A CMOS Compatible Monolithic Fiber Attach Solution with Reliable Performance and Self-alignment

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Abstract: We report a fiber-attach solution interfacing self-aligned, standard-cleaved fibers to monolithic photonic integrated circuits, fabricated in Globalfoundries 300-mm CMOS production facilities. Statistical yield analysis and reliability assessment were performed to demonstrate the robustness of the proposed solution.

OCIS codes: 050.6624 Subwavelength structures, 250.5300 Photonic integrated circuits, 130.3120 Integrated optics devices.

1. Introduction

Silicon Photonics devices have demonstrated substantial growth in the past decade to provide solutions to short-reach interconnects, LIDAR, quantum optics, internet of things, and neuromorphic computing [1]. The commercial demand for photonics solutions has facilitated CMOS foundries to develop the volume production of photonic integrated circuits (PIC) and has substantially reduced the pricing pressure even for chips with higher complexity [2]. However, appropriate optical I/O packaging solutions with high cost-efficiency and lower complexity is still undefined and is under development. As the cost-efficiency gap between PIC fabrication and PIC packaging increases, incremental improvements alone can not bridge the gap prompting the need for novel and disruptive packaging concepts.

GLOBALFOUNDRIES has developed a unique high-performance high-yield solution to circumvent the lagacy progress in PIC packaging by transferring part of the packaging complexity to the high volume 300-mm monolithic PIC manufacturing [3]. The on-chip fiber-attach solution with high performance and high yield entails building (1) a self-aligned structure using standard micro-electro-mechanical system (MEMS) processes for fiber placement and (2) a metamaterial spot-size converter (SSC) for robust optical coupling. With the demonstrated packaging module, we also verify the chip packaging reliability for standard commercial applications. In this paper, we report our achieved CMOS integrated, broad band, large mode, metamaterial interfaces for fiber-to-chip coupling, including wafer-scale probing data, statistical chip coupling-loss assembly data, and module reliability data to demonstrate the commercial maturity of it.

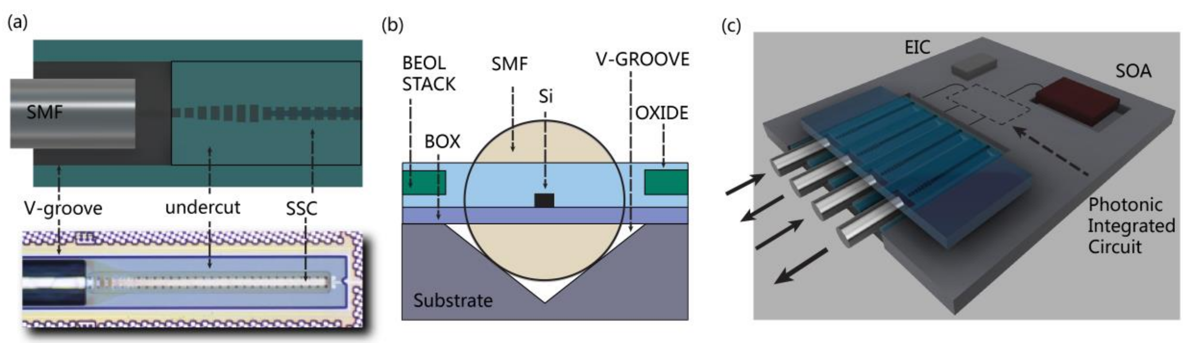

Fig. 1. (a) Schematic and microscope top view of an metamaterial edge coupler with V-groove and fiber attach. (b) Cross-sectional diagram of the edge coupler with V-groove at the fiber interface. (c) Schematic of the PIC chip package with attached single-mode fiber array, the cover, the optical source, and the attached electric chip. SMF: single-mode fiber, SSC: spot size converter, BEOL: back-end-of-line, SOA: semiconductor optical amplifier, EIC: electric integrated circuits.

2. Result and discussion

The key elements, facilitating assembly in this approach, are efficient large-mode photonic couplers and converters and the self-alignment structures defined on 300-mm wafer to dictate alignment accuracy. High-volume manufacturing enables self-alignment of standard cleaved fibers to efficient large-mode photonic couplers and converters with high accuracy on the wafer-scale. As shown in Fig. 1 (a), we design a silicon meta-material waveguide spot-size converter named IOSMF in our product design kit (PDK), for fiber coupling with the V-groove structure. The V-shaped groove is defined and fabricated on the wafer using standard MEMS processes to dictate alignment accuracy (Fig. 1(b)). The meta-material silicon waveguide mode converter is tailored to improve robustness to fabrication imperfections as compare to conventional solid-core inverse tapers. For parallelized self-aligned assembly, a standard MPO (multi-fiber push on) fiber stub is placed using an existing microelectronics pick and place equipment. The bare fibers or fiber array are individually re-aligned by a V-groove array covered with a customized buffer layer. The V-groove is filled with an index matching material and can be batch cured oustside the assembly tool with a non-disruptive process [4]. Fig. 1(c) shows a typical placement of the fiber-attach assembly within the chip packaging.

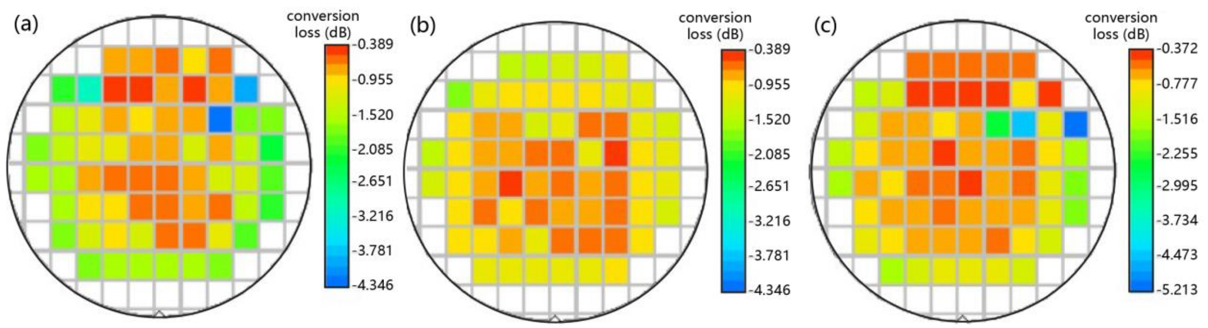

Fig. 2. Inline coupler quality monitor for fiber attach die selection based on dedicated test structures. (a) Conversion loss of low-PDL(polarization-dependent-loss) IOSMF in TE polarization, (b) conversion loss of low-PDL IOSMF in TM polarization, (c) conversion loss of low-ORL (optical return loss) IOSMF in TE polarization. The measured transmission loss indirectly reflects the conversion efficiency due to different index match conditions (air cladding layer in the inline test while better index match in assembly). The total variability is exaggerated by the index mismatching with air cladding and inline test variability. The inline test efficiently enable the wafer-level coupler quality monitoring as die with abnormal transmission can be easily detected (the blue die showing in the wafermap test data).

The metamaterial waveguide taper defines the performance of the silicon spot-size converter [5]. A much higher fabrication and alignment tolerance can be achieved with metamaterial couplers than with simple solid-core inverse taper designs, providing a much wider parameter space to satisfy the target performance [6]. Fig. 2 shows the measured inline mode conversion loss for the SSCs on a wafer. This helps to remove bad die at the product level yield screening.

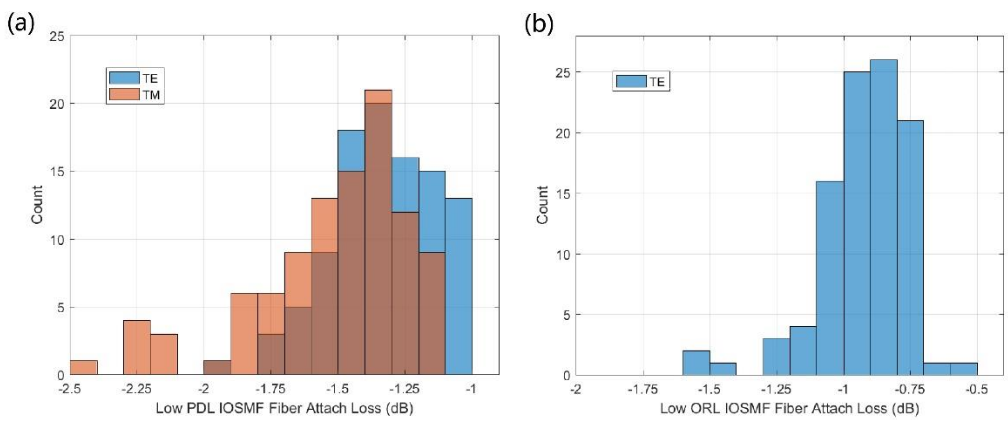

Fig. 3. Sampling fiber-attach insertion loss data. (a) Statistic data of insertion loss of IOSMF design with low polarization-dependent loss, (b) statistic data of insertion loss of IOSMF design with low optical return loss. A total of 100 samples for each design were picked randomly, over 4 lots and 8 wafers. The test was done with several cleaved single-mode fibers under IPA index match condition.

Two versions of the fiber couplers are designed to serve the transceiver application on GF’s 300 mm silicon photonics platform. The first severs as the bridge connecting transmitter parts with external laser and helps TE mode propagation with a low optical return loss (ORL). The second serves with a minimum polarization-dependent loss (PDL) for the TE and TM modes at the receiver end. For optical performance yield analysis, 200 die level samples were picked randomly over four lots and eight wafers and tested with several fiber pairs under the index match condition criteria. Fig. 3 shows measurements done to elucidate the statistical insertion loss yield analysis. The results show that the loss from a self-aligned standard optical fiber to a rectangular silicon waveguide through the IOSMF is -0.9 dB for the design with low ORL, and -1.3 dB/-1.5dB in TE/TM for the design with low PDL. The test data were collected without any active fiber alignment but fiber self-aligned with the V-groove.

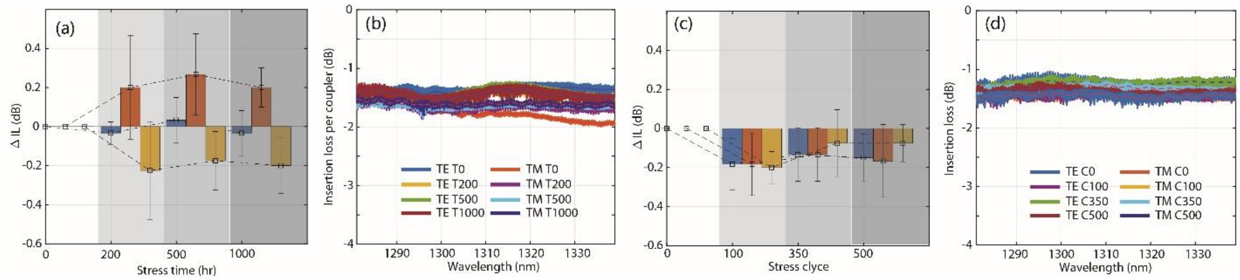

Fig. 4. Fiber-attach package reliability assessment. (a) IL variation and (b) corresponding spectra with damp heat stress test over 200, 500, and 1000 hours, (c) IL variation and (d) corresponding spectra deep thermal cycle stress test over 100, 350 and 500 cycles.

Finally, reliability assessment studies were conducted on the chip package. Several samples were assembled at GlobaFoundries’ packaging line and at IBM Bromont and tested through damp-heat stress (85°C /85% humidity) for over 1000 hours. An average insertion loss drift smaller than 0.3 dB has been observed. Also, another set of assembled samples has been tested similarly through deep thermal cycle stress (-40°C to 85°C) for over 500 cycles. An average insertion loss drift smaller than 0.2 dB has been achieved. The results show high reliability of our on-chip fiber-attach solution. The results also testify the robustness of the embedded moisture barrier and guard layer structures in the technology.

3. Conclusion

In summary, we have demonstrated a robust monolithic silicon photonics fiber coupler optical I/O solution based on GlobalFoundries’ 300 mm high volume manufacturing silicon photonics technologies. We demonstrate a statistical performance from self-aligned, standard cleaved fiber to Si routing waveguide of -0.9 dB with the TE polarization for transmitter connection and -1.3/-1.5 dB with the TE/TM polarizations for receiver connection, respectively. An early reliability test under standard stress conditions on the preassembled modules verifies a stable performance of the fiber-attach solution with a variation below 0.3 dB.

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