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Two-dimensional fiber array with integrated topology for short-distance optical interconnections

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Abstract *A two-dimensional fiber array is proposed for short-distance parallel optical interconnections. In contrast to conventional fiber bundles, interconnection topology is integrated by configuring the spatial position of the input and output end of each fiber.*

1. Introduction

Optical technologies are expected to play a critical role in short-distance interconnections such as that between VLSI chips [1]. While novel high-density two-dimensional (2D) optoelectronic-optomechanical devices have been successfully introduced in the field (such as vertical-cavity surface-emitting lasers (VCSEL) or micro electro mechanical systems), a proper integration technique and a reliable technology for managing high-density plane-to-plane optoelectronic interconnects is still to be conceived and developed. In this article, we present a prototype of a fiber-based interconnection module, possessing a fixed interconnection topology between inputs and outputs. Moreover by combining these light-efficient, mechanically-stable, and geometrically-scalable optical interconnection modules, it is possible to build a robust multi-stage interconnection networks able to provide an arbitrary set of permutations.

2. Two-dimensional (2D) fiber module with integrated interconnection topology

Diffractive optical elements (DOE) can be used for free-space parallel interconnections to obtain an interconnection topology between input and output device planes including fanning-out capability from a single optical source to several different destinations. However, advanced design and fabrication technologies may be needed in order to obtain high-diffraction efficiencies. Scalability of interconnection becomes a difficult issue with the enlargement of the arrayed devices.

In contrast, fiber-based interconnections can provide good transmission efficiency. It has also been shown that these can be more efficient in terms of volume-consumption compared with free-space optics [4]. However, image fiber bundles, which have already been demonstrated in optical interconnection applications, provide only point-to-point connection that copies the input pattern to the exit.

With these considerations, as well as the nature of multi-stage interconnection systems that will be mentioned later, we developed a 2D optical fiber-based module that contains its own internal interconnection topology.

Figure 1 represents a VCSEL array connected to a photodetector (PD) array through a bunch of optical fibers. In this example, each channel corresponds to a unique fiber. The spatial position of inputs and outputs is selected based on the targeted interconnection topology.

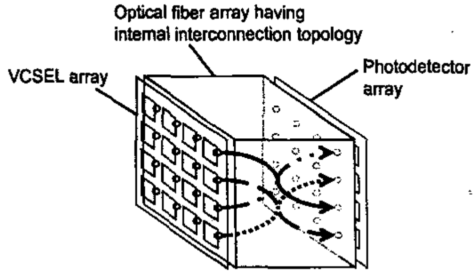

Figure 1 Two-dimensional fiber array having its own internal interconnection topology

3. Pipelined System and the 2D fiber module

Figure 2 shows an example of an optical architecture where the paradigm of modular, fiber-based interconnections fits well. In this example, six layers of processing element (PE) array are arranged in a pipelined fashion [2]. Each PE has its owns optical inputs and outputs (I/O). The fiber modules are placed between these PE arrays, thus providing a particular interconnection topology between adjacent 2D arrays.

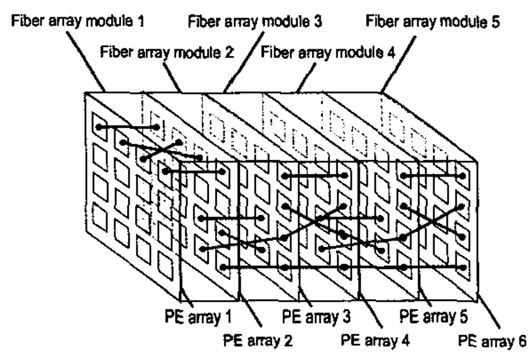

Figure 2 A Multi-stage interconnection network

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In Figure 2 one can see the interconnection topology of the well known Banyan multistage-interconnection network (folded in 2D and having 16x16 I/O in the example). As suggested by this example, many multi-stage interconnection networks needs only point-to-point interconnections following a specific permutation between input and output planes; the absence of fan-out is another reason why the fiber-based paradigm can match well to the multi-stage network approach.

As can be seen, fiber array module 3 and 5 of Fig.2 are built by combining basic topologies shown in Fig. 3(a). In short, the required interconnections used within the 16x16 Banyan network of the example has been achieved by combining only two elemental modules. This fact indicates that a relatively small set of fiber modules can be enough for providing complex architectures and functions. Research on the elemental modules required for building most common multistage networks is underway.

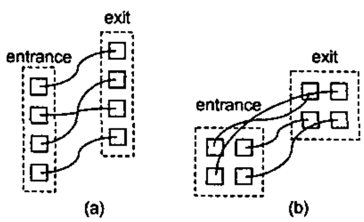

Figure 3 Basic interconnection used in the Banyan example

4. Experiment

To experimentally validate the approach, a 4x4 fiber array was designed and implemented. Figure 4 shows its output. We can see the arrays of fibers (250μm pitch) integrated into a 2mm x 3mm ferrule with 5mm thickness. Prototype characteristics are summarized in Table 1, while its interconnection topology is schematically depicted in Fig. 5 (a).

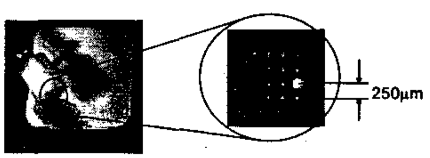

Figure 4 The fiber array

We characterized the module by directly coupling a VCSEL array to its inputs, and imaging the output on a CCD camera. The VCSEL array has 8x8 channels and the same pitch than the fiber module. Operating wavelength is 854nm. Figure 5 (c) shows the exit of the fiber array observed through a CCD camera, for different VCSEL emission patterns. Based on the topology shown in Fig. 5(a), proper connection is achieved through the fiber array. The alignment tolerance for a single channel has been measured (Fig. 6). The half-maximum width is about 50μm. The maximum transmission efficiency is 38.45% from one VCSEL channel to the exit of the fiber.

5. Conclusions

A fiber-based parallel optical interconnection prototype module has been presented that integrates a specific interconnection topology. Design concerns include light transmission efficiency, scalability, and nature of multi-stage interconnection based systems. A comprehensive, technologically grounded comparison between free-space and fiber-based interconnections as well as related alignment and packaging issues is also being pursued [3][4].

Table 1 Specifications of the fiber array

Two ferrule prototypes: Zirconium and SiO2
Pitch: 250 ± 5 μm
Multimode graded index fibers: NA=0.21
core 50μm, cladding 125μm
Transmission loss: 3dB/km
Length: 30 cm

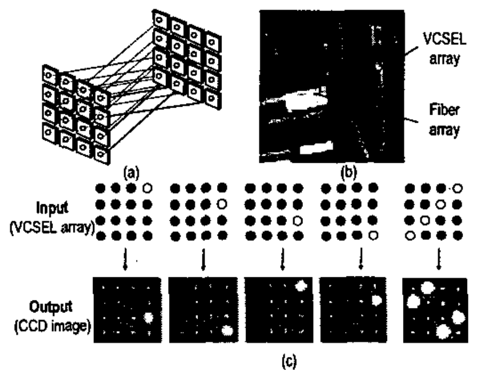

Figure 5 Interconnection topology and experimental results

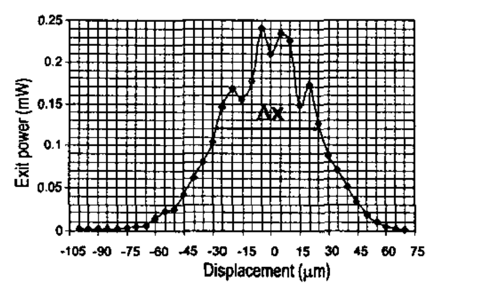

Figure 6 Alignment tolerance for a channel

References

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