# Multichannel Optical Interconnections using Imaging Fiber Bundles

Donald M. Chiarulli, Steven P. Levitan, Paige Derr, Raju Menon, and N. Wattanapongsakorn
University of Pittsburgh, Pittsburgh, PA 15260

Bryan. Greiner and Matt Robinson
Schott Fiber Optics 122 Charlton Street Southbridge, MA 01550-1960

## 1. INTRODUCTION

Recent advances in optoelectronic devices and in processing technology have focused attention on the packaging of multi-chip optoelectronic systems. Alignment tolerances and geometrical restrictions often make the implementation of free space optics within these systems quite difficult. Critical alignment issues also characterize fiber-per-channel guided wave systems based optical ribbon cable or large core fiber arrays. In this paper, we present an alternative architecture based on imaging fiber bundles that can deliver a set of spatial optical channels to and from the surface of an optoelectronic chip. In an imaging fiber bundle, each channel is carried by multiple fibers. An array of spots, such as shown in Figure 1, imaged at one end of the fiber bundle is correspondingly imaged on the opposite end. In this manner, imaging fiber bundles are capable of supporting the spatial parallelism of a free space interconnect with relaxed alignment and geometry constraints.

Fiber bundles can be used in OE system to directly connect pairs of OE chips or they may connect each chip to the set of optical elements for routing and distribution of the channels. In addition, hybrid configurations, produced by bonding multiple bundles in various configurations can implement fan-out structures such as parallel optical passive stars (POPS) [1], and optical cross-bar networks [2]. In this paper, we report on a series of designs and preliminary experiments for system architectures based on imaging optical fiber optic bundles.

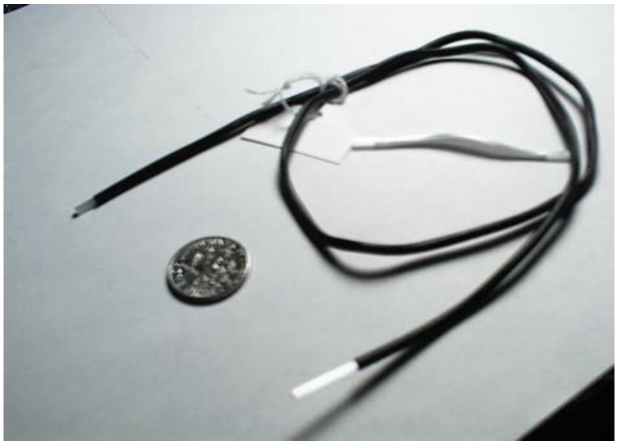

**Figure 2: Sample Fiber Bundles**

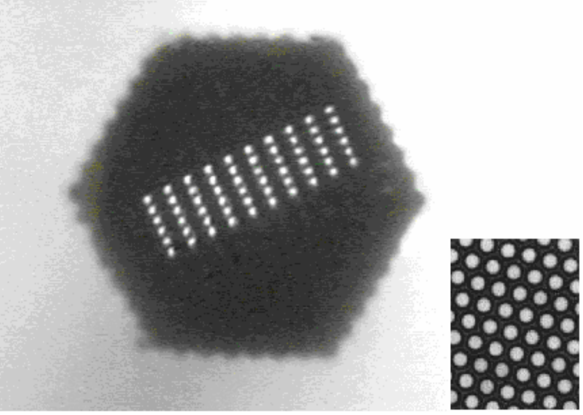

**Figure 1: Photograph of Fiber Bundle with Spot array image Inset: fiber core lattice**

## 2. IMAGING FIBER BUNDLES

The fiber bundles descibed in this paper are fiber image guides (FIG's) produced at Schott Fiber Optics. These bundles have been traditionally used in medical imaging systems and remote inspection devices such as flexible endoscopes. Arrays of fiber cores are arranged in a hexagonal lattice shown in the inset of Figure 1. Fiber diameters typically range from 8 to 20 microns yielding core densities of two to fifteen thousand cores per square millimeter. The relative spatial position of each fiber within the lattice is maintained throughout the length of the bundle. Figure 2 shows examples of 2mm diameter flexible fiber image guides. These FIG's are rigid at both ends and flexible in the central part.

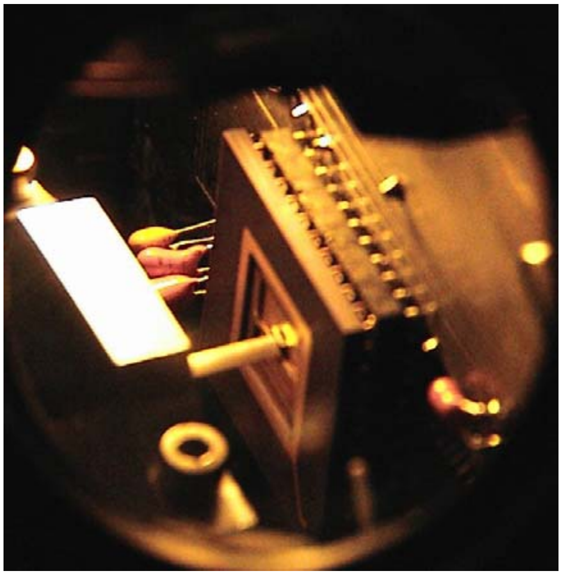

**Figure 3: Photograph of FIG coupled to MQW array**

Individual fibers of the FIG are fabricated using a rod-in-tube method. In this technique, a solid core glass is surrounded by a cladding tube to create the individual waveguide structure. The cladding is then surrounded by a second tube of acid-soluble glass (ASG). This three glass system is drawn down into a single mono fiber that is stacked into a hexagonal array, called a multi-assembly. This multi-assembly is further drawn down into a multi rod. A second stacking and drawing operation follows to create a multi-multi rod. Throughout these draws, the glasses maintain their shape, preserve the core/clad boundaries, and reduce any manufacturing variances in the original mono fiber. The ASG fuses together during the draw, locking the waveguides into the designed lattice. The multi-multi rods, which are rigid at this point, are cut and polished to the appropriate length. Prior to placing the bundle in an acid bath, the ends of each bundle are encased in wax. The acid dissolves the ASG in the middle of the bundle while the wax protects the ASG at the ends. After the wax is removed, the central part of every fiber is free to flex. Rigid guides can also be manufactured by omitting the ASG layer, thus increasing the effective core transmission area.

## 3. ARCHITECTURES

Figure 3 shows a photograph of a FIG butt coupled to the surface of OE-VLSI device, in this case a superscalar processing element fabricated as part of the 1997 CMOS-MQW Coop program [3]. In initial investigations we have been successfully coupled dense 2D spatial optical channels into the fiber bundles both from CGH spot arrays generators and by directly butt coupling to and LED array. We have obtained VCSEL array sources through the GMU co-op program[4], however at the time of this writing, drivers were not available to test the coupling issues for VCSELS.

In conjunction with our investigation of coupling issues, we are evaluating three classes of optoelectronic system architectures based on fiber image guides. The first, shown in Figure 4 is a simple point-to-point VCSEL interconnect. In this architecture, the VCSEL array is interleaved with detector sites in a regular pattern. By coupling the fiber to the chips at a 180° relative rotation, it is possible to match each VSCEL source with a corresponding detector site with no additional or geometrical restrictions on the position and orientation of the chips.

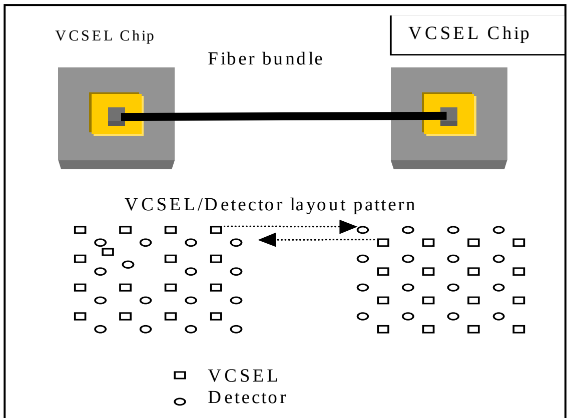

**Figure 4: Point-to-point VCSEL array interconnection**

The second architecture demonstrates the use of fiber bundles in conjunction with external optical elements for signal routing and fanout. Such configurations are capable of implementing multi-chip interconnections or, as in this example, may provide for the insertion of optical power for modulator based systems. The design shown in Figure 5 implements a two-chip interconnection for the CMOS-MQW superscalar processing elements. The core optical element is a polarizing beam splitter. This element distributes the spot arrays into each fiber where it is modulated and reflected on the surface of each chip. Since traversing the fiber bundle has the side effect of unpolarizing the optical signals, one polarization of the reflected channel is directed by the beam splitter into the fiber bundle of the other chip. Alignment of this system is done between the bundles and the interface to the beam splitter. As shown in the figure, a slight offset is introduced to image the reflected spot arrays onto the detector sites of the other chip.

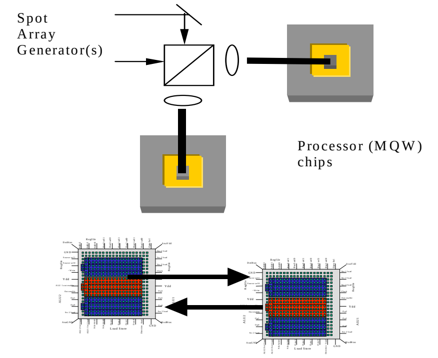

**Figure 5: Example Architecture: Multi-chip processor configuration using CMOS-Seed chips**

The third architecture, a passive spatial switch, is created by bonding together two stacks of rectangular bundle waveguides. Each stack is fabricated by bonding the waveguides at one end while coupling the other end to an OE chip. The bonded end of each stack is then bonded end-to-end with a 90° rotation. The resulting network provides for spatially resolved bidirectional channels within the image waveguides at each OE chip. Thus, A VCSEL/detector array in one region of an OE chip couples directly to a corresponding region on another chip. At present a 3x3 version of this structure has been built and is being characterized.

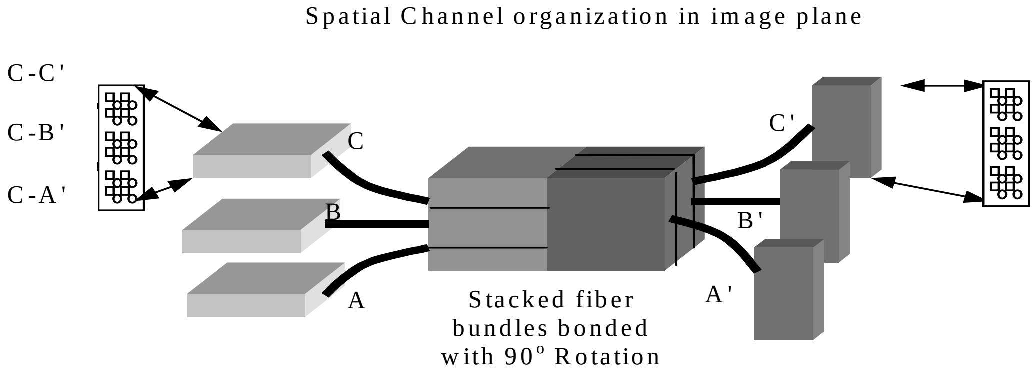

**Figure 6: Stacked Waveguide Passive Spatial Inteconnection Network**

## 4. ACKNOWLEDGEMENTS

Authors Chiarulli and Levitan were supported, in part, by AFRL/Rome contract F30602-96-C-0206. The authors also wish to acknowledge the support of Schott Fiber Optics Inc. and the Consortium for Optical and Optoelectronic Technologies in Computing for devices and foundry services.

## 5. REFERENCES

1. D. Chiarulli, S. Levitan, R. Melhem, J. Teza and G. Gravenstreter; “Partitioned Optical Passive Star (POPS) Interconnection Networks with Distributed Control”;*IEEE Journal on Lightwave Technology*; Vol. 14; No. 7; pp. 1601-1612; July 1996.
2. A.A. Sawchuck, B.K. Jenkins, C.S. Raghavendra, and A. Verma, "Optical Crossbar networks", Computer, 20(6):50-60, 1987.
3. D.M. Chiarulli, S.P. Levitan, R.P. Menon, N. Wattanapongsakorn, "Super Scalar Processor Using Chip Level Optical Interconnections" IEEE/OSA International Topical Meeting on Optics in Computing (OC'98), pp.119-122, Brugge, Belgium, June 17-20, 1998.
4. http://co-op.gmu.edu.