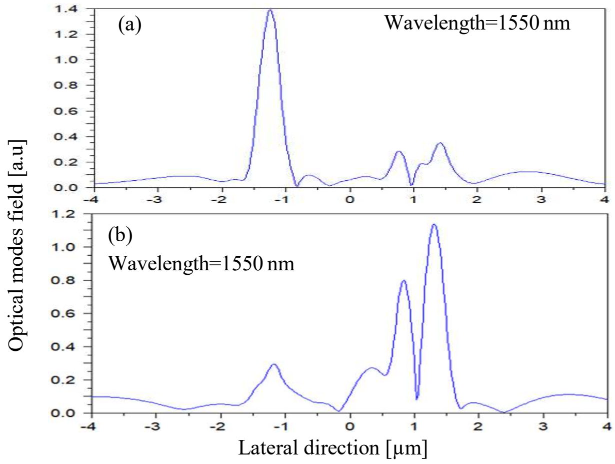

Fig.3 Intensity profile at output. (a) TE_0 (b) TE_1.

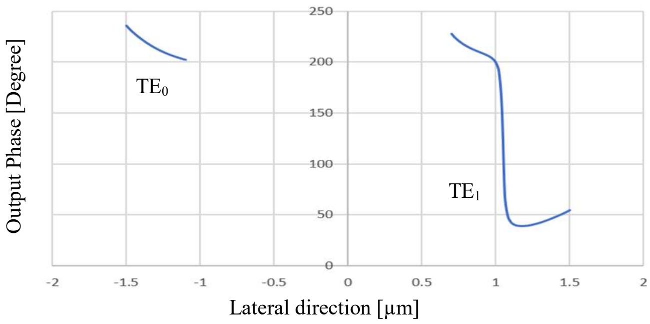

Fig.4 Phase profile at the output for TE_0 and TE_1.

IV. Conclusion

Multimode demultiplexer was proposed by using nano-pixel configuration in a square of $3.0 \times 3.0\ \mu m^2$. The simulated results demonstrate mode XT of 13.6 dB and 11.4 dB for 0th and 1st order modes, respectively. We believe that much higher-order mode evolution will be realized soon based on this very compact nano-pixel configuration.

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