Technology Demonstrator of an Optical Board-to-Board Data-Link

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Compared with electrical interconnects, optical interconnects offer several advantages, such as higher channel bandwidth and density, longer reach, and insensitivity to electro-magnetic interference. We developed an optical printed circuit board (PCB) technology platform and demonstrate a 12 × 10 Gbps optical link between boards. Embedded polymer waveguides guide the optical signals, which are generated and detected by 12-channel optoelectronic modules. A polymer waveguide flex is used as optical link between boards. All connections between elements are based on passively aligned, standard MT interfaces, keeping costs low and providing compatibility with parallel fiber optics. The technology is also compatible with standard PCB processes.

Optical Interconnects

The increasing performance of microprocessors leads to higher bandwidth requirements for the data flow to and from the processor. Today, all signaling on a PCB is performed electrically, using copper lines that are integrated in the board. However, issues such as propagation loss and interchannel crosstalk, limit the scalability of electrical interconnects to ever higher bandwidth densities. A possible solution for these issues is the implementation of optical interconnects. Optical interconnects feature a higher bandwidth × length product, are more power-efficient and enable a higher channel density than electrical interconnects above a certain data rate. It is especially this higher channel density of optics that drives the research on optical PCB technology for inter-system interconnects [1]. However, we expect that before optical interconnects can find widespread use in PCBs, first the following two requirements have to be met: First, passive alignment, whereby the optical elements are simply plugged into the board without the need for optical monitoring and/or further fine adjustment, and, secondly, compatibility of optical PCB production with standard PCB manufacturing processes.

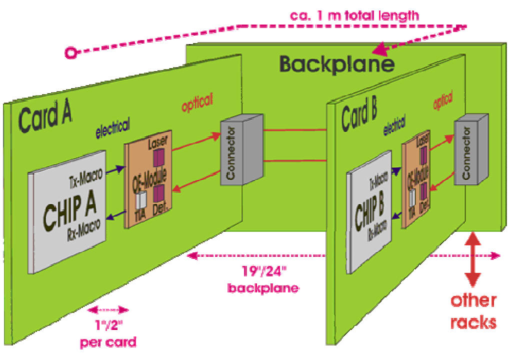

Fig. 1: Schematic drawing of an optical interconnect system

The schematic in Fig. 1 shows a basic optical interconnect configuration, in which chips A and B, mounted on daughter cards A and B, are connected via a backplane. The required building blocks for such a link are **optoelectronic modules**, which are mounted close to the chips and convert signals between the electrical and optical domain. In addition, **polymer optical waveguides** in the board are used to transmit the optical signals. Finally, an **optical connection system** is required to connect the individual optical elements, such as optoelectronic modules to daughter cards, daughter cards to backplanes, and backplanes to flexible optical waveguides or optical fiber bundles for connection to other racks. To achieve

reliable data transmission at 10 Gbps, the overall optical losses should not exceed 15 dB for a link. Besides the propagation losses in the waveguides, the losses in the optical connections between elements are the main contributors to the overall system loss. Thus, finding a cost-effective method for achieving low-loss optical connections is an important requirement for a successful implementation of optics in the PCB world.
After a brief introduction to waveguide technology and of the optoelectronic modules, we will focus on our solution to connect optical elements to PCBs and on its impact.

Waveguide technology

Because of the precision and smoothness requirements for optical waveguides, the patterning of the actual waveguides cannot be performed using standard PCB processing equipment. Therefore, we implemented a direct laser writing tool for large-scale waveguide patterning [2]. Thick-film cladding and core layers are applied on a board substrate using doctor-blading, spray-coating or inkjet printing. Waveguides having core sizes ranging from 35 to 50 µm, pitches between 62.5 and 250 µm, and propagation loss values below 0.04 dB/cm have been realized. To increase the density of the waveguides at the board edge, two-dimensional waveguide arrays with up to four waveguide layers were built.

Optoelectronic modules

The optoelectronic modules are butt-coupled to the waveguide facet in the PCB, while the electrical signals are transmitted through an electrical flex that provides a 90° bend in the electrical domain. The 12 channel transmitter and receiver elements consist of a 1×12 VCSEL array and a laser driver or a 1×12 photodiode array and a TIA (trans-impedance amplifier), respectively, developed in collaboration with IntexyS Photonics [3].

Mechanical alignment reference for optics

The implementation of optics into PCBs necessitates a proper connection of optical elements to an optical PCB. Precise mechanical alignment features in the PCB are required to enable a pluggable connection to the board. During the assembly, these alignment features have to be positioned passively in the PCB. The major obstacle to achieving precise passive alignment is the large discrepancy in positioning tolerances between the optics and the PCB world. In standard PCB processing, manufacturing tolerances of more than 100 µm are acceptable. However, the multimode waveguides we use allow an alignment tolerance of only 8 µm to keep the optical loss due to misalignment to less than 0.5 dB.
We chose an interface based on the MT standard, using two guiding pins with a diameter of 700 µm. This also enables compatibility with standard parallel optical fiber equipment.
In this paper, we propose a passive alignment concept that fulfills the following requirements: First, the alignment structures are created and compatible with standard PCB manufacturing processes. Second, they enable a passive assembly of a mechanical element within an 8 µm alignment tolerance with respect to the waveguides.
These alignment structures are formed by standard PCB photolithography in a copper layer on the board substrate, and we will therefore refer to them as “copper markers”. The laser writing tool we use for waveguide definition provides the flexibility to compensate for substrate distortions for each PCB individually, simply by adapting the waveguide pattern to the position of the copper markers. The next step is to use these

copper markers also for mechanical alignment. The surface of the copper acts as vertical alignment reference, and a slot in the copper acts as horizontal reference, see Fig. 2.
Because these copper markers are laminated into the PCB together with the waveguides, they have to be retrieved. First, a laser drill process is used to retrieve and clean the surface of the copper. The laser beam is reflected by the copper, and only material above the copper layer will be removed. However, in the copper marker we placed a photolithographically defined opening, through which the laser drilling continues into the polymer underneath the copper. This generates a slot in the copper marker, which can be used as horizontal reference. As the copper acts as a mask for the laser beam, the position of the slot is defined by the original opening in the copper marker and not by the relatively inaccurate laser drilling process.
In summary, the optical waveguides are aligned with the copper markers thanks to the direct laser writing. In addition, also the vertical and horizontal reference planes for the mechanical alignment are defined by the copper markers. Thus we have created a mechanical reference system that is precisely aligned with respect to the waveguides. Fig. 3 shows a set of copper markers with illuminated waveguides.

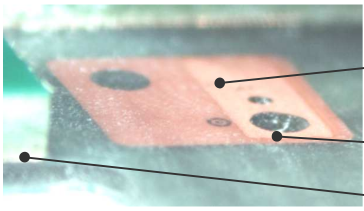

Fig. 2: Copper marker

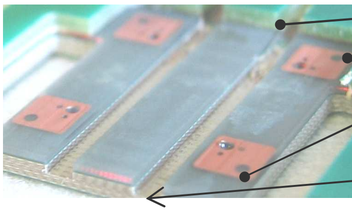

Fig. 3: Set of copper markers with waveguide facet

A mechanical adapter acts as a bridge between the copper alignment markers and the required MT guiding pins. Fig. 4 shows the details of the mechanical alignment of such an MT adapter. Fig. 5 shows an MT adapter passively inserted into an optical PCB with the illuminated waveguide array between the guiding pins.

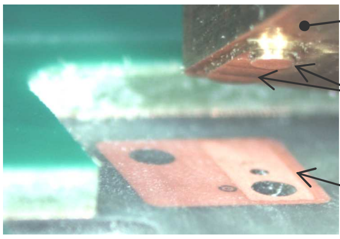

Fig. 4: Adapter insertion into copper structures

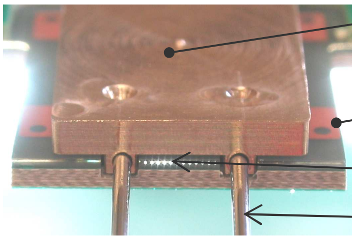

Fig. 5: Passive aligned MT adapter with optical facet

Alignment inspection

We developed an inspection system to measure the passive alignment precision with respect to the waveguides in order to improve the performance of the fabrication process. The inspection concept is based on a mechanical gauge with reference markers at the target center position of the waveguides and alignment holes corresponding to the standard MT interface. After mounting the gauge on the MT adapter, which is assembled onto the board, pictures of the waveguides and the reference markers are taken while the waveguides are illuminated from the backside. Subsequent image processing yields the offset values of the waveguides relative to the reference markers. We achieved standard deviations below 4 µm for vertical and horizontal alignment. As this is below the required 8 µm alignment tolerance, less than 0.5 dB loss per interface due to misalignment is expected.

Demonstrator Results

A demonstrator, as shown in Fig. 6, was built to test the performance of the proposed technology. A transmitter and a receiver module are inserted into optical PCBs, which provide polymer optical waveguides to the board edge. A fiber bundle with MT connectors is used as substitution for a backplane to connect the two board edges. Both the connections of the optoelectronic modules in the boards and of the fiber bundles to the board edges use the passive alignment system with MT interface proposed in the preceding sections.

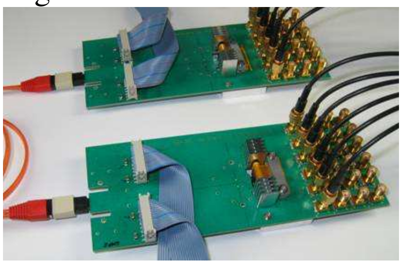

Fig. 6: Twelve-channel board to fiber to board link

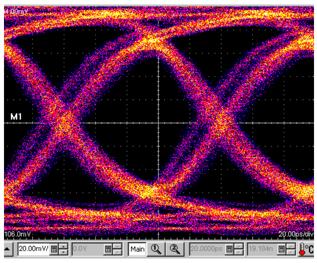

Fig. 7: Eye-diagram (channel 9) at 10 Gbps

A pulse pattern generator is used to create the signals, which are detected by a signal analyzer after the transmission through the optical link. Fig. 7 shows the open eye-diagram of one channel (all 12 channels operating), demonstrating the capability of data transmission at 10 Gbps per channel. Conservatively estimated, the optical losses are below 9 dB, which is well below the limit of 15 dB.

Summary

A passive alignment system that uses one set of copper markers for both optical and mechanical alignment is introduced. The fabrication of this alignment system is compatible with standard PCB processes. Using the system, we can precisely integrate an optical connector (MT standard) into an optical PCB. We achieved alignment tolerances below 4 µm, leading to an optical loss due to misalignment below 0.5 dB.
A system demonstrator based on this passive alignment system successfully transmitted signals over 12 channels, each at a data rate of 10 Gbps, from board to board via an optical fiber cable, through four passively aligned optical interfaces. The calculated optical losses are below 9 dB for this link. A board-to-board link via an optical backplane is the next target.

References

[1] Christoph Berger, Bert Jan Offrein and Martin Schmatz, “Challenges for the introduction of board-level optical interconnect technology into product development roadmaps”, in Proc. SPIE, Vol. 6124, 61240J (Mar. 3, 2006)

[2] T. Lamprecht, et al., “Passive Alignment of Optical Elements in a Printed Circuit Board”, in Proceedings of the ECTC 2006, ISBN: 1-4244-0152-6

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