O-Band Fiber-to-Chip Edge Coupler for High NA Fiber Based on a CMOS Compatible SOI Platform

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Abstract: A SiN edge coupler is experimentally demonstrated with a < 1.9 dB/facet loss over the whole O band for a 4μm MFD fiber. The power is further transformed into Si waveguide using a SiN-to-Si transition.

OCIS codes: (130.3120) Integrated optics devices; (060.1810) Buffers, couplers, routers, switches, and multiplexers

1. Introduction

Fiber-to-chip coupling is playing an essential role for optical engine based on silicon photonics. Edge coupler (also known as spot size converter SSC) has become a more predominant coupling scheme than grating coupler, due to its broad bandwidth, high coupling efficiency and low polarization dependent loss (PDL).

There have been numerous research efforts on edge coupler, aiming to provide a low-loss coupling solution for industry standard single-mode fibers (SMF-28). Nonetheless, due to the large mode filed diameter (MFD) of SMF-28 and limited buried oxide (BOX) thickness, a low-loss edge coupler scheme is not quite straightforward. One popular solution is using under-cut (UCUT) to suspend the edge coupler structure while the removed silicon substrate is replaced by index matching fluid [1], however this method is notorious for bad mechanical stability and reliability. Another approach is to deposit an overlay material (such as SiON, SU8) and pattern it into an overlay waveguide to confine the input beam against leakage [2]. Nonetheless very thick (~10 μm) overlay waveguide is required to match the SMF-28's MFD, which is beyond the capabilities of major CMOS compatible foundries. Last but not the least, using multiple SiN stack layers in back-end of the line (BEOL) process is also a reasonable approach [3]. This method, however, still requires foundry to adapt the process to deliver suitable BEOL SiN thickness and critical pattern dimensions, limiting its applications.

Due to the difficulty in low-loss edge coupling to SMF-28 fiber, fiber with reduced MFD (such as high NA fiber, lensed fiber) becomes an alternative solution. Compared to the lensed fiber, high NA fiber is more favorable due to its convenience to form fiber array (FA) and its robustness in packaging. Over recent years, many novel edge couplers are demonstrated on high NA fibers based on conventional CMOS compatible processes. Most research efforts in the past were based on C-band and some of which even remarkably realized sub-decibel dual-polarization SSC [4,5]. O-band SSC, however, is more challenging to deliver low PDL due to strong birefringence of silicon waveguide at O band. On the other hand, SiN has become a favorable candidate for edge couplers and other passive devices, not only because of the low birefringence, but also due to its low thermal sensitivity, better phase control and strong power handling capability. There were reported O-band SSC designs for fiber with reduced MFD based on SiN/Si hybrid platforms [6,7], but without experimental verification.

In this paper, a SiN-Si hybrid edge coupler is experimentally demonstrated, utilizing SiN SSC to achieve O band fiber-to-chip coupling. Based on a CMOS compatible SiN-on-SOI platform, SiN edge coupler delivers less than 1.9 dB/facet loss over the entire O band for both polarizations. The power can be further transferred into Si waveguide using SiN-to-Si transformer and 2.35 dB/facet total TE coupling loss is experimentally achieved.

2. SiN SSC Design

The SiN SSC is designed based on AMF's SiN-on-SOI platform, targeting a 400 nm thick PECVD nitride with a refractive index ~ 1.975 @ 1310 nm wavelength. SiN layer is located at 250 nm above Si waveguide layer, which sits on a 3 μm BOX layer. To alleviate PDL caused by facet mode mismatch, dual-tip SiN is deployed such that the supported super-modes offer decent TE & TM mode overlap with a 4 μm MFD Gaussian mode.

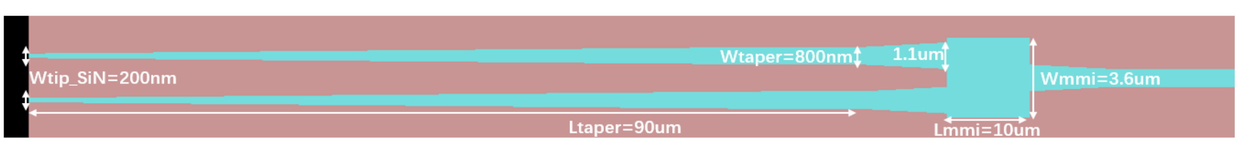

Fig 1. Schematic of SiN edge coupler for 4 μm MFD

Here under a 200 nm tip width and a 2 µm center-to-center spacing, 90% TE and 83% TM mode overlap is calculated at 1310 nm wavelength. Although smaller tip width can further improve TM mode overlap, considering the constraints of 248 nm lithography SiN process and the DRC requirement, a 200 nm min CD is used on the SiN layer. SiN dual-tips are placed at 1 µm from chip edge following AMF's DRC rule and the coupled super-modes will be transformed into TE/TM fundamental mode pairs, which eventually get combined by a dual-polarization MMI. The structure is simulated by Lumerical FDTD and in an ideal condition where the fiber is in intimate contact with the chip facet, leading to less than 1dB TE loss and 1.4 dB TM loss. In reality fiber-facet intimate contact may not be possible due to their small slanted angle together with fiber misalignment. Hence further simulation is taken introducing a 2 µm air gap between the high NA fiber and the chip edge which results in 1.4 dB TE loss and 1.8 dB TM loss over entire O band. The additional coupling loss comes from the air interface reflection and the mode-mismatch due to the beam expansion in air.

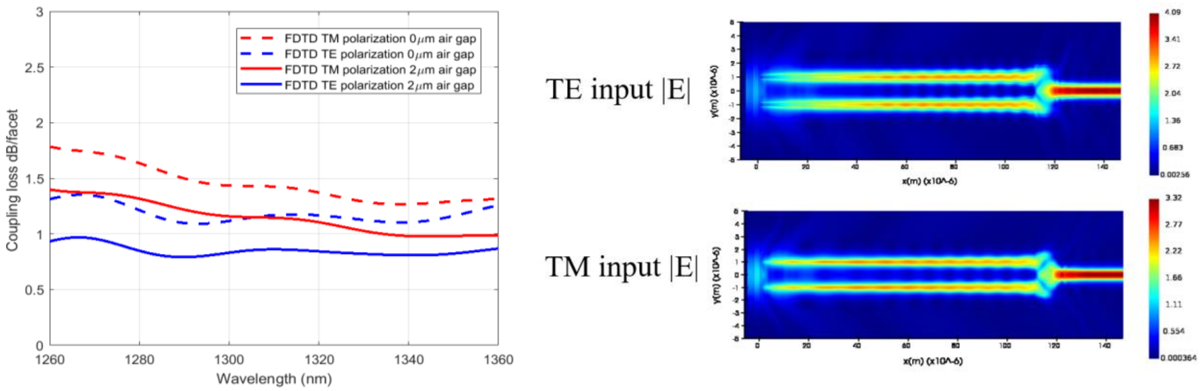

Fig 2 (a). 3D FDTD simulated SiN SSC spectrum (b). |E| top view under TE and TM input with 2 µm air gap

3. Fabrication and Measurement

The SiN SSC is fabricated on AMF's Active SiN-on-SOI 200 mm platform, which is a full flow process that integrates both passive and active devices. This allows our design to go under more realistic evaluation than short-loop passive platforms. Two SSCs are put in parallel with a 127 µm spacing, designed for high NA FA coupling. SSCs are deployed with an 800 nm wide SiN routing waveguide and a U turn with a 25 µm bend radius. The total routing length plus two SSCs counts to about 600 µm. All edge couplers are deployed perpendicular to the chip edge and the SiN tips are placed 1 µm away from the deep trench boundary.

FAs with UHNA1 fiber (4 µm MFD @ 1310nm) spliced to SMF-28 are provided by Suzhou Agix Optical Technology Co. for testing purpose. Each FA is specially made such that the lid is moved backwards to avoid clash at deep trench bulge (~20 µm) after chip dicing. Agix deliver the FA with 0.35 dB average insertion loss per channel including the splicing loss, which translates to a 0.7 dB power loss when using FA to test a loop-back SSC pair. All fibers are placed within ±1 µm transverse misalignment and the FA facet is polished to 90 ±0.5 degree.

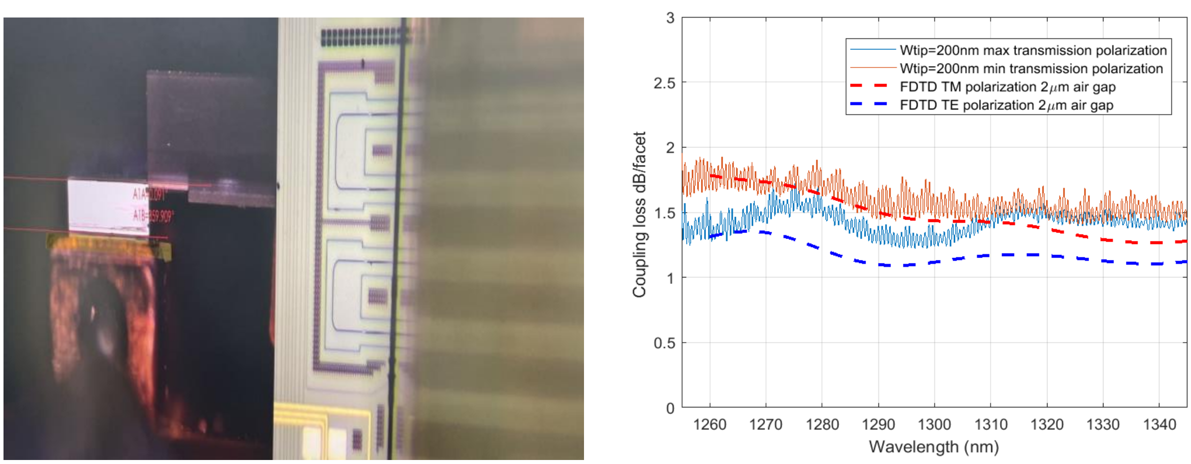

Fig 3 (a). side view image and top view image of measurement setup (b) characterized SiN SSC loss spectrum vs. FDTD simulation result

Measurement is carried out by using a GouMax TSL1000 O-band tunable laser and an LSA200 power meter. The TSL1000 and LSA200 are triggered for synchronization, enabling fast wavelength sweeping and power reading. A polarization controller (PC) is used to adjust the input polarization before feeding to the FA. The FA is mounted on a FA holder placed horizontally, coupling the laser beam into and out from the chip. Figure 3 (a) shows our measurement setup. SSC loss is characterized by using laser power subtracting 0.7 dB FA loss (one input + one output channel) as baseline. Optical power through device is measured by adjusting PC such that maximum and minimum power is found, followed by spectrum sweeping. Then the power coupled through the chip is measured and its difference from the baseline is treated as twice the SSC edge coupling loss. The measured edge coupling loss agrees reasonably well with the FDTD simulated performance as shown in Figure 3 (b). The measured SSC gives a < 1.9 dB/facet TM loss and a < 1.6 dB/facet TE loss over the entire O band. Meanwhile a small ripple with FSR of ~ 0.7 nm is observed (matching the total length of a 600 μm long SiN cavity) due to the reflections at the air gap.

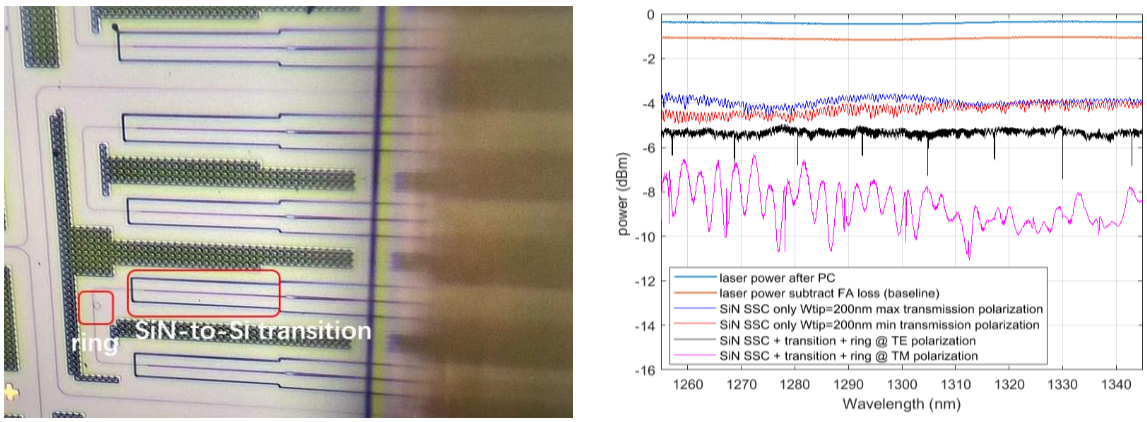

Fig 4 (a). top view image of SiN-Si hybrid edge coupler measurement (b) measured power spectrum

Such SiN SSC is also cascaded with AMF's SiN-to-Si transition in PDK library to transfer power into silicon waveguide, after which a small silicon ring is used to identify polarization. The measured spectrum in figure 4 (b) shows only high Q ring resonance as a proof of TE polarization and meanwhile a spectrally flat 2.35 dB/facet total TE loss of coupling into Si waveguide is obtained. TM coupled power, however, suffers a 3-4.8 dB/facet loss with significant ripples. Undesired TM coupling may come from the SiN-to-Si transition PDK cell that is designed for TE only, which likely introduces additional insertion loss and reflection to cause unfavorable interference. If a low-loss dual-polarization transition is available, both TE and TM could be coupled into Si waveguide more efficiently.

4. Summary

In summary, a low-loss SiN edge coupler has been experimentally demonstrated using a commercial CMOS compatible silicon photonic platform. The coupling loss with UHNA1 fiber (4 μm MFD) for both polarizations is below 1.9 dB/facet over the entire O band. In addition, the SiN SSC is cascaded with a transition cell to transform power into Si waveguide with a total TE loss of about 2.35 dB/facet. Remarkably this performance is obtained on a full-flow active run since complicated processes after front end usually deteriorate the passive device performance. Meanwhile high NA fibers are used as FA that resembles a more realistic manner of doing fiber-to-chip coupling for commercial products. Therefore, this work provides a widely applicable solution for O band fiber edge coupling, which does not require special process development provided by the foundry.

5. References

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