Effects of Reflow Soldering Process Conditions on the Reliability of Specialty Optical Fibers

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Abstract: We will review the reliability of specialty optical fibers for high temperature uses with an emphasis on fibers through reflow soldering process conditions. Coating thermal stability, fiber mechanical properties, and induced optical loss will be discussed. © 2020 The Author(s)

1. Introduction

Applications for optical fibers in opto-electronics integration systems require the fibers to survive further process steps, such as reflow soldering, and to perform their roles reliably in the system. Reflow soldering process presents a condition where the maximum processing temperature, e.g. 260°C, exceeds the designed temperature rating of a standard optical fiber for telecommunications.

We have studied thermal stability of specialty optical fibers for various applications at high temperatures and harsh environments [1-4]. In this paper, we will present our latest work on fiber reliability at simulated reflow soldering conditions. Results on coating appearance, change in fiber mechanical properties, induced loss for several specialty optical fibers, along with standard telecom fiber as a reference, will be reported and discussed. The intrinsic lifetime of fibers will be estimated in terms of minimum bend radius allowed.

2. Experiment Details

Optical fibers with three different coating systems were selected and were drawn using preforms of the same design. The characteristics of the fibers are summarized in Table 1. The fiber waveguide was designed as a bridge fiber between high NA planar silicon waveguides and standard 0.12NA single mode silica fiber to optimize the coupling efficiency. In addition, the high NA fiber would offer lower bend loss in small footprint of photonic integrated chips compared to the standard single mode fiber.

Table 1 also describes the coating type for each fiber type. Fiber A used standard dual acrylate coating which has an upper use temperature of ~85°C. Fiber B and C were specially developed to provide better stability for high temperature uses. In this study, all fibers were thermally conditioned in air and nitrogen environments respectively by a simulated reflow process. The thermal profile of the simulated reflow process is shown in Fig. 1.

Table 1. Fiber sample list

Fiber Type	Fiber Characteristics	Coating Type
A	Glass Diameter 125μm	Standard UV Curable Dual Acrylate
B	Numerical Aperture 0.28	Special UV Curable Silicone / High Temperature Acrylate Dual Coat
C	Mode Field Diameter 4.9μm at 1550nm	Special UV Curable High Temperature Acrylate Mono Coat

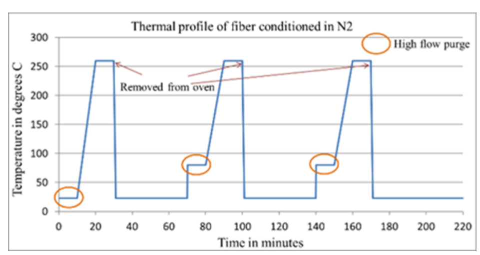

Fig. 1. Thermal profile of simulated reflow process in nitrogen

Fibers before and after the reflow conditioning were subject to various measurements and tests as described below. Fiber appearances were visually inspected. Fiber coating diameters were measured by using a PK2400 Fiber Geometry System. Fiber dynamic strength and fatigue parameters were measured in accordance with TIA/EIA-455-28C (FOTP-28). Fiber bend losses were measured by the power change after wrapping fibers on mandrels with different radii.

3. Results and Discussions

Coating appearance was visually inspected before and after the reflow conditioning as shown in Fig. 2. All three fibers turned yellow or brown after conditioning. Samples after reflow in air showed more change in color than in nitrogen. Sample A after reflow in air showed the most severe color change indicating a significant coating degradation.

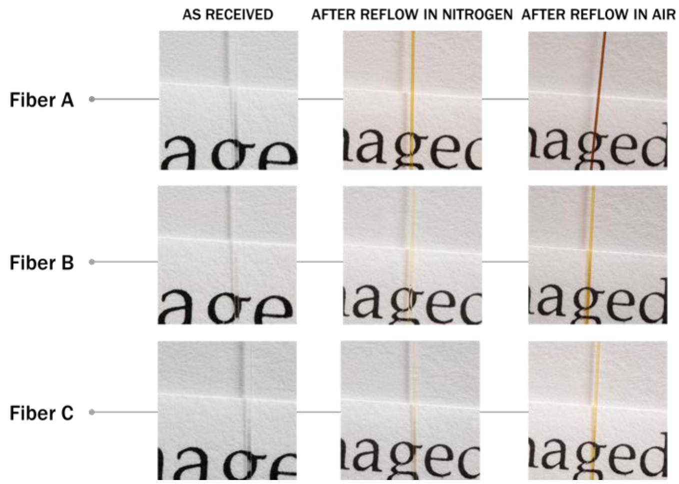

Fig. 2. Fiber appearance before and after reflow in nitrogen and air

The impact of the reflow conditioning on the fiber geometry was measured by the change in fiber diameter as shown in Table 2. The fiber diameter change was only due to the coating volume change because the silica glass structure does not change under this condition. Fiber A showed the greatest reduction in coating volume while sample C showed the least reduction. Fiber coating volume reduction was observed to be lower after reflow in nitrogen than in air. Table 2 also shows the fiber weight loss after the reflow conditioning. The degree of weight loss change was consistent with the results of fiber diameter change. The fiber weight loss was only due to coating weight loss as well.

Table 2. Fiber diameter and weight before and after reflow in nitrogen and air

	As Received		After Reflow in Nitrogen				After Reflow in Air			
Fiber	Fiber diameter (μm)	Fiber weight (g)	Fiber diameter (μm)	Coating volume reduction (%)	Fiber weight (g)	Fiber weight loss (%)	Fiber diameter (μm)	Coating volume reduction (%)	Fiber weight (g)	Fiber weight loss (%)
A	242.56	16.6728	216.22	20.54	15.2584	8.48	214.82	21.56	14.7590	15.09
B	249.13	17.4008	236.46	9.91	16.2917	6.37	235.87	10.36	15.8338	9.62
C	242.00	17.6413	237.08	4.02	17.1473	2.80	234.52	6.09	16.2615	6.56

Fiber mechanical properties were evaluated using dynamic strength and fatigue tests. The results are shown in Table 3. Fiber A had the greatest reduction in strength and n value within all three fibers after reflow. The reduction in median strength was 3% after reflow in nitrogen and 5.5% after reflow in air. The reduction in n value was 14% after reflow in nitrogen and 21% after reflow in air. There was no reduction in fiber strength for Fiber B and C. The reduction in n value for Fiber B was 10% after reflow in nitrogen and 15.3% after reflow in air. Fiber C showed the smallest reduction in n value which was 1% after reflow in nitrogen and 12.1% after reflow in air. These results show that Fiber A had the most significant degradation in mechanical properties.

Table 3. Fiber mechanic properties before and after reflow in nitrogen and air

	As Received			After Reflow in Nitrogen			After Reflow in Air		
Fiber Samples	Median Strength (kpsi)	Slope (m_d)	n value	Median Strength (kpsi)	Slope (m_d)	n value	Median Strength (kpsi)	Slope (m_d)	n value
A	695	145	19.8	675	121	17.0	657	91	15.6
B	699	104	19.2	701	113	17.3	736	85	16.3
C	657	72	19.3	704	143	19.1	751	66	17.0

For the fiber used in small footprint of photonic integrated chips, it is usually placed under small diameter bend. The optical loss under such small diameter bending is one of the most important properties to determine device performance. The optical loss was studied at different bend radii for fibers before and after the reflow conditioning. As shown in Table 4, the optical loss induced after reflow was minimal for all fibers. The induced loss could be from micro bend loss due to coating degradation after thermal conditioning. The minimal increased loss was probably due to 0.28NA single mode fiber which was less sensitive to micro bend than 0.12NA fiber.

Table 4. Fiber optical losses (dB) under wrapping 10 turns at different mandrel radii, R (mm)

	As Received			After Reflow in Nitrogen			After Reflow in Air		
Fiber Samples	R=2	R=2.5	R=5	R=2	R=2.5	R=5	R=2	R=2.5	R=5
A	0.005	0.012	0.004	0.005	0.001	0.004	0.062	-0.018	0.011
B	0.001	0	0	0.006	-0.003	-0.003	0.023	0.005	0.052
C	-0.008	0.001	0.002	-0.016	0.003	0.006	0.078	-0.085	0.035

In general, the strength of an optical fiber is limited by the severest surface flaw on the fiber. However, the strength of the fiber approaches its intrinsic strength on a short piece of fiber where the probability of having an extrinsic surface flaw is low. To further evaluate the reliability of fibers through reflow soldering process, the intrinsic lifetime of fibers was estimated based on parameters measured by dynamic fatigue tests [5, 6]. Table 5 shows estimated minimum bend radius allowed at the failure probability of 1×10^{-6} over 20 years. The minimum bend radius allowed had no change for fibers B and C after reflow while the radius increased 33.6% for fiber A after reflow in air. A fiber having a smaller minimum allowed bend radius means that the fiber can have a greater maximum allowed stress at bending. For example, 33.6% increase in minimum allowed bend radius would result in approximately 26% reduction in maximum allowed stress.

Table 5. Estimated minimum bend radius allowed for fibers at a specific failure probability

Failure probability of 1×10^{-6} over 20 years	Estimated minimum bend radius allowed (mm)		
Fiber Samples	As Received	After Reflow in Nitrogen	After Reflow in Air
A	2.65	3.11	3.54
B	2.81	2.81	2.81
C	2.81	2.62	2.74

4. Conclusion

The effects of reflow process conditions were studied on coating thermal stability, mechanical properties, and induced loss for optical fibers with three different coatings. The intrinsic lifetime of fibers was estimated in terms of minimum bend radius allowed at a specific failure probability. All three fibers after reflow in nitrogen showed less degradation than fibers after reflow in air. Fiber with standard dual acrylate coating showed a significant degradation compared to the other two fibers with special coatings. Fiber B and C appear to be better choices to use in photonic integrated chips compared to fiber with standard dual acrylate coating.

5. Acknowledgement

We thank our many colleagues who helped with various aspects of this work, particularly Steven Beauregard, Alit Chanthala, Bent Edvold, Toby Cotter, Dave Burgess, Andrei Stolov, Deb Simoff, Xiaoguang Sun, Marta Chlus, and Kyle Bedard.

6. References

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