Demonstration of a Single-Mode Expanded-Beam Connectorized Module for Photonic Integrated Circuits

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Abstract *We present a pluggable photonic module for data centre and communication applications. We use micro lenses to expand the single mode beam between the fiber array cable and the photonic chip. We show high remating reproducibility and losses of 3 dB per coupler. ©2022 The Author(s)*

Introduction

The work reported here is part of the Single-Mode Expanded Beam Module (EBM) project undertaken by a collaboration of groups participating in the International Electronic Manufacturers Initiative (iNEMI) [1]. The goal of the effort was to design, build and test a PCB-mounted module housing a Photonic Integrated Circuit (PIC), and having an expanded-beam connector interface to Single Mode (SM) fiber cable. By implementing the connector interface, the fiber pigtails, typically used for today's modules are eliminated, thus simplifying board assembly. Furthermore, the use of the expanded-beam connector improves performance in the presence of dust, debris or other contamination [2]. To simplify the transition to manufacturing, the package was designed to facilitate automated alignment and assembly.

The design and performance targets for the EBM demonstration were derived from an industry-wide survey performed by iNEMI in 2019 [4]. That survey attempted to capture expert input on expected new technology needs for wide-scale implementation of board-level fiber optic interconnect in high-performance equipment such as data servers, telecom switches, and supercomputers. It included 99 respondents, distributed across industrial sectors including semiconductor foundries, connector manufacturers, assemblers, OEMs, ODMs, EMSs, design services and government or academic labs. The goal was to provide the basis for a project to assess expanded-beam connectors as module interfaces. Key survey conclusions showed industry preferences for: SM over Multi-Mode (MM) fiber (for compatibility with high-functionality semiconductor Photonic Integrated Circuits (PICs) and seamless upgrade to higher bit rates); for connectorized, rather than pigtailed, modules (for compatibility with standard board assembly processes); for expanded-beam over physical-contact connectors (for dirt/debris resistance [2]); edge coupling as opposed to surface grating coupling (for broad-wavelength functionality and lower-profile cable for closely-spaced boards); horizontal mating and fiber exit parallel rather than perpendicular to the PCB (for board clearance and connector access, e.g. in backplane connectors). The consensus loss target was < 1 dB per mated connector pair.

Optical Design

The basis for the pluggable prototype is a reference Photonic Integrated Circuit (PIC) chip. It was designed by PIXAPP Photonics Pilot Line and was fabricated by LioniX® on a SiN platform. Reference PICs are a new concept in photonic packaging and are simple structures that can be produced in high volumes to use to develop and optimize disruptive packaging processes [5].

The design of the chip is shown in Fig. 1. It

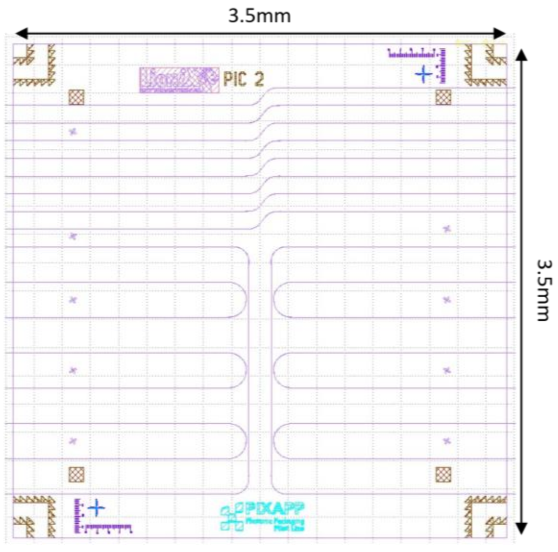

Fig. 1: Design of a reference SiN PIC.

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contains only edge couplers connected by short waveguides configured as straight-through and loopback structures. For all experiments, micro-lenses were used to couple light in and out of one of the short loopbacks. The mode-field diameter (MFD) of the couplers is nominally 10µm, i.e. compatible with standard single-mode fibres.

The PICs were diced using a standard dicing saw with small grit (2 µm) and no further facet processing was performed. This shows an advantage of SiN-based devices for edge-coupling applications because the waveguide refractive index is similar to that of fiber and of a majority of optically-transparent epoxies that are used in packaging. Therefore, while the diced waveguide facet is rough with the index-matching epoxy at the interface the coupling losses associated with scattering will be minimized.

The cable side of the optical interface is composed on a standard US Conec MTP ferrule equipped with a moulded micro-lens plate that expands and collimates the beam from a Single Mode Fiber (SMF) to ~50 µm diameter [6].

As the primary goal of the prototype was to use standard, off-the-shelf components, the PIC micro-lens (Cat. #18-00997) was selected from a catalogue of SUSS MicroOptics [7] by means of ZEMAX optical simulations that minimized coupling losses (0.91dB) between the components at a mated lens-to-lens design distance of 2.3 mm. It should be noted that the system is not fully optimized and with custom components better performance can be achieved.

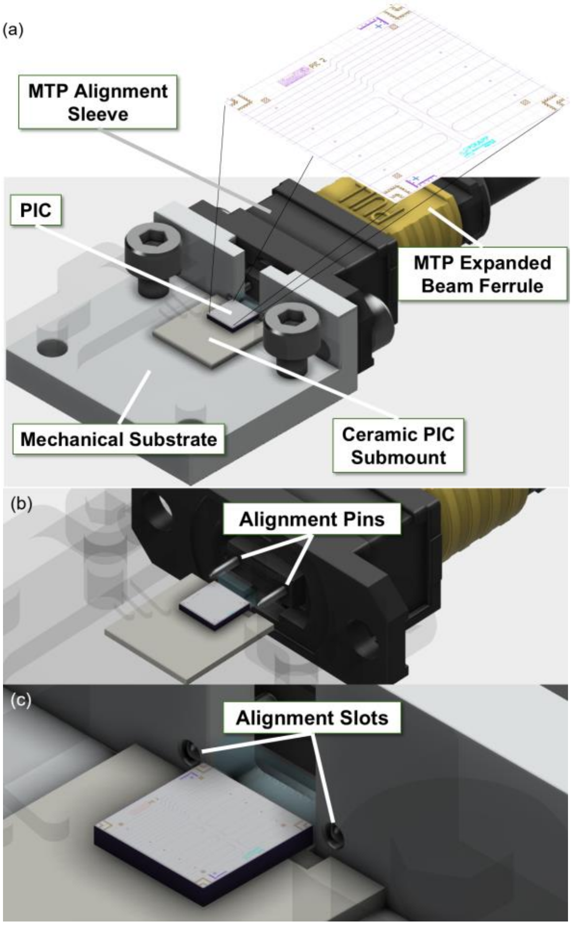

Fig. 2: (a) Mechanical design of the pluggable prototype. (b) and (c) show the pins and slots which as mechanical register for fine alignment of the ferrule to the PIC assembly.

Mechanical Design

The design of the package for the pluggable prototype is shown in Fig. 2a. The PIC is attached to a ceramic sub-mount yielding a “PIC sub-assembly”, which is suspended ~100 µm above the surface of an aluminium mechanical substrate. This allows for clearance during the active alignment between the PIC sub-assembly and the expanded beam ferrule.

The ferrule plugs into a dedicated MTP alignment sleeve, which provides coarse alignment. High-precision alignment is then maintained by the pins (which are part of the ferrule) and slots, which are machined into the substrate. High-precision machining is critical to maintaining reproducible loss through repeated mate/de-mate cycles.

The assembly of the prototype is done in two steps. First, the SUSS micro-lens is aligned and attached to the facet of the PIC. The lens is actively aligned using a free-floating MTP ferrule to achieve highest coupling efficiency, then bonded in place using DELO Dualbond® OB6268 epoxy UV-cured using an Hg fibre-coupled lamp. In the last step, the MT ferrule is plugged into the sleeve, then the PIC sub-assembly is actively aligned to it and attached to the mechanical substrate using the same epoxy.

Pluggable Prototype

Fig. 3 shows alignment tolerances of all the

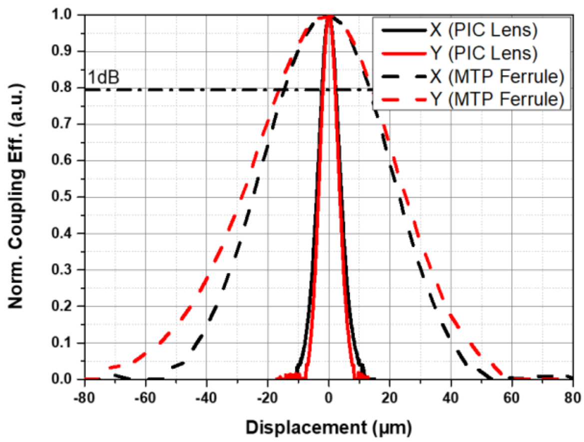

Fig. 3: Alignment tolerances of PIC-to-Lens (solid line) and PIC lens-to-MTP ferrule (dashed line). Dash-dot line shows 1dB threshold.

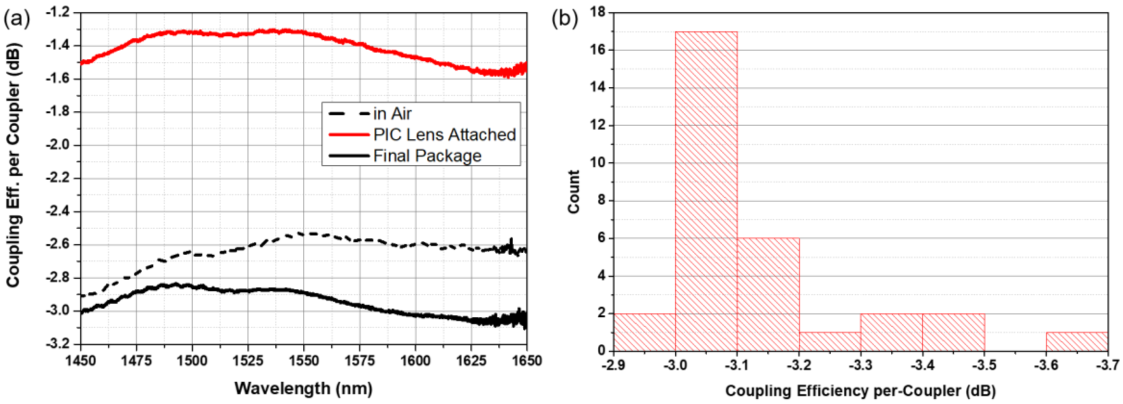

Fig. 4: (a) Per-coupler coupling efficiency at various stages of packaging: in Air, with PIC lens attached and in final package, where the PIC assembly is placed on the substrate. (b) Histogram of 30 trials of the pluggable connection.

elements acquired during first stage of alignment. Tolerances are defined as the displacement that decreases the efficiency below ~80%, or in other words, where losses increase above 1 dB.

While the tolerance for aligning the lens to the PIC is 2.3 µm (a figure comparable to butt-coupling of a SMF to the PIC with 10 µm mode expander), by expanding the beam between the lenses to 50 µm, the tolerances of aligning the MTP ferrule to the PIC sub-assembly are relaxed to ~14.5 µm. This relaxation is critical for enabling pluggable packaging solutions [8]. The more the beam is expanded, the greater displacement the optical link can tolerate. Additionally, the more a Gaussian beam is expanded and collimated, the smaller its natural divergence and hence the optical communication between the fibre and the PIC can be established over longer distances; for other applications, such as LIDAR [9] or biomedical (e.g. OCT [10]) this is a crucial factor.

Fig. 4a shows per-coupler coupling efficiency at various stages of packaging. Since the light on the PIC travels through a loopback, these values are averages of input and output. When there is an air gap between the PIC lens and the PIC at the initial stages of the process (i.e. in air), the losses are ~2.5-2.6 dB. When the lens is attached and the index-matched epoxy fills the space between PIC and lens, the losses drop down to 1.3-1.5 dB. However, after the 2nd step of packaging, when the PIC sub-assembly is attached to the submount, the losses increase to 2.8-3.0 dB. This is caused by the vertical shrinkage of the epoxy displacing the sub-assembly from its optimal position during UV curing.

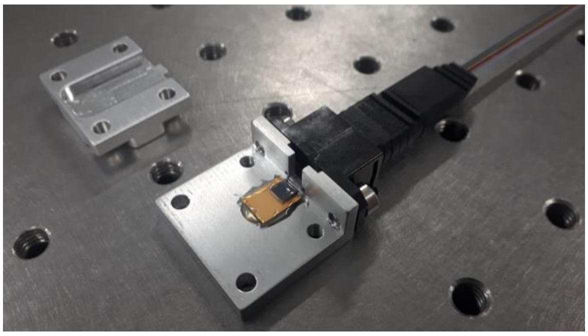

Fig. 5: Packaged prototype with a cover lid removed.

Fig. 4b shows a histogram of 30 re-mating cycles of the pluggable connection. It shows a very strong central peak in 3.0-3.1 dB range, consistent with the results shown in Fig. 4a. The higher-loss tail consists of 20% of all trials, but the additional losses don't exceed 1dB. This is a result of gradual mechanical wearing of the alignment slots which, in the prototype are made in softer material (Al) as opposed to the pins (steel). The packaged device is shown in Fig. 5.

Conclusions

We have demonstrated a prototype pluggable optical package with an expanded-beam single-mode optical interface operating in the edge coupling regime. While the losses of the packaged device are approximately 3 dB per coupler, with further process refinement these can be decreased to 1.3 dB. Mating and re-mating of the optical link using off-the-shelf components is highly reproducible and with harder material forming the substrate, we can avoid degradation due to wear in the fine alignment system.

In the next steps, the process of attachment of the lens to the PIC and then the assembly of the device will need to be automated. In conjunction with the advantages of the pluggability, this will significantly reduce the cost of photonic packages.

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