Three-Dimensional Low-loss Waveguide Shuffler and Splitter / Combiner using Novel Mirror Structure

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Abstract: *We present 3D low-loss optical waveguide shuffler and splitter/combiner which will become important for high-channel count optical interconnect. We used a couple of TIR mirrors at a shuffling point and could avoid crosstalk and crossing-loss.*

1. Introduction

There is a large demand for higher speed data communications for the off-chip I/O bandwidth of central processor unit (CPU) in personal computers and server systems because the on-chip performance of CPU has become improved rapidly. A wiring density of electric circuits on a printed circuit board (PCB) is restricted by the electromagnetic interference during the wirings, and date rate is restricted by the dielectric signal loss for electrical interconnect. On the other hand, the optical interconnect is not restricted that speed by the propagation medium and wiring density, so the rapid development is expected as the next generation data-communications. Recent progresses in optical interconnects realize low power [1], high speed [2], and high data rate density [3]. Especially, a polymer waveguide (PWG) is very useful wiring of the optical interconnect. Since optoelectronic circuit of high wiring density can be realized by a PWG, it is considered as an important means of the high-speed data communications in a short distance between elements on PCB such as CPU, memory, and optical connector. The communications between the boards through optical connectors can be also considered. However, in order to realize the board-to-board parallel optical interconnection, we should think a channel shuffling mechanism such as a transmission from a transmitter (Tx) ch1-ch12 to Receiver (Rx) ch24-ch13. We should also think a splitter such as a transmission from Tx-ch1 to Rx-ch1 and Rx-ch2 simultaneously, and a combiner such as a transmission from Tx-ch1 and Tx-ch2 to Rx-ch1.

Hereafter, we explain the conventional shuffler and splitter / combiner technology. There have been a lot of proposals such as a fiber / waveguide intersection topologies on the same plane (Fig.1). But when N becomes larger, the wiring design becomes a very complex topology. And there are also the demerit such as a crosstalk and a crossing loss at each waveguide intersection point.

2. Three-Dimensional Waveguide Shuffler and Splitter/Combiner Design

In order to solve these problems of the conventional shuffler and splitter / combiner, we should superimpose two waveguide array films in different angles (90 degrees, for example) such as Fig.2 and send an optical signal from ch-N of the top waveguide sheet to ch-M of the bottom waveguide sheet through a couple of 45deg mirrors.

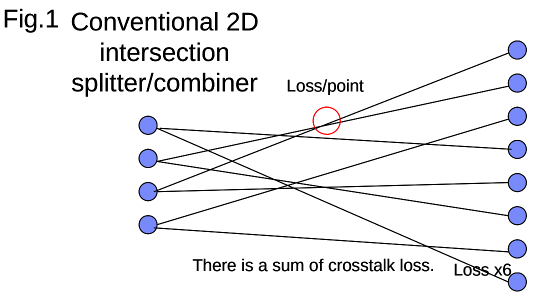

Fig.1: A conventional 2D intersection splitter/combiner,

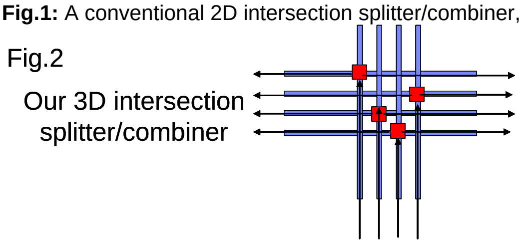

Fig.2: Our 3D intersection splitter/combiner

There are a total structure of our shuffler (Fig. 3(a)), a detailed structure of this (Fig. 3(b)), and a mirror-to-mirror transmission image as an optical via (Fig. 3(c)).

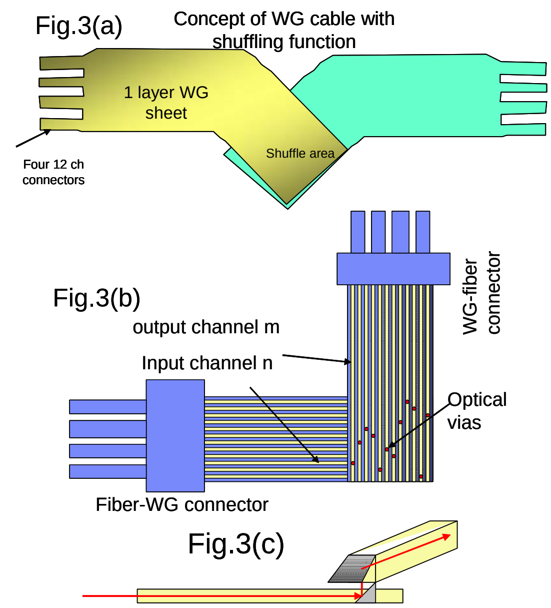

Fig. 3(a): A total structure of our shuffler, **Fig. 3(b):** A detailed structure, **Fig. 3(c):** A mirror-to-mirror transmission image as an optical via

We also realized a shuffler and a splitter simultaneously by sending an optical signal from ch-M of the top waveguide sheet into a valley line of 90deg V groove mirror at ch-N of the bottom waveguide sheet. Fig. 4(a) shows a 3D image of our splitter, and

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Fig. 4(b) shows a top view of this. We can also realize a combiner by just sending an optical signal in two directions simultaneously. We can realize a shuffler and a splitter / combiner between arbitrary channels by these simple waveguide paths without a crosstalk and a sum of crossing loss which were contained in a conventional splitter. We can also realize low loss mirror-to-mirror transmission by making an improved concave shape on a 45deg mirror surface.

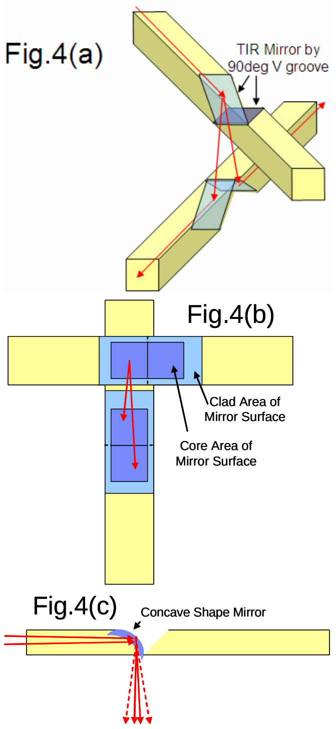

Fig. 4(a): A 3D image of our splitter, **Fig. 4(b):** A top view of this, **Fig. 4(c):** A low loss splitter using a concave shaped 45deg mirror

3. Fabrication of our 3D Waveguide Shuffler

Fig. 5(a) shows our parallel type 3D waveguide shuffler prototype. We fabricated double layered waveguide array and made a 90 deg V groove at both surfaces of this waveguide films using an excimer laser based micro-machining system. The 90 deg V grooves act as TIR mirrors of waveguides. Fig. 5(b) shows our orthogonal type 3D waveguide shuffler prototype. The optical path turns 90 degrees when an optical signal goes from an upper waveguide to a bottom waveguide. We demonstrated the 3D waveguide shuffler using these prototypes. The positioning error between an upper waveguide and a lower waveguide was under ±10μm. And a coupling loss from an upper mirror to a bottom mirror was 2.1dB. We should make a curved mirror, or a lens configuration, or a high-refractive index structure attached mirror in order to realize a lower-loss shuffler.

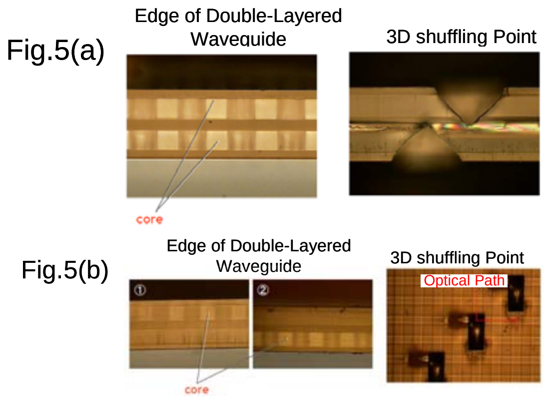

Fig. 5(a): our parallel type 3D waveguide shuffler prototype, **Fig. 5(b):** our orthogonal type 3D waveguide shuffler prototype

When our shuffling splitter becomes two steps, this splitter can split N-ch into 2N-ch firstly, and can split 2N-ch into 4N-ch secondly. The first waveguide layer consists of 8ch waveguide array, for example. Then we just turn the photo lithography mask for the first waveguide layer into 90 degrees, and we can build up the second waveguide layer under the first layer. Then we just make 45 deg TIR mirrors at our desirable intersection points of the first and the second waveguides on the top of the first layer and on the bottom of the second layer using a pulse laser. And we can make 16ch optical outputs from the split waveguides. Then we just turn the mask for the second waveguide layer into 90 degrees, and we can build up the third waveguide layer under the second layer. Then we just make 45 deg TIR mirrors at our desirable intersection points of the second and the third waveguides on the top of the second layer and on the bottom of the third layer using a pulse laser. And we can make 32ch optical outputs from the split waveguides. One of the advantages of our method is an easy construction of low loss splitter by a simple design and easy process. And when optical signal detection limit is 10dB loss, we can realize the 3rd step splitter with 4 waveguide layers using a single photo lithography mask. We said that it's easily possible to split waveguides till 3 steps (2^3 = 8 partition = 9dB).

4. Conclusions

We presented our three-dimensional low-loss optical waveguide shuffler and splitter/combiner which will become important for high-channel count optical interconnect. We made a couple of 45deg TIR mirrors at a shuffling point of a waveguide using an excimer laser based micro-machining system. We could realize a shuffler and a splitter / combiner between arbitrary channels by these simple waveguide paths without a crosstalk and a sum of crossing loss which were contained in a conventional splitter. We wish to thank Koji Choki and Mutsuhiro Matsuyama (Sumitomo Bakelite Co., Ltd.) for their helpful suggestions and discussions. This work was supported by NEDO.

5. References

[1] S. Nakagawa, et. al., Tech. Dig. OFC 2008, OThS3.
[2] T. Anan, et. al., Tech. Dig. OFC 2008, OThS5.
[3] C. Schow, et. al., Tech. Dig. OFC 2008, OMK5.