Low-Loss, High Extinction Ratio Fiber to Chip Connection via Laser Fusion for Polarization Maintaining Fibers

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Abstract: We present a new method for PM-fiber to photonic chip connection via laser fusion. This enables low cost and robust coupling with -1.1dB loss per facet while maintaining 20dB or greater polarization extinction ratio.

1. Introduction

The ever-increasing demand for bandwidth has led to great advancements in Silicon Photonics for data-center applications. But the increasing data-rates have also led a surge in power consumption in the optical networks. This has led to recent push for energy efficient designs and methodologies like co-packaged optics [1][2], ring-based modulators [3], and polarization division multiplexing (PDM) [4]. While these applications hold the promise of more energy efficient optical networks, they are also very sensitive to polarization. Current devices rely on laser sources integrated on the silicon-photonic chips. While this allows for clean polarization, it also increases the heat density of the photonic engine. Since, the photonic engine needs to be close to the electronics (which are a significant source of heat themselves) the additional heat from the integrated laser poses multiple challenges with regards to cooling and power efficiency of the devices. One of the biggest contributors to the loss of efficiency is the reduced output of the integrated lasers at higher temperatures [5]. This has led to the concept of keeping the laser source external and far away from the photonic engine and electronics package [2, 5]. This approach resolves the issues related to heat density, but requires a polarization maintaining (PM) fiber connection between the external laser source and the silicon photonic chip [2].

Most widespread packaging methods rely on grating assisted coupling or edge coupling. While grating assisted couplers have large alignment tolerances and give optical access from the top of the chip, they have a narrow bandwidth and typically require bulky fixtures [6]. On the other hand, edge couplers are broadband but have small mode field diameter (MFD) leading to tight alignment tolerances. Additionally, they require bulky fixtures, lens structures [7] and/or adhesives. It should also be noted that the lens assisted [7] and grating assisted [6] coupling schemes lead to approximately -2dB of coupling efficiency. The relatively high losses are counter to the target of higher efficiency photonic engines.

In this work we present low loss, low cost, and robust PM fiber to chip edge coupling attach via laser fusion. We design and fabricate oxide mode-converters to minimize the mode mismatch between a silicon nitride taper and a single mode PM fiber. The laser fusion allows for single shot and permanent attachment of the fiber to chip while allowing for -1.1dB coupling efficiency per facet and maintaining 20dB or greater polarization extinction ratio.

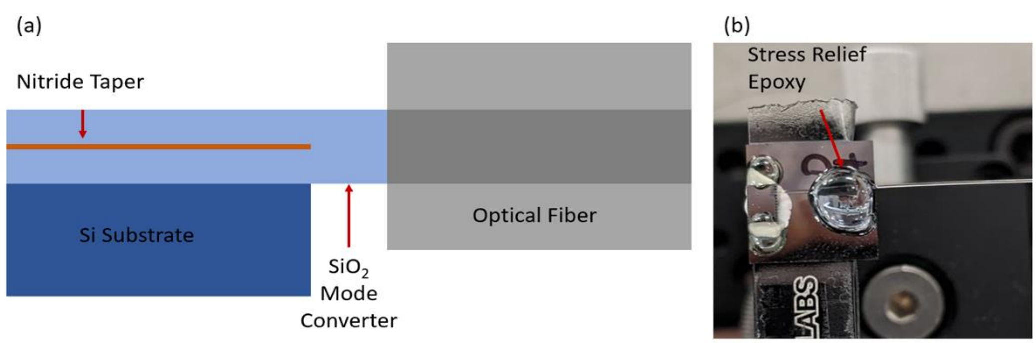

Fig. 1. (a) A 2-D view of the chip design. (b) Chip with fused fiber, and a droplet of epoxy applied 5mm away from the joint for stress relief.

2. Device Design and Fabrication

We design an oxide mode converter at the edge of the chip to minimize the mode mismatch between the fiber mode (single mode Corning PANDA PM fibers) and the waveguide taper mode. We engineered the oxide mode converter to maximize the optical coupling between the PM fiber (MFD 10.4µm) and the silicon nitride waveguide taper at the design wavelength of 1550nm. With an oxide thickness of 10µm, the oxide mode converter was designed to maximize the power throughput using the approach outlined in [8], leading to a simulated coupling efficiency of -0.9dB. The length of the oxide mode converter is set to 10µm to ensure mechanical stability with negligible optical loss. For mechanical stability, the mode converter structure is designed to sit in a 127µm wide U-grooves.

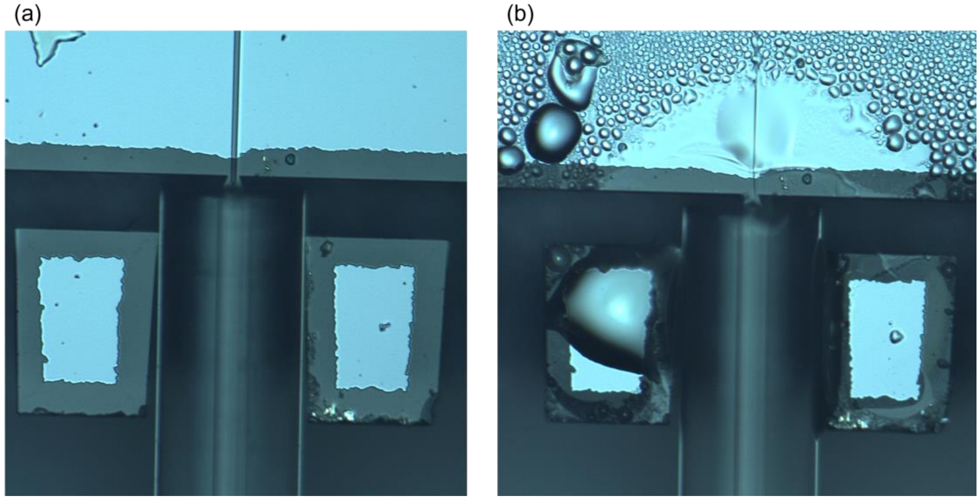

Fig. 2. (a)The fiber aligned to the chip, prior laser fusion. (b) Fiber attached to chip, post fusion process.

We fabricate the silicon nitride photonic device using standard CMOS compatible processes at the Cornell Nanoscale Facility. The device is designed with 10µm total oxide thickness. A 5µm layer of silicon oxide is deposited using plasma enhanced chemical vapor deposition (PECVD). Then 300nm of silicon nitride is deposited via PECVD and waveguides are patterned using standard DUV lithography at 248nm using an ASML PAS5500. The waveguides are etched in an inductively coupled plasma reactive ion etcher (ICP-RIE) with a CHF_3/O_2 chemistry. Once etched, the waveguides are clad with a 5µm layer of silicon oxide via PECVD. We pattern the oxide mode converters and U-grooves using DUV lithography and etched them using ICP-RIE. The U-grooves were etched via silicon deep etch. Once diced, we undercut the device using XeF_2 to optically isolate the mode converter from the silicon substrate.

3. Fiber to chip fusion and testing

We demonstrate coupling efficiency of -1.1dB and -2.3dB in C+L and O bands respectively with a polarization extinction ratio of higher than 20dB. A single mode PM PANDA fiber is stripped and cleaved before being mounted in a fiber rotator and aligned to output TE light at 1550nm wavelength. Next, we align the fiber to the chip. We monitor the output using a cleaved SMF-28 fiber. Once aligned, we fuse the PM fiber to the chip using a CO_2 laser. As can be observed from Fig.2 (b) the laser caused the oxide on the chip and the fiber to melt together without distorting the fiber core. Pre fusion we measure a fiber-to-fiber coupling efficiency of -3.9dB. Waveguide loss has been estimated to be 0.5dB for these devices [8], giving us a per facet efficiency of -1.7dB. The output power increases by 0.6dB post-fusion. We can attribute this to the fusion eliminating any Fresnel losses due to air gaps at the input. The post fusion coupling is measured to be 3.3dB, giving us coupling efficiency at the PM fiber to chip joint to be -1.1dB at 1550nm. The input laser wavelength is scanned in the C+L band to obtain coupling efficiency for the input joint (Fig. 3). We also measure the coupling efficiency for the O-band, which results in coupling efficiency ranging from -1dB to -2.3dB per facet as shown in Fig.4. This can be improved by optimizing the design for operation at 1310nm, given that the tested devices are designed for operation at 1550nm. Post fusion, we apply epoxy approximately 5mm away from the joint for mechanical stress relief and stability (Fig.1-b).

To measure the polarization extinction ratio, we collect the light using a 0.4NA/40x microscope objective. The collected light passes through a linear polarizer and is measured using NEWPORT 818-IG detector. The measured extinction ratio stays above 20dB though the range of the laser in both C+L band (Fig.3-a) and O-band (Fig.3-b).

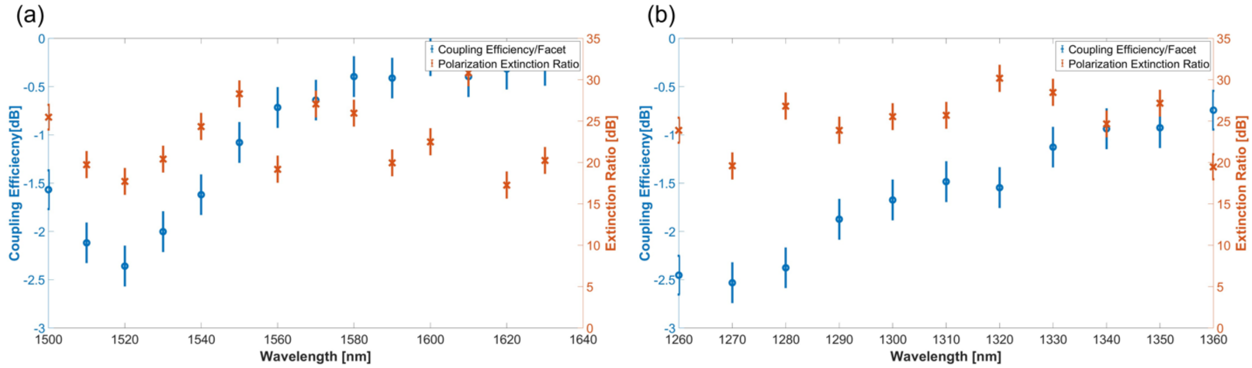

Fig. 3. Measured loss/facet and polarization extinction ratio for the fused PM fiber to chip connection (a) In C+L band. (b) In O band. Error bars of +/-0.2dB included in the loss per facet and +/- 1.5dB in the polarization extinction ratio, to indicate the fluctuations in power measurements.

4. Conclusions

There is a clear need for PM fiber to chip connections for integrated photonics applications. Especially given the interest in external laser sources and the inherently polarization sensitive nature of chip scale photonics. We have demonstrated a fast and cost-effective method for connecting a PM fiber to chip while maintaining robust coupling efficiency and greater than 20dB polarization extinction ratio. The lack of optical glue at the joint, enables greater flexibility in the epoxies that can be utilized and enables compatibility with solder reflow process. Since in this case, the optical properties of the epoxy don't have any bearing on the performance, epoxies with favorable mechanical and thermal characteristics can be employed purely for stress relief. This should lead to more stable fiber to chip connections under a wider set of temperatures and operating conditions.

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