Single-Shot, Multiple I/O Photonic Chip to Fiber Array Packaging Using Fusion Splicing

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Abstract:

We show a novel multiple I/O photonic packaging method for 4-fiber array using fusion splicing. We demonstrate a minimum loss of 2.5 dB per facet with a variation of +/-0.1 dB through a 4-fiber array.

Summary of Research:

With increase in parallelism and switching in data communication and increasing integration between electronics and optics, highly efficient communication links are needed. However, packaging of integrated devices with multiple I/O ports in a single run remains a challenge. To keep up with the highly data driven communication systems, a low-cost and low-loss packaging technique for photonic integrated circuits with multiple port devices like switches, interferometers and modulators [1,2]. Current packaging methods for multiple I/O photonic chip utilize packaging of a single fiber individually. This process is inefficient while packaging many output ports, however, as the parallelism between electronics with optics increases, multiple I/O ports will be required for switching. In a silicon photonics foundry, packaging each fiber individually consumes equipment time and increases packaging cost of a single chip. We introduce a packaging technique for packaging multiple fibers (2,4) at once using a CO_2 laser to splice the fiber-array to the photonic integrated circuit.

Multiple packaging methods use special fixtures, fabrication steps and tools for aligning fiber arrays to a photonic chip, however, these methods use optical adhesive for packaging the devices which shrinks during curing and leads to misalignment losses. Most techniques also use special fixtures like v-grooves, specialized connectors or polymer lids/waveguides with optical adhesive for packaging photonic devices with multiple I/Os [3-5]. The v-grooves are used for passive alignment of the fiber to the chip, however, packaging of the fiber array is still done using optical adhesives. Optical adhesives shrink during curing and since alignment tolerances are tight, it becomes challenging to achieve low losses with high scalability. Fabrication of v-grooves requires very precise etch rates and increases fabrication steps.

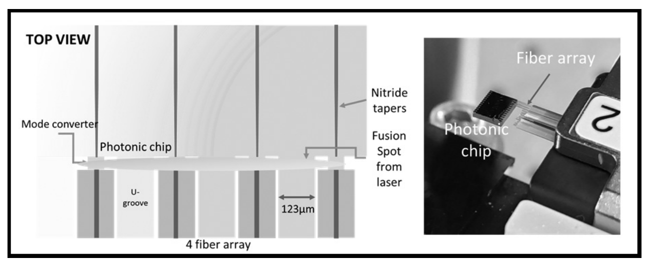

Figure 1: Left; Schematic representation of the top view of the method shows the fusion splicing spot from the CO_2 laser and the u-grooves for aligning fiber arrays. Right; A photograph of a packaged photonic device to a fiber array on a holder.

We demonstrate a novel photonic packaging method for permanent optical edge coupling between a fiber-array and a photonic chip using fusion splicing which is low-loss, low-cost, robust, and scalable to high volume manufacturing without using an optical adhesive. We fabricate u-grooves on the chip for placement of fiber arrays with a pitch of 250 µm as shown in Figure 1. These u-grooves help in the placement of the fiber, which is coupled to the oxide mode converter [6]. The oxide mode converter matches the modes between a SMF-28 optical fiber (mode size of 10.4 µm) to a waveguide (mode size < 1 µm). We engineer the geometry of the two sides of the oxide mode converter to maximize the coupling from the waveguide nanotaper to the cleaved optical fiber.

We fabricate silicon nitride waveguide devices using standard CMOS compatible, microfabrication techniques. A 5 µm thick layer silicon dioxide is deposited via a plasma-enhanced chemical vapor deposition (PECVD) on the silicon wafer and 309 nm of silicon nitride are deposited via low pressure chemical vapor deposition. The waveguides are patterned with standard DUV optical lithography at 248 nm and etched using a fluorine chemistry in an inductively coupled plasma reactive ion etcher. We clad the devices with 5 µm of silicon dioxide using plasma enhanced chemical vapor deposition. We then pattern the chip structure with u-grooves and deep-etch the silicon to a depth of about 100-120 µm. After dicing, we remove the silicon substrate underneath the oxide mode converter to optically isolate it.

We fusion splice an entire fiber-array of four fibers to the mode-converter using a CO_2 laser in a single shot to achieve high manufacturing scalability. We use a cylindrical lens to focus the beam of the CO_2 laser in one dimension to a width ~ 3 mm. As the beam is focused into a line, it is aligned at the fiber to mode converter interface and then radiated with CO_2 laser for 1 sec at ~ 10W of laser power. The width (3 mm) is selected to enable fusing a 12-fiber array in a single shot for future applications. Fusing multiple fibers at once significantly decreases the time and the cost involved in packaging a single chip. Fusing the fiber array and the chip together using radiative heating leaves no residue behind and forms a permanent bond, not requiring extra fixtures or adhesives for durability.

We fuse cleaved 1, 2 and 4-fiber arrays to the oxide mode converter using a single shot from the CO_2 laser and measure a coupling loss of 1.2 dB, 2.2 dB and 2.5 dB per-facet respectively. A waveguide propagation loss of 0.4 dB was subtracted from the measured loss. We expect to see a decrease in the coupling loss after the application of an optical adhesive [7]. We measure variation of ± 0.1 dB through a 4-fiber array at 1550 nm and ± 0.05 dB through a 2-fiber array at 1550 nm as shown in Table 1.

Photonic packaging has the potential to achieve manufacturing scalability at industry level using single shot fusion splicing using a CO_2 laser, which is cost and time efficient. We envision that this method can be fully automated using passive alignment techniques to enable efficient, fast and low-cost fiber array to chip packaging in high volume applications. To provide more mechanical stability, the fiber array can be fused to the chip at multiple spots eliminating the need for optical adhesives.

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No of fiber	Coupling loss per-facet (dB)	Deviation (dB)
1	1.2	0
1	2.2	(+/-)0.05
2	2.3	
1	2.5	(+/-)0.1
2	2.6	
3	2.7	
4	2.7	

Table 1: Coupling losses for 1, 2, and 4-fiber arrays.