Slim Push-Pull Fiber Array Connector for Optical Chips

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Abstract: We report connector loss of 0.42 dB for a low-profile fiber-to-chip connector to replace fiber pigtails and enable flip-chip electronic assembly of optical chips for co-packaged optics.

1. Introduction

The main channel for high-speed data transmission is low-loss optical fiber which covers short to long reach distances for computing, datacom, and telecom applications. The link consists of a sequence of optical fiber interconnects which are connected via fusion splicing or connectors. Each link requires one transmitter and one receiver. Silicon photonic integrated circuits (PIC) offer a low-cost, integrated, and scalable transceiver platform for high-speed optical interconnects. However, the much smaller mode sizes of the integrated silicon photonic waveguides require a mode conversion for matching the optical fiber mode for low-loss coupling [1]. Today, the interface between integrated waveguides and optical fibers is not standardized and fiber connectivity to the PIC is mainly a customized solution based on attached fiber pigtails. Such fiber pigtailed optical chips are dominant for pluggable transceivers but also considered for co-packaged optics (CPO) and near-packaged optics (NPO) [2], which leads to handling constraints and thermal limits for the packaging process due to thermal limitations of the polymer materials which are part of the fiber ribbon cable and connector assembly. Electrical sockets are considered for NPO modules with fiber cables running to the faceplate of a datacenter switch, one of the applications for NPO/CPO. Achievable electrical pitch density is limited by sockets compared to direct flip-chip assembled chiplets. The larger footprint of socketed modules requires longer electrical lines and adds reflection points which increases the loss and limits signal integrity and power savings. For CPO, a small form-factor fiber connector to the edge of the PIC or intermediate waveguide substrate like glass needs to be low-profile to fit between heat sink and printed circuit board and should be mateable during fiber harness assembly. In addition to a lensed fiber to chip interface, butt-coupling to the optical chip is an option by leveraging the well-established MT (mechanical transfer) ferrule concept with guide pins for precision fiber alignment.

2. Connector Design

The novel connector is based on the multi-fiber push-on MPO-16 ferrule and has a compact connector housing. The optical chip has two guide pins assembled in mechanical trenches to enable passive alignment. Without the need for a plastic MPO receptacle, this connector requires four-times less interface area compared to a MPO adapter and enables flip-chip assembly like solder and thermo-compression bonding of chips. The assembled pins and the mating process of the connector to the optical chip is shown in three steps in Fig. 1(a)-(c).

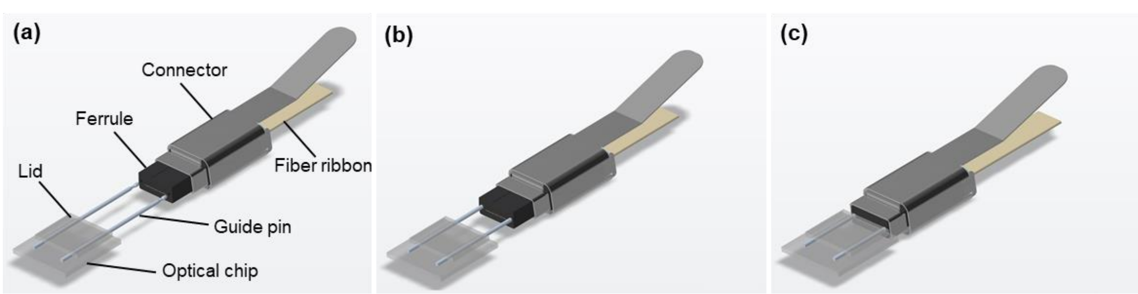

Fig. 1. Mating sequence to an optical chip in three steps: (a) guide pins engage with the ferrule, (b) guide pins sliding through the bores of the ferrule, and (c) connector completely mated with the optical chip.

The guide pins with 550 µm in diameter have a groove close to the tip of the pin. The pins go through the bores of the ferrule which are 8.05 mm for MPO-16. The pin length behind the ferrule is 2.55 mm. The assembly length on the optical chip can be customized and was chosen to be 5.4 mm for a robust assembly. All parts of the connector plug are shown in Fig 2(a). In the back of the connector are three parts, a spring guide (green), a magazine spring (light grey) and a pin fixture (grey), which closes the connector from the back side with a slot opening for the fiber ribbon to exit. The assembled connector plug is shown in Fig. 2(b). During the mating process with the optical chip, the pin fixture snaps into the grooves of both pins when the connector is pushed in, and sets the spring under compression which pushes the ferrule towards the edge of the photonic chip.

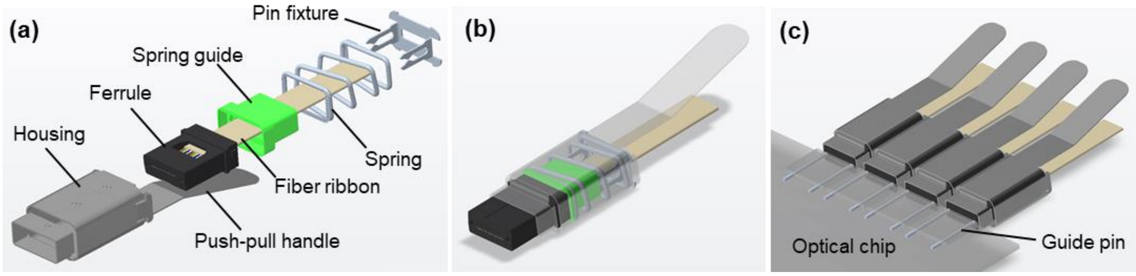

Fig. 2. 3D design view of the (a) exploded connector, (b) assembled connector, and (c) four mated connectors to on opitcal chip with eight assembled guide pins.

Depending on the interface (air gap, refractive index matched or physical contact), the force of the spring can be defined. Springs with a force of 2.5 N, 5 N and 10 N were prototyped and evaluated for this work. A housing encloses the MPO-16 ferrule and all other components. The housing has a push-pull handle above the fiber ribbon that allows the operator to grab the connector for mating (push) and demating (pull). The height of the connector is 4.4 mm (without handle). The connector is 7.5 mm in width which is only slighly wider compared to the 7 mm MPO-16 ferrule. Connectors can be placed next to each other with minimum gap of less than 1 mm because of the push-pull design as shown in Fig. 2(c). As such, four of these connectors would only require a total width of 33 mm for 64 fiber channels (MPO-16 ferrules) and 96 fiber channels (MPO-24 ferrules) [3].

3. Optical Chip and Connector Prototype

The connectors were tested on optical chips made of glass. A waveguide array with 250 µm pitch was fabricated in aluminosilicate glass by silver ion-exchange waveguide technology [4]. The waveguides were mode-matched with single-mode fiber (Corning® SMF-28 Ultra Optical Fiber). Due to the elliptical waveguide shape, the mode-mismatch loss was 0.3 dB per interface. The waveguide end-facet was laser cut with leaving an optical-quality region of 6.5 mm around the connector interface [5]. Two of the metal guide pins were placed inside short-pulse laser ablated trenches (Fig. 3(a)) with separation of 5.3 mm [6]. These fiducials were aligned using automated machine vision on lithographically defined 0.5 mm diameter circular fiducials formed in the same lithography process as the waveguide mask for highest precision. For passive alignment, the accurate placement of the two trenches with respect to the pre-existing glass waveguide array was critical to enable low-loss connector coupling.

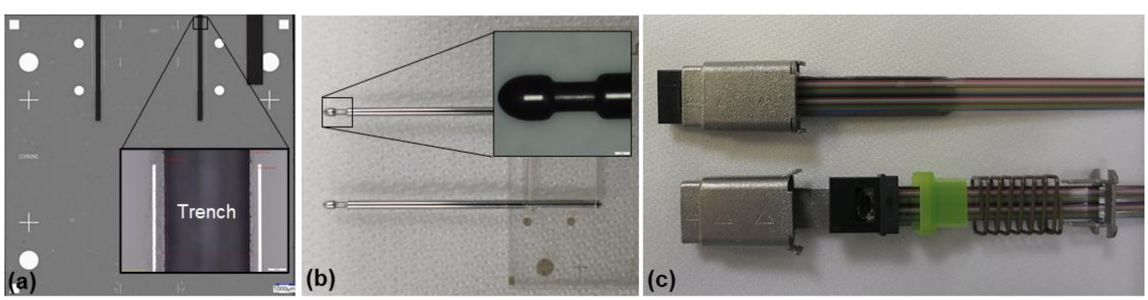

Fig. 3. (a) optical chip with a pair of trenches, (b) guide pins with trench assembled to the optical chip, (c) prototype of plug before and after assembly

Measurements made on 16 samples yielded a standard deviation for trench alignment accuracy and the width of the laser ablated trenches of ±0.4 µm and ±1.2 µm, respectively. A 4 mm x 6.4 mm x 0.7 mm glass lid covered both pins which were assembled in the 5.4 mm long trenches (Fig. 3(b)). The gap between the waveguide substrate and the lid was filled with a dual-cure thermally stable adhesive. Prototypes were made for the connector plug, pin fixture, spring, and spring guide, and slid over the single-mode fiber ribbon before the ferrule assembly. Afterwards, the ferrule and all parts on the ribbon were inserted into the back of the metal housing as shown in Fig. 3(c). The back of the housing was covered by the pin fixture which loaded the spring. A single-row MPO-16 ferrule can be applied for optical chips with pin and waveguide center position in the same plane. Keeping the main portion of the pin above the optical chip surface, a two row MPO ferrule with fibers populated in the lower row, creates a 250 µm vertical distance between the optical fiber and the center position of the pin.

4. Experimental Evaluation

High coupling efficiency can be achieved between fiber and waveguide with similar properties (mode profile and effective model index) [1] and optimized alignment. Each connector was mated with the optical chip as shown in Fig. 4(a) and fiber probed on the opposite end of the 15 mm long straight waveguide section. Before the mating experiment with different connectors, the insertion loss for the optical chip was measured for optimum alignment as a baseline by fiber probing on both waveguide facets at wavelength of 1310 nm. For each waveguide, the baseline insertion loss was subtracted from the insertion loss measurement with connector. The connector loss data for a random mating study including four optical chips and six connectors with three different spring forces (2.5 N, 5 N and 10 N) is shown in Fig. 4(b). The lowest average connector loss was found to be 0.42 dB for the 5N connectors. The average connector loss of four optical chips (#1, #2, #3 and #4) measured with the 5 N connector is shown in Fig. 4(c). Waveguide sample #1 and #2 had the lowest coupling losses. The connector loss is driven by lateral misalignment because of variations in the laser ablated trench width and placement, as well as the tolerance of the ferrule, pin, and fiber concentricity.

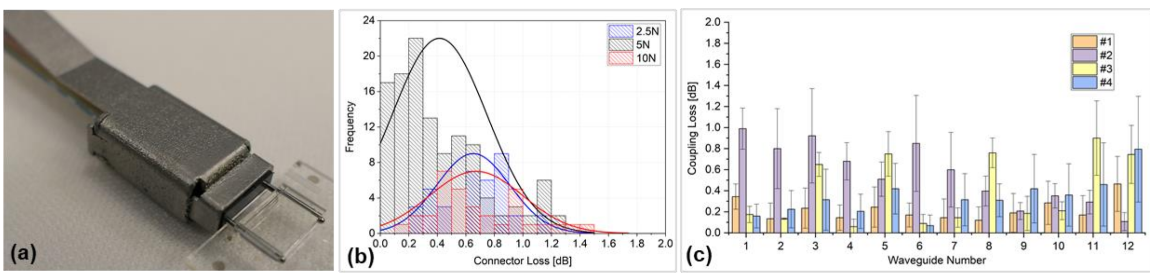

Fig. 4. (a) Mated connector with optical chip, (b) connector loss for random mating study for different connectors with 2.5 N, 5 N and 10 N spring force, (c) average coupling loss for 12 measured waveguides of four different optical chips (#1-4) with at least two mating cycles.

5. Conclusion

We demonstrated a novel low-profile connector for mating an array of optical fibers with an optical chip which could be a transfer waveguide substrate for CPO or a direct mating to an optical transceiver chip. A high-precision MT-ferrule in combination with two guide pins with latching features directly placed in mechanical alignment trenches on the chip surface enabled a four-fold smaller form factor compared to a standard MPO-16 connector. The lowest average fiber-to-chip coupling loss due to misalignment was 0.42 dB for a connector with 5 N springs. This work demonstrates the potential of passively assembled guide pins to optical chips for ferrule based low-profile connectors to overcome packaging limitations of pigtails for CPO.

References

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