Optical performance of Photonic Wire Bonds under temperature and humidity cycling

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ABSTRACT

Photonic wire bonds are polymer waveguides developed using lithographic adjacent techniques. We report on the optical insertion loss of photonic integrated circuits under temperature and humidity cycling conditions. Photonic wire bonds were used for optical I/O and were compared to conveniently attached fiber assemblies. Clad and unclad photonic wire bonds were employed to compare performance in extreme environments. The testing was carried out via military standard 810H which defines a myriad of high temperature and humidity tests. To be specific, high humidity constant temperature, induced storage and transit, hot humid, and cyclic high relative humidity tests were run on chips containing loopback waveguides. The optical insertion loss was characterized via the waveguide cut back method, where the optical transmission is measured in waveguides of different lengths. Conventionally fiber attached and photonically wire bonded devices showed little degradation in optical performance, whereas the unclad photonically wire bonded devices show significant optical loss in high temperature and humidity conditions. This is the first known report on the optical performance of photonic wire bonds under temperature and humidity cycling tests.

Keywords: Silicon Photonics, Photonic Wire Bonds, Fiber Optics, Optics,

1. INTRODUCTION

Photonic Integrated Circuits (PICs) have produced a new exemplar module for telecommunications, quantum computing, high performance computing and many other industries. Allowing for high density integration, CMOS compatible fabrication, and streamlines the reduction of SWAP-C (size, weight, power, and cost) in respective systems, silicon photonics is the material platform which is most often employed. Silicon Photonics allows for the integration of a myriad of on chip devices, such as high-speed modulators, photodetectors, and is quickly moving towards integrating these devices with waveguides in large scale integration [1-3]. To fully take advantage of silicon photonic based modules, a laser source is required. Generally, the laser source is integrated with the silicon PIC via optical fibers and micro-optic lenses. When the fiber is coupled to the PIC on the edge of the chip or in plane, this is referred to as edge or end fire coupling [4]. End fire coupling is generally performed with an on-chip inverse taper, which allows for mode matching between the fiber and the chip by making the taper narrower at the chip edge. The close matching between the refractive index of the glass fiber and the oxide on chip allows for efficient coupling between the chip and the fiber [5]. Additionally, one can optically couple to the PIC vertically. Alternatively, the laser can be bonded directly onto a silicon wafer for coupling. Each of these methods has been observed to produce coupling losses in excess of 2.5dB, while impurities and strains introduced in the wafer bonding process can produce poor quality bonds [6-7]. Photonic wire bonding which is the freeform generation of polymer waveguides via a femtosecond pulsed laser, allows for dense integration, automated mass production, with less stringent alignment requirements than those in other hybrid integration techniques [8]. To be specific, a femtosecond pulsed laser 3D prints a polymer waveguide through two photon absorption. Early on in its inception, researchers were able to obtain 1.6dB of average insertion loss, with losses less than 0.7 dB being obtained recently [9-11]. While current research focuses on hybrid and heterogeneous integration of III-V lasers with silicon waveguides and the performance of such systems, few have reported on the optical performance of photonic wire bonds in extreme environments.

In this paper, we report on the optical performance of photonically wire bonded modules under temperature and humidity cycles. The empirical demonstrations were adopted from tests in MIL-STD 810H, with some modifications based on the

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test equipment that was available. We compare the results of clad and unclad photonically wire bonded modules with conventionally wire attached modules.

2. DESIGN & TEST

For this experiment, we leveraged Photonic Integrated circuits with “loopback” waveguides, which allow for in-situ testing of fiber-to-fiber coupling loss. These PICs were developed by AIM Photonics, a pure play foundry that offers Multi Project Wafer runs to fabless design companies. Figures 1 and 2 show conventionally fiber attached, and photonically wire bonded modules.

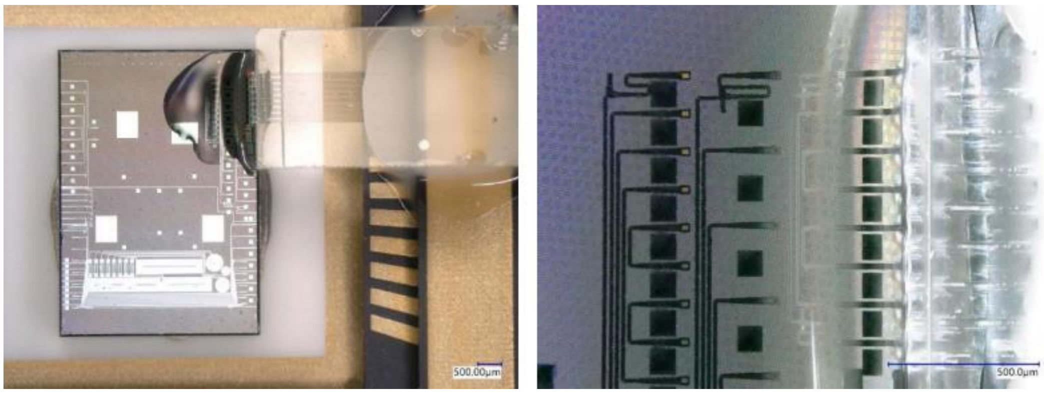

Figure 1. Close up image of conventionally fiber attached PICs. The PIC consists of loopback waveguides for fiber-to-fiber insertion loss.

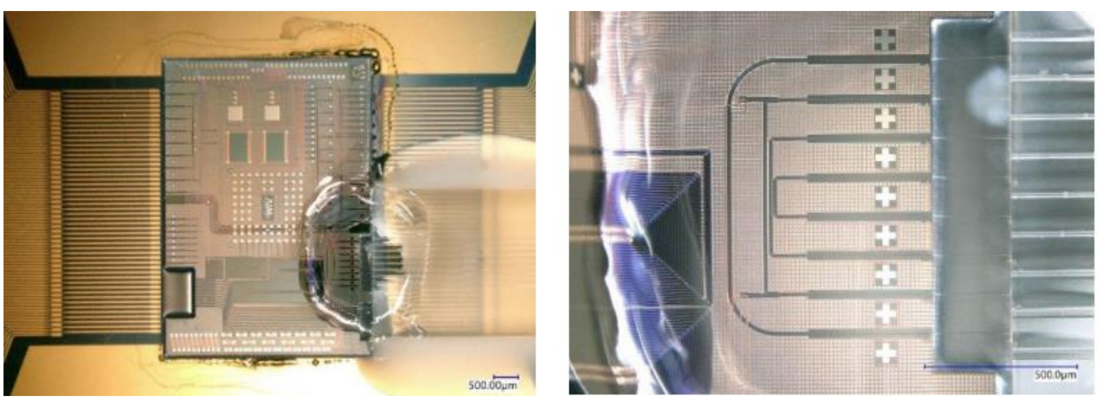

Figure 2. Close up image of photonically wire bonded PICs. The PIC consists of loopback waveguides for fiber-to-fiber insertion loss.

This test was also conducted with unclad photonically wire bonded modules, which do not contain a protective cladding layer around the photonic wire bonds. Figure 3 illustrates the unclad photonically wire bonded module.

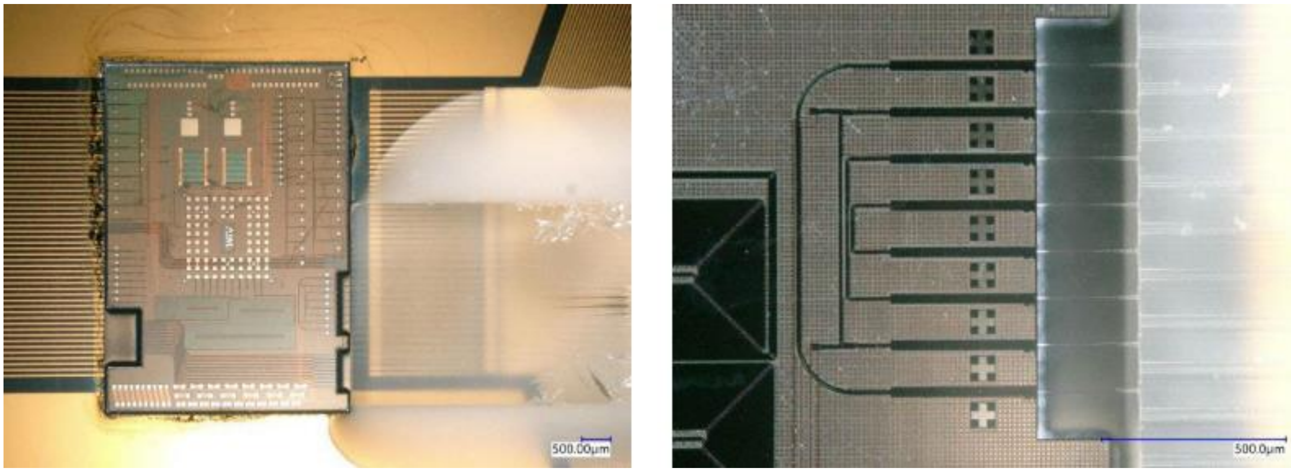

Figure 3. Unclad photonically wire bonded module. The photonic wire bonds bridge the gap between the optical fiber and the photonic integrated circuit.

In this demonstration, four different humidity/temperature cycling tests were performed. These tests were modeled from MIL-STD 810H, and run in a Tenney BTRC Environmental Chamber for a run time of 24 hours each test. For the first test we ran a natural high humidity constant temperature cycle. The chamber was set to 23 ± 2°C and 95-100% relative humidity. In the second test, a natural hot humid cycle was run. The temperature was cycled between 31-41°C and the relative humidity was cycled from 59-88%. Thirdly, we performed an induced storage and transit test where temperature cycled between 35-71°C and the relative humidity was cycled between 14-80 %. Lastly, a cyclic high relative humidity test was run, where the temperature was cycled between 27 – 34°C with relative humidity cycled between 74-100%. For each of the tests, the fiber-to-fiber coupling loss was measured before and after though an optical power meter, with a standard benchtop laser being used as the optical source.

3. RESULTS

The optical performance of each of the modules was compared for each of the four aforementioned tests. All three modules survived without catastrophic failure (assembly/off chip connection stayed intact). The table below summarizes the performance of each of the modules.

Test	Structure	IL before (dB)	IL after (dB)
Natural Constant Temp	CFA	-4.93	-4.85
	CPWB	-3.1	-3.03
	UCPWB	-3.75	-8.65
Natural Hot Humid	CFA	-4.85	-6.93
	CPWB	-3.03	-3.2
	UCPWB	-8.65	-6.55
Induced Storage/Transit	CFA	-6.93	-4.55
	CPWB	-3.2	-3.2
	UCPWB	-6.55	-6.73
Cyclic High Relative Humidity	CFA	-4.55	-4.6
	CPWB	-3.13	-3.15
	UCPWB	-6.73	-13.1

Table 1. Insertion loss results from the humidity cycling tests. All values are in dB. CFA – conventional fiber attached, CPWB – clad photonic wire bonded, UCPWB - unclad photonic wire bond.

While the conventionally fiber attached and the clad photonic wire bonded modules showed little degradation in performance, the unclad photonic wire bonds experienced significant degradations throughout the humidity cycles, which could be due to the hydrophobic nature of the polymer used for photonic wire bonds.

4. CONCLUSION

We report pioneering work on the optical performance of photonically wire bonded PICs under harsh environmental conditions. To be specific, we compared the insertion loss between conventional fiber bonds and photonic wire bonds under humidity cycling tests akin to those in MIL-STD 810H. We observed that the clad photonically wire bonded module had the lowest loss and the most consistent performance, while the unclad photonically wire bonds degraded significantly in performance. We intend to expand upon this work by adding other harsh environments and comparing the performance between conventionally fiber attached and photonically wire bonded modules.

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