Self-Aligned Polymeric Fiber Interface with 20/mm Port Density and 1.1 dB O-Band Loss

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Abstract *We show a self-aligned compliant polymer interface between standard fiber connectors and nanophotonic waveguides with a polarization independent 1.1dB loss and a broadband response. The required chip interface is available through a commercial photonic foundry.*

Introduction

A rising number of applications require substantially higher on-chip optical I/O port density than is currently offered by most packaging approaches. Such applications include the integration of optical engines within large co-packaged routing switches, on-chip photonic based switches, and even the currently contemplated 800G DR8. A polymer photonic interface is uniquely well suited to transform the large pitch of fiber connectors to a substantially smaller pitch on chip for efficient use of chip area. We have proposed such a scalable interface[1] and have demonstrated the concept and performance in the C-band using chips fabricated in an R&D pilot line, as summarized in[2]. This interface uses a mechanically compliant polymer ribbon with lithographically defined polymer optical waveguides (POW) to couple light in-between a standard MT fiber interface and silicon photonic waveguides. The use of a polymer ribbon has many advantages for assembly and reliability, since the compliant ribbon can mechanically adjust to chip camber and strains occurring within the photonic package. In this paper, we show our first O-band demonstration using chips fabricated at Advanced Micro-Foundry (AMF), a widely accessible commercial wafer foundry. We demonstrate performance with -1.1 dB peak transmission for both plugged-in and active-aligned connectors. This is a 34% loss reduction over our older C-band design[2] and is a result of several improvements on the polymer waveguide and the chip interface designs. The spectral roll-off over a 1265-1340 nm band is of 0.4 dB. We demonstrate repeatability of our automated assembly on 96 optical ports with performance ranging from -1.1 to -1.8 dB loss over all ports, polarizations and spectral roll-off covering the FR4 and CWDM4 spectral grids.

Implementation at AMF

SiN-on-SOI multi-project wafer (MPW) platform was employed to fabricate the chips on a commercial 8-inch 220-nm-thick SOI wafer with 3-µm-thick buried oxide layer in AMF. A process-plug-in module on top of the standard

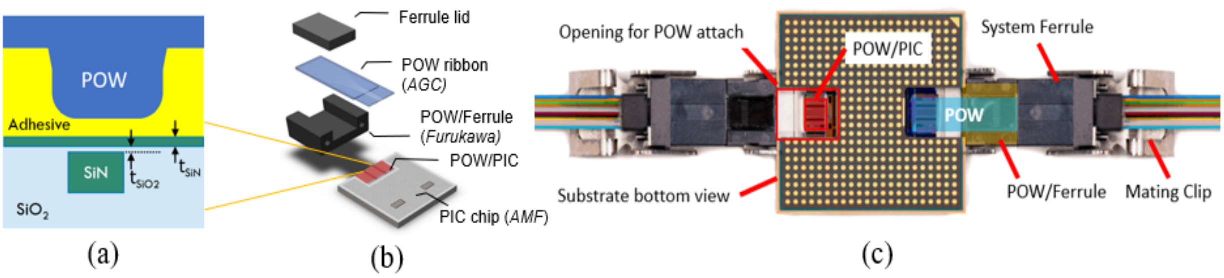

Fig.1: (a) Cross-sectional view of polymer optical waveguide (POW) and AMF Photonic Chip (PIC) silicon nitride waveguide where adiabatic coupling occurs (not to scale). The mode coupler is designed to accept some final offset between POW and SiN waveguide. (b) Exploded view of polymer interface and its constituent. (c) A test vehicle package using two PIC loopback chips and POW assembly with ferrule. POW ferrules are mated to standard MT ferrules.

flow was developed to form the interfacing structures for coupling the polymer ribbon with AMF's Si-Photonics circuits. Firstly, the silicon waveguide structures were defined by deep UV photolithography and transferred by dry etching. Afterwards, an oxide layer was deposited on top followed by the Chemical Mechanical Polishing (CMP) process to flatten the surface of the wafer. After the SiN window (oxide) opening, a 400-nm-thick PECVD SiN layer was deposited. Then the SiN waveguides were patterned and etched inside the window followed by the dielectric fill in and planarization. A thin oxide layer, thinner than 50 nm, was formed over the SiN in order to achieve the minimum coupling loss to the polymer waveguide ribbon. Subsequently, another 30-nm-thick SiN film layer was deposited and defined as the etch stop layer, as illustrated in Fig.1a. After the coupler region oxide opening and top dielectric layers removal (SiN and oxide), the alignment grooves were formed by silicon wet etching with the controlled depth ~25 μm for the good alignment accuracy during the polymer waveguide ribbon attachment process.

Polymer interface optical results

The self-alignment structures located on both ends of the ribbon are key to relax the placement accuracy requirement to enable the usage of automated high-throughput assembly equipment for photonic packaging[3]. On one side, the alignment structures self-align into a MT compatible custom ferrule[4]. On the other end, the alignment ridges will be inserted in corresponding grooves on the PIC chip. An exploded view is presented in Fig.1b. The design of the coupling interface uses mode engineering to enhance the coupling by taking into account the variations in fabrication, assembly, as well as components tolerances. Optical mode evolution designs are used to perform adiabatic transfer along the POW and at the PIC interface. The importance of the optical adhesive characteristics and bondline control are presented in[5].

A novel O-band non-linear inverted taper was designed and heavily optimized to achieve the most robust adiabatic coupling between the POW and the chip. Optical coupler designs have been implemented into loopback chips and silicon nitride waveguides were used for adiabatic coupling instead of silicon waveguides as done in the past. Various couplers were implemented to validate the design features and quantify the impact of fabrication and assembly tolerances on performance. Fig.2a presents insertion loss results for a 6 optical loopbacks chip, highlighting the FR4/CWDM4 region in the spectrum. These measurements include the losses induced by the single mode fiber (SMF) interface to the polymer coupling, the polymer waveguide propagation, and the adiabatic coupling from the POW to the silicon nitride waveguide. The performance of 48 loopbacks (8 samples, 96 ports) assembled using our automated POW assembly process is presented in Fig.2b. We demonstrate a polarization-insensitive performance of -1.1 dB peak transmission and a spectral roll-off over a 75-nm bandwidth of 0.4 dB. The repeatability of our automated assembly on 48 optical loopbacks have performances ranging from -1.1 to -1.8 dB

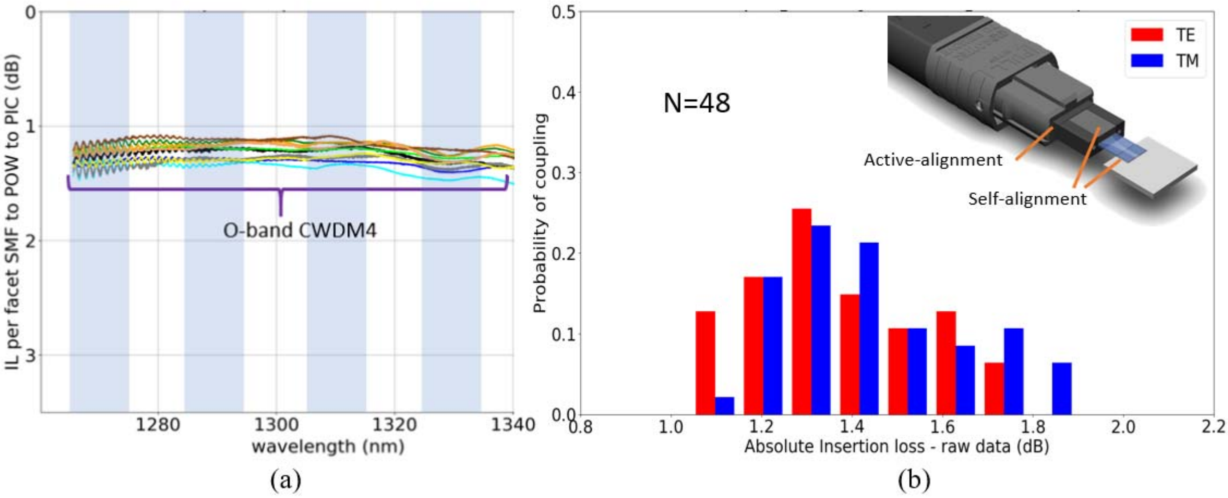

Fig. 2: (a) Insertion loss measurement for an assembly with 12 on-chip ports arranged into 6 on-chip loopbacks. Both polarizations are drawn. The reported loss includes the single mode fiber interface to polymer, the polymer propagation loss and the adiabatic coupling to the SiN waveguide on chip. (b) Statistical distribution of performance with automated assembly, using high-throughput equipment, to chips taken from various wafer locations. An average value over 75nm of the O-band transmission spectrum (FR4/CWDM4 channels) is plotted for both TE and TM mode for 48 loopback measurements (96 ports). Active alignment between standard fiber ferrule and polymer waveguides was used to isolate ribbon and chip variability from MT-connector variability.

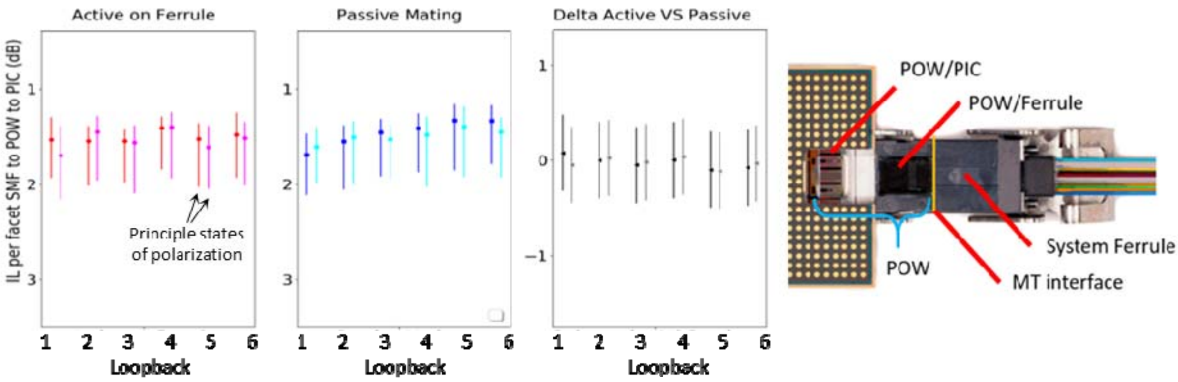

Fig. 3: The optical results of the passive ferrule mating are comparable to active alignment at the ferrule face (MT interface) to validate that the POW ferrule alignment is within the allocated optical budget. Spectrum measurement range over 100nm are represented with the average value for each loopback. A detailed picture of the POW assembly with the ferrule mated to standard MT ferrules explains the integration within the package.

loss for all ports, both polarizations, and over all the CWDM4 and FR4 channels.

An implementation of the polymer interconnect technology within a package is shown in Fig.1c, where two polymer interfaces were assembled on chips that were flip die-bonded on a laminate with integrated cut-outs. We anticipate that no cut-outs would be required in the future with the polymer ribbon fitting within the chip to laminate spacing provided by C4 solder connections. A metal clip is used to latch the polymer interface ferrule to a standard ribbon ferrule on each side of the assembly. Insertion loss measurement comparing passive plugged-in alignment to active alignment at the connector interface are presented for each loopback in Fig. 3. These measurements validate that the ferrule plugged-in (passive) mating penalty losses are within our <0.5 dB specification, when compared to active alignment of the MT interface.

Conclusions

We have demonstrated a well-suited fiber interface for applications requiring high optical port density at the photonic chip. The current demonstration employed a relatively conservative 20/mm port density which could further be extended to 40/mm port density. The required interface on the photonic chip is available via the Advanced Micro-Foundry (AMF) for both O-band and C-band applications. The polymer ribbon shows a low profile and is therefore compatible with flip-chip and 3D packaging approaches. The assembly relies on self-alignment throughout for low-cost and high throughput. Design optimization and implementation improvements lead to this new O-band interface with repeatable 1.1 dB loss and a 0.4 dB roll-off over the FR4 and CWDM4 channels.

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