Low Loss Photonic Packaging Using Fusion Splicing

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Abstract:

We present a novel photonic packaging method for permanent optical edge coupling between a fiber and chip using fusion splicing. We demonstrate minimum loss of 1.0 dB per-facet with 0.6 dB penalty over 160 nm bandwidth from 1480-1640 nm.

Summary of Research:

One of the biggest challenges in the silicon photonics industry is to permanently attach an optical fiber to a photonic chip, with high optical coupling efficiency. Multiple packaging methods have been demonstrated to increase the coupling efficiency between an optical fiber and a chip while increasing throughput for high volume manufacturing. Some of these methods use grating couplers to couple light from the top of the chip, but grating couplers are fundamentally bandwidth-limited while edge couplers use a form of waveguide taper and/or lensed fiber and are inherently broadband but require access to the sides of a chip and have tight misalignment tolerances [1]. When used in packaging applications, individual fibers and fiber arrays are permanently placed over grating couplers using optical adhesive and fixtures or ferrules. Optical adhesives shrink during curing and alignment tolerances are tight, it becomes challenging to achieve lower losses with high scalability.

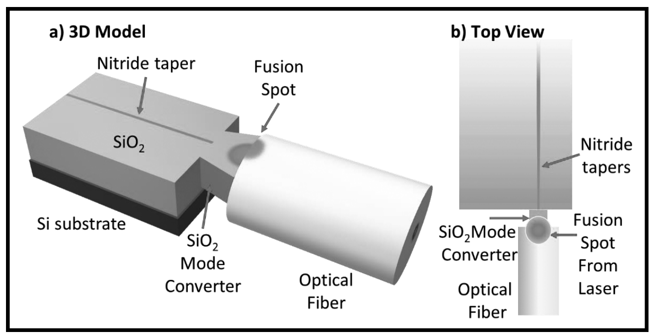

Figure 1: a) 3D model of a packaged device using silicon dioxide mode converter fused to SMF-28 fiber. It shows undercut silicon substrate which isolates the oxide mode converter from the chip, b) schematic representation of the top view of the method shows the fusion splicing spot from the CO_2 laser which improves the coupling efficiency.

We present a novel photonic packaging method for permanent optical edge coupling between a fiber and a photonic chip using fusion splicing which is low-cost, low-loss and scalable to high volume manufacturing [2]. We introduce a cantilever-type silicon dioxide mode converter which is mode matched to a single mode fiber at the input facet and a silicon nitride waveguide at the output facet [3-5]. The silicon dioxide mode converter is permanently fused to the optical fiber using a CO_2 laser (Figure 1) [5]. As the main components of an optical fiber are silicon dioxide same as the silicon dioxide cladding on the photonic chip, it readily absorbs 10.6 µm of radiative power from the laser and forms a permanent bond between the two interfaces. This packaging method is compatible with any photonic device with a cladding of silicon dioxide with different types of inverse nanotapers. The geometry of the oxide mode converter can be engineered to match the mode profile of the waveguide nanotaper. The proposed method is compatible with standard foundry processes and does not require any deviations from the standard fabrication process. The oxide mode converter uses two-stage mode conversion: first mode conversion from the waveguide (mode size < 1 µm) into the oxide mode converter and second, from the oxide mode converter to the optical fiber (mode size of 10.4 µm). The two sides of the oxide mode converter are engineered to maximize the coupling from the waveguide nanotaper to the cleaved optical fiber.

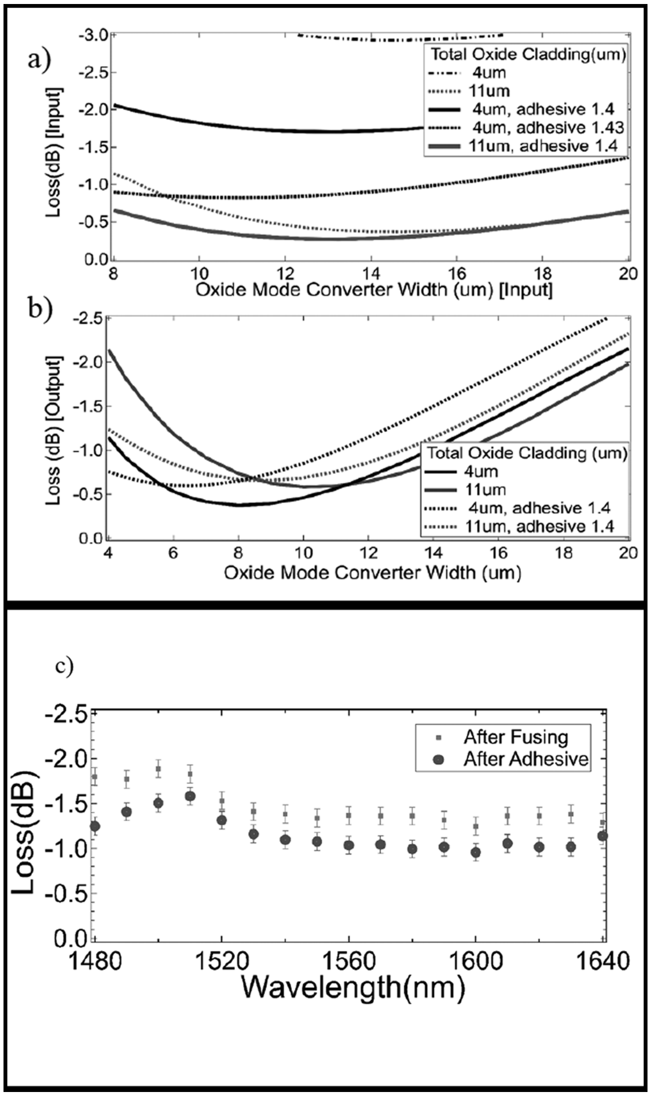

Figure 2: Coupling loss between the fiber and the mode converter as a function of oxide mode converter input width, a) at the input interface from the fiber to the mode converter, and b) from the mode converter into the waveguide. c) The coupling loss per-facet after fusing and after applying adhesive as a function of wavelength, a minimum loss of 1.0 dB is measured.

The width of the oxide mode converter is calculated with different total oxide cladding thickness (µm) (Figure 2a and b) with a fixed nitride waveguide taper width. Our simulations also show that a minimum coupling loss of 0.3 dB can be achieved with 14 µm oxide mode converter width and 11 µm total (top plus bottom) oxide cladding thickness with an adhesive of refractive index 1.4. The waveguide nanotaper is made of silicon nitride and is 0.18 µm wide at the tip and 100 µm long with a linear profile. We also calculated the 1 dB penalty in misalignment tolerance between the fiber and the oxide mode converter, which is +/- 2.5 µm and +/- 2.4 µm in horizontal and vertical directions respectively.

The devices were fabricated using standard CMOS compatible, microfabrication techniques. The waveguides were patterned using standard DUV optical lithography at 248 nm, the devices were etched using inductively coupled plasma reactive ion etcher and cladded oxide using plasma enhanced chemical vapor deposition. After dicing, we remove the silicon substrate underneath the oxide mode converter to optically isolate it. We fuse the SMF-28 cleaved fiber to the oxide mode converter using a CO_2 laser and reinforce the splice by adding an optical adhesive of suitable refractive index. Fusing the fiber and the chip together using radiative heating leaves no residue behind and forms a permanent bond.

We demonstrate a minimum loss of 1.0 dB per facet with a 0.6 dB penalty over 160 nm bandwidth near the C-band on a standard, cleaved SMF-28 fiber fused to the silicon nitride photonic chip (Figure 2c) [2]. We measure coupling loss after fusing and after the addition of optical adhesive of refractive index 1.3825.

We measure a -30.1 dB of optical return loss using a circulator for 1550 nm after fusing the optical fiber to the chip. The coupling loss before fusing was 2.1 dB with 0.4 dB of waveguide propagation loss. After fusing the fiber to the chip, the loss decreased to 1.3 dB on the fused facet and further decreases to 1.0 dB after the application of optical adhesive.

References:

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