Passive Aligned Glass Waveguide Connector for Co-Packaged Optics

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Abstract. Co-packaged optics require novel packaging concepts for high fiber counts and low-cost assembly. We design and fabricate a glass waveguide substrate with MPO interfaces that yield an average connector loss of 0.5 dB. Simulations are performed to assess the required spring force for physical contact.

Introduction

The demand for low-cost and power-efficient interconnects in hyperscale datacenters requires optical signals to be routed as close as possible to electronic integrated circuits [1]. The first industry wide adaption of co-packaged optics (CPO) will be the integration of optical transceivers and ethernet switch Application Specific Integrated Circuit (ASIC) on a multi-chip module (MCM) substrate for datacenter switches [2]. Optical interfaces between integrated waveguides and optical cables must be managed for a high number of interconnects in combination with advanced photonic packaging technologies to enable CPO [3]. Optical interconnects have been demonstrated in polymer [4] or glass [5] for short-reach interconnects between photonic chips and optical fibers. Figure 1 shows a CPO design study for an optoelectronic glass substrate with an ASIC chip in the center surrounded by 16 transceiver tiles and 16 optical fiber connector interfaces for interconnecting up to 256 optical fibers.

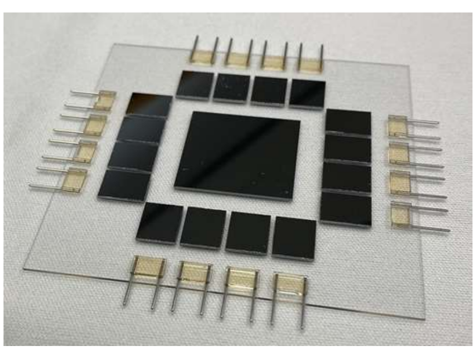

Fig. 1: CPO concept for a 75 mm x 75 mm glass substrate with ASIC, 16 transceiver tiles, and 16 connector interfaces.

The multi-fiber push-on (MPO) connector is a fiber-to-fiber array connector for accurate and repeatably mating of two fiber arrays which uses precise guide pins to achieve a low insertion loss of <0.35 dB by physical contact (PC) [6]. The fiber ferrule end-faces are polished and a constant spring force is applied on the back of the fiber ferrules to maintain PC for all fibers. Applying the MPO interface at the edge of an integrated waveguide substrate leverages the existing fiber connector eco-system including ferrule fabrication, fiber assembly, fiber end-face polishing and characterization. The MPO interface to polymer [7,8] and glass [9,10] was explored with active and passive alignment of guide pins in reference to the integrated waveguides. Our work focuses on low-cost surface-mount passively aligned connector interfaces with low-loss coupling to integrated single-mode glass waveguides for upcoming CPO generations.

Passive MPO-16 Guide Pin Assembly

A set of two MPO-16 guide pins were assembled on the surface of a glass waveguide substrate as shown in the schematic cross-section in Figure 2.

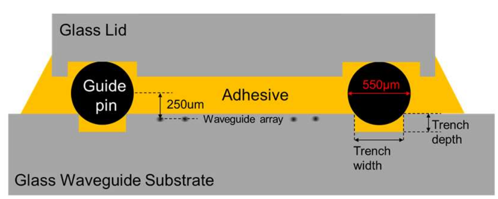

Fig. 2: Schematic cross-section of a glass waveguide substrate with laser ablated trenches, and guide pin assembly with glass lid for three point passive pin alignment.

Two MPO-16 guide pins were placed inside laser ablated trenches separated by 5.3 mm. The trench width depends on waveguide design and needs to be smaller as the pin diameter to enable the edge alignment. A two row MPO-16 ferrule compensates for the 250 µm offset between the center of the pins and the waveguide array.

Lateral misalignments in the horizontal and vertical directions are driven by the placement accuracy of the trenches in reference to the waveguides and trench width, respectively.

Ultrafast pico-second laser pulses were focused on the glass surface in order to ablate two surface trenches. The width of the laser ablated trenches determined the depth at which the guide pins rest and thus the height of connector waveguides which must align to the glass waveguides (Figure 1). As such the depth of the trenches need not be controlled so long as it is deep enough to not touch the guide pin which make contact with the edges of the trench. The trench fabrication process yielded a variation of only 1.5 µm in the width. The accurate placement of the two trenches with respect to the pre-existing glass waveguide array is critical to enable the low loss connector coupling using passive alignment. A placement accuracy of 0.8 µm was achieved using automated machine vision on lithographically defined fiducials of the IOX diffusion mask layer.

A 0.7 mm glass lid, with the same coefficient of thermal expansion (CTE) to reduce the thermo-mechanical stress, was adhesive bonded on top of the guide pins. The adhesive layer thickness is minimized by adding trenches in the lid that are wider as the pin diameter, e.g. 600 µm. A glass waveguide sample with attached pins and lid is shown in Figure 3.

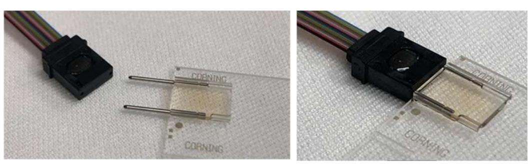

Fig. 3: Two passively aligned 550 µm diameter guide pins in a 5 mm long trench covered with glass lid and adhesive bonded to a glass waveguide substrate with (a) un-mated and (b) mated MT fiber jumper.

The glass waveguide sample has twelve 1.5 mm long waveguides which were fiber probed at 1310 nm wavelength yielding an average baseline insertion loss of 0.82±0.07 dB. This insertion loss consists of a single-mode fiber (SMF) to glass waveguide mode-mismatch of ~0.31 dB per waveguide facet and waveguide propagation loss of ~0.1 dB/cm. Then, four different two-row non-angled multi-mode MPO-16 ferrule jumpers populated with SMF were plugged to the pins to compare the fiber probed data obtained with active alignment with that obtained using the passive alignment via guide pins and ferrules. The average insertion loss was measured to be 1.19±0.16 dB for four different mechanical transfer (MT) fiber jumpers. Index matching fluid was used at all fiber-to-glass interfaces. The maximum loss difference is ~0.8 dB as shown in Figure 4, which summarizes all data.

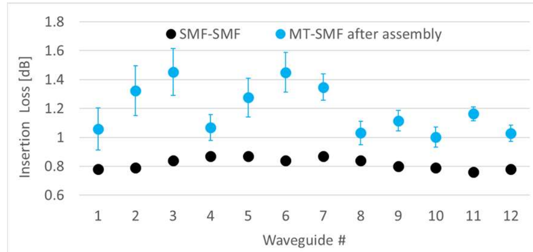

Fig. 4: Insertion loss of the twelve 15 mm long waveguides probed with single mode fiber using active alignment (black circles) and a passively aligned MT fiber connector array (blue circles; averaged over 4 different MT fiber arrays).

The loss can be further reduced by using single-mode MPO-16 ferrules with tighter bore tolerances for the guide pins and fibers.

Glass Waveguide Facet for Physical Contact

The singulation of the glass substrate was achieved using Corning's ultrafast laser nanoPerforation cutting process [11]. The laser modification regions were controlled to avoid damaging the ion-exchange waveguide regions. A mechanical force was applied to separate the substrate along the defined nanoPerforated line. The resulting waveguide end-face, as shown in Figure 5, enables low-loss optical edge coupling without additional post-processing steps, e.g. polishing to smooth the surface. A maximum change profile height difference of 2.5 µm was characterized by optical interferometry of the glass waveguide end-face.

Fig. 5: End-face of glass waveguide sample with the two trenches separated by a distance of 5.3 mm. Optical area covers full widht of the MPO-16 ferrule (6.5mm).

A model was created to simulate the fiber-to-glass waveguide interface to study the required mating force and glass waveguide facet requirements. A flat glass waveguide facet is evaluated with 2.5 µm tilt over the 6.5 mm width of the waveguide interface containing the 16 fibers. The fiber height of one MPO-16 connector was measured to be in the range 2.4 mm and 2.72 mm and used as input to the Finite Element Method (FEM) model. The impact of variations in the fiber radius of curvature (RoC) was considered by defining all fibers with a RoC of 5 mm except fiber eight and nine which were defined to have a RoC of 3.5 mm. Up to 0.32 µm of differential fiber height must be compressed before the lowest fiber contacts the waveguide. The guide pin stiffness was included to permit the ferrule rotation into the equilibrium position as force was applied to the ferrule. Zero clearance was modelled between the guide pin and ferrule bore. The waveguides were integral parts of the waveguide substrate and structurally act as one piece. The contact diameter as a function of the applied force for each of the 16 fibers in the connector is plotted in Figure 6.

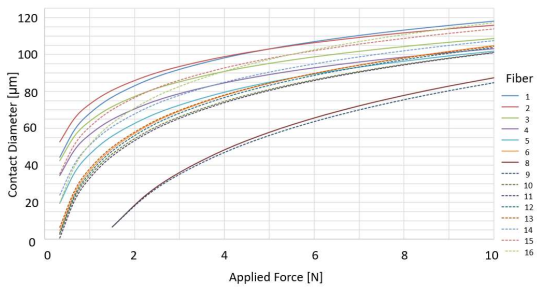

Fig. 6: Contact diameter between fiber and glass for each fiber dependent on applied spring force of the connector.

Deflection of the guide pins and the ferrule permit rotation of the ferrule which partially compensates for waveguide end-face tilt. The fiber maintains alignment with the waveguide within 60 nm with up to 10 N of connector force applied. Approximately 35% more force is required to achieve the minimum contact area to cover the 9.4 µm mode-field diameter of at wavelength of 1310 nm for SMF-28® for 2.5 µm tilt compared to 0.5 µm tilt. Less than 1.7 N force is required to achieve a minimum of 10 µm contact diameter in the full 16 fiber connector when mated to a waveguide with up to 2.5 µm tilt across the width of the fiber contact. The guide pin to ferrule friction was not included in this initial attempt to model the interface and will increase the required connector mating force. The model predicts that physical contact can be achieved with the laser processed end-facets.

MPO Glass Waveguide Adapter

The adapter was designed for phyiscal contact characterization with a standard MPO connector providing a constant mating force of the fiber ferrule against the glass waveguide facet by the spring that is part of the MPO connector assembly. The adapter is designed to use the standard latching mechanism of the MPO-16 connector which guides the bores of the ferrule to the assembled guide pins. Protoypes were precision machined from polyetherimide plastic (ULTEM-1000). In order to be able to guarantee the required accuracy, the adapter must be completely machined in one clamping step. The narrow slots required a diameter-length ratio greater than 20/1 for the tool. The design and prototype are shown in Figure 7.

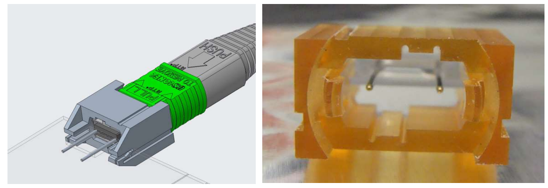

Fig. 7: (left) Adapter design with mated MPO-16 connector and (right) prototype assembled on glass waveguide substrate.

Simulation results indicated that a spring force of less than 10 N is sufficient for achieving physical contact for all fibers at a glass waveguide facet. For the experiment, MPO-16 connectors were assembled with 3.1 N and 7.5 N springs to study the difference.

Characterization

MPO-16 cables were mated on the adapter side. Some jumpers outperformed others and an average insertion loss for those were 1.19±0.14 dB and 1.01±0.27 dB for the 3.1 N and 7.5 N springs, respectively. For the MPO-16 with 7.5 N spring, the average misalignment loss was only 0.19 dB after subtracting the baseline insertion loss of 0.82 dB using active alignment with SMF. The SMF mismatch adds 0.31 dB for a total average connector coupling loss of 0.5 dB for the best jumper in our experiment. Return loss was measured to be -40 dB. Mating experiment for the same jumper was done showing very consistent results for fibers four to eleven as shown in Figure 9.

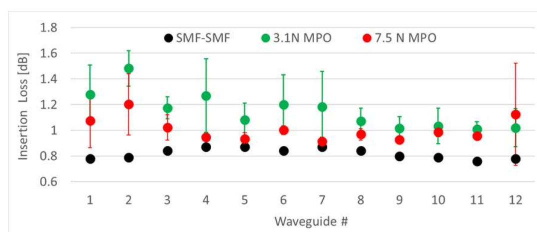

Fig. 9: Insertion loss at 1310 nm wavelength for fiber probing both sides (black circles; SMF – SMF) and with mated connector on one side (MPO) using a spring force of 3.1 N (green circles) and 7.5 N (red circles).

Conclusions

Low-loss coupling (0.5 dB) of single mode fiber to glass waveguide coupling was demonstrated for passively aligned MPO-16 connectors with a spring force of 7.5 N. The connector loss variation between different jumpers can be explained by the core position variation between the SMF position inside the multimode MPO-16 ferrules and the misalignment to the single-mode glass waveguides.

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