Polymer-based Channel Waveguide Array for Large Fanout Optical Interconnects

R. Shih and R. T. Chen
Physical Optics Corporation
2545 W. 237th Street, Suite B
Torrance, CA 90505

ABSTRACT

Various components needed for optical backplane applications have been demonstrated from gelatin-based polymer integrated optic material. An array of waveguides have been realized with packaging density as high as 1250 channels/cm and loss of 0.1 dB/cm. A 1-to-8 Y-junction splitter and a 32 × 32 star coupler have been fabricated using photolithographic techniques. The unification of the star coupler and a modulator array is for backplane optical interconnects is under investigation.

1.0 INTRODUCTION

The need for a high speed, highly parallel optical computing system which may contain as many as 10^5 high performance processors [1] has highlighted the severe limitations of current electrical interconnect capabilities. The interconnection hierarchy ranges from connections for computer/computer to individual transistor/transistor in high performance computing system. Current systems are restricted in performance by limitations imposed by the electrical interconnections. In other words, it is the speed of electrical interconnects rather than the speed of the processors which limits the performance. The attempt to replace electrical interconnects with optical interconnects has so far centered on computer-to-computer interconnections with single-mode and multi-mode fibers. Lower level hierarchies such as board-to-board (backplanes), inter-multichip-modules (MCM), and intra-MCMs, are all currently connected electrically. For speeds beyond 150 MHz [2], board-to-board electrical interconnects represent the most serious problem in high performance computing system due to the long interconnection lengths involved (~ few cm to 1 m). Such a limitation demonstrates clearly the advantage of optical interconnects over electrical interconnects for large-systems (longer distance) and high-speed computing machines.

2.0 OPTICAL BACKPLANES

Optical backplanes are used to eliminate the speed limitation of board-to-board interconnections. Basically, there are various types of optical interconnect suitable for optical backplane applications such as optical fibers, free space interconnects, and polymeric waveguides. The low packing density and topology incompatibility with printed circuit boards of optical fibers limit their use in backplane applications. Free space optical interconnects are very popular and offer extremely high interconnect density and low crosstalk. However, disadvantages of free space interconnection include complexity of alignment and intolerance of dust particles. Therefore, polymeric channel waveguides are best suited for optical backplane interconnects.

In order to communicate between boards through optical backplane, modulation is needed to convert electrical signals to optical signals. There are two schemes to accomplish the task: direct and indirect modulation of an optical source. Direct modulation involves directly varying the current that drives the laser diode. This scheme is often used in fiber communication but is not feasible in optical backplanes communication because of the large number of laser diode sources

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needed, the short lifetime (few hours) due to the large amount of heat that would be generated by the lasers, and the high cost of such an interconnect systems. The solution is to use a single high quality laser diode with some laser diode redundancy for backup far from the backplane for independent thermal management. Thin film channel waveguides are needed for high packaging density and easy alignment (lithographic alignment during waveguide fabrication). Indirect modulation (external polymeric waveguide modulators) is necessary for high density and high speed operations.

In this paper, various important components vital to the realization of an optical backplane have been fabricated. The simplified architecture of an optical backplane is shown in Figure 1 where massive fan-out device is used to distribute the light from a high quality laser diode into an array of optical bus and waveguide modulators. An array of high density channel waveguides have been fabricated on the graded index gelatin-based polymer. In addition, a 1-to-many Y-junction splitters and a 32 × 32 star coupler have been demonstrated for optical source distribution. An array of high density waveguides and waveguide modulators have also been fabricated on the same material system[3].

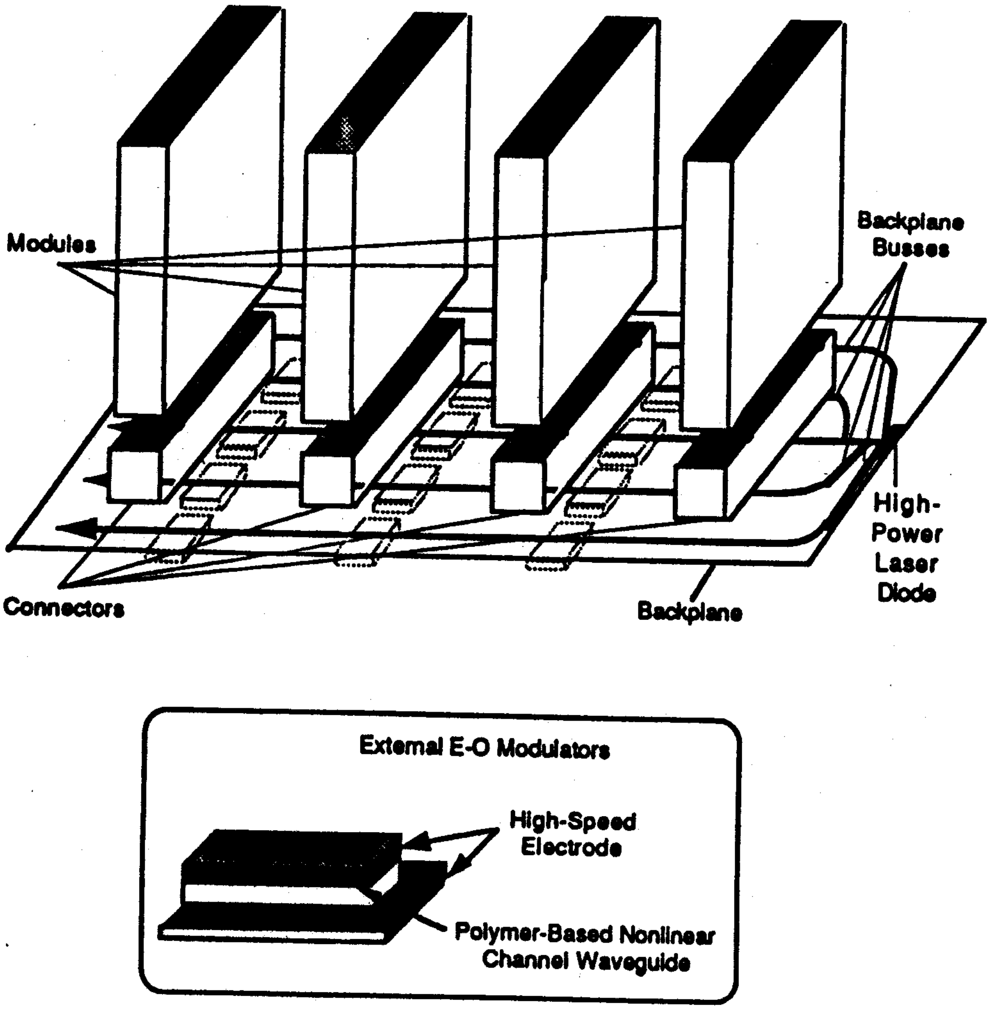


Figure 1
Simplified Architecture of an Optical Backplane

3.0 HIGH DENSITY POLYMERIC CHANNEL WAVEGUIDES

Interest in photolime gelatin material as a serious contender in the integrated optic material system has increased recently. This arises from the fact that waveguides fabricated from gelatin have loss as low as 0.1 dB/cm, a graded index nature for waveguide formation on any substrate, and holographic capability for passive devices like holographic mirrors, beam splitters, wavelength division multiplexers, and various types of gratings [4-7].

Dichromated gelatin (DCG) is a very popular holographic material. The variation of the intensity interference from 2 beams modifies the degree of crosslinking of the DCG. After a wet processing procedure, the strains induced by the crosslinking modify the index of refraction . The same concept, which involves a contact mask, is used to make channel waveguides on DCG . An array of channel waveguides with density as high as 1250 channels/cm has been fabricated. The channel waveguides can be implemented on any substrates of interest due to its graded index nature after special processing treatment. Figure 2 shows the schematic diagram of the measurement technique to demonstrate the high density waveguides. A prism coupler is used to couple the laser into the waveguide array. The outcoupling is done by cleaving the sample to obtain an optical quality end face. A microscope objective is used to image the near field pattern of the waveguide array into a video camera. Figures 3(a) and (b) shows the near field pattern of end fire output at 0.638 μm and 1.31 μm, respectively. Figure 3(c) demonstrates the horizontal and vertical profile of the output by a CCD array at 0.638 μm.

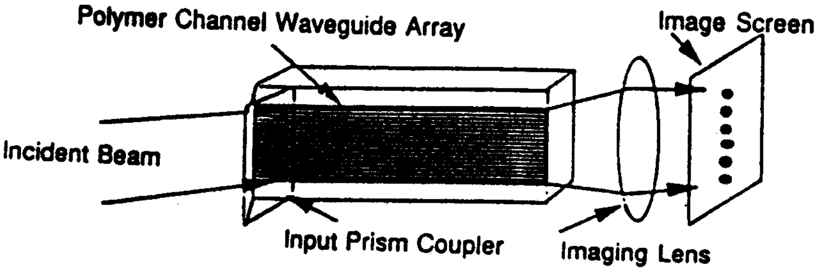


Figure 2
Schematic of High Density Channel Waveguide Measurement Technique

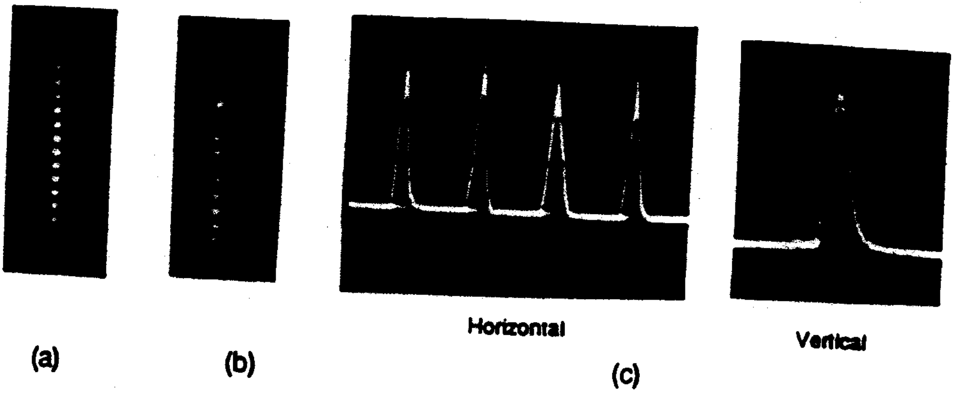


Figure 3
Near-Field Pattern of the Channel Waveguide Arrays at (a) 0.638 μm, (b) 1.3 μm and (c) the Mode Profile of the Array at 0.638 μm

4.0 OPTICAL DISTRIBUTION DEVICES

In the present optical backplane architectural design, an optical power dividers is essential only if a single high power diode laser source is provided. There are many power dividers that can distribute an optical signal into two or more branches. These include Y-branching waveguides, directional waveguide couplers, and star couplers.

A cascaded Y-junction tree splitter from 1-to-8 channel waveguides has been fabricated on dichromated gelatin on a glass substrate. The critical branching angle is designed to be 1° to avoid excessive loss. The tip of the Y branch is controlled so that it is less than 0.5 µm to minimize scattering loss at 1.3 µm. Figure 4 shows the edge out coupling of the 1-to-8 tree splitters at 1.3 µm. The width of each channel is 10 µm and the final separation between waveguides is 50 µm.

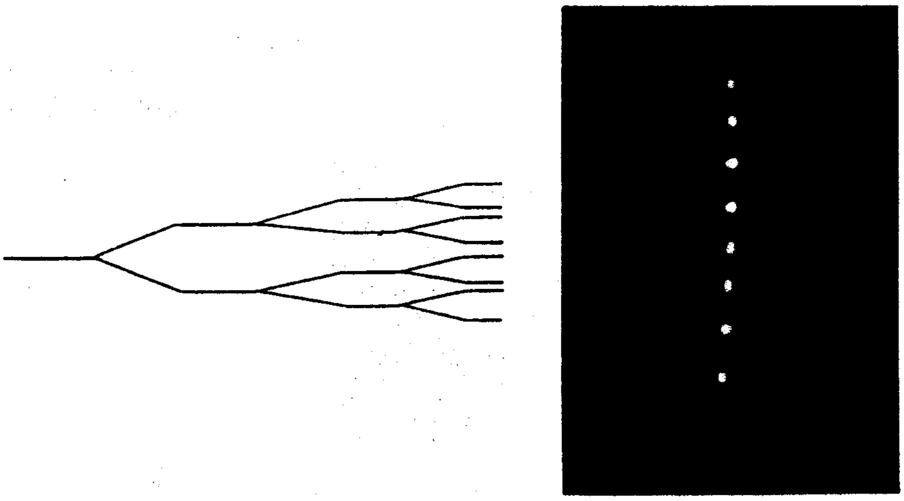
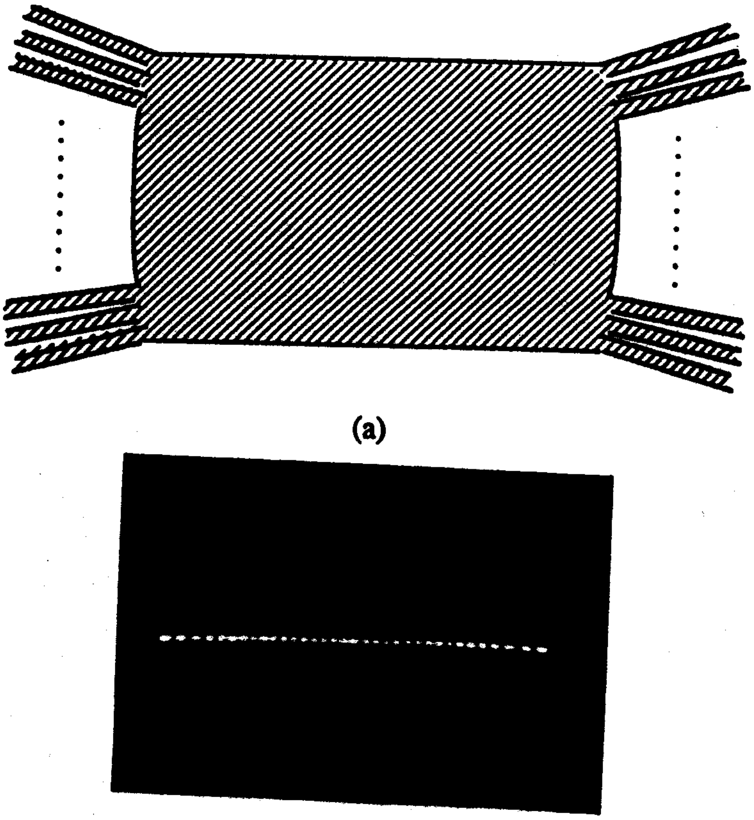


Figure 4
1-to-8 Y-Junction tree splitter

A tree splitter can be used as an optical distribution element if a reliable laser diode source is available. It is important to provide a redundancy of laser diode sources to prevent the failure of the entire system due to a failed laser diode. A 32 by 32 star coupler is designed and fabricated for this consideration. An N × N star coupler is a major component in many integrated optics systems mainly due to its ability to distribute any one of the single input signal equally into a massive output channels. The redundancy of laser source can be provided by having an array of laser diodes at the input end of the star coupler. Only one laser is operating at the time. When a failure occurs, another laser diode is immediately switched on to prevent disruption of service.

The basic architecture of the star coupler is shown in Figure 5(a). It is composed of a symmetric arrangement of two arrays of channel waveguides separated by a planar region. The width of each input and output channel waveguide is 10 µm. The final separation between waveguides at the planar region is 3 µm. The waveguides are directed towards the phase center of the other array. This condition needs to be satisfied to ensure uniform field distribution of the marginal elements of the receiving arrays[8]. Detailed description of the design will be published elsewhere. The star coupler consists of 40 channels including 8 dummy channels on the outermost regions of the array. Figure 5(b) shows near field image of the 34 out of the 40 end coupled out array. There are some field uniformity issues that need to be addresed.


(a)

(b)

Figure 5
(a) Schematic of the 32 × 32 Star Coupler, (b) Near Field Pattern of the Coupler

5.0 CONCLUSION

In conclusion, a graded index gelatin-based polymer material system has been developed for optical backplane interconnect applications. Channel waveguides with loss as low as 0.1 dB/cm have been fabricated using lithographic techniques. The highest density achieved in the array of waveguides are 1250 channels/cm. In addition, high fan-out devices such as 1-to-8 Y-junction splitter and a 32 × 32 star coupler have also been fabricated.

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6.0 REFERENCES

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