Solder Reflow Capable Multifiber Ferrule for Co-Packaged Optics

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Abstract *Multifiber MT ferrules molded from a high temperature material exhibit significantly improved solder-reflow performance. CTE and T_g data is reported and compared to conventional multifiber ferrules. Dimensional measurements demonstrate that the ferrules are capable of surviving multiple reflow cycles.*

Introduction: Paths to 51.2Tb Switching

With 25.6Tb switching ASICs available in 2020, the industry is now looking to solutions for 51.2Tb switching[1]. These future applications introduce challenges for all areas in the link including passive optical components.

For the purposes of this investigation, we first consider challenges associated with three possible paths to 51.2Tb switching:

1. 800G pluggable optics x 64
2. On Board Optical (OBO) Tx/Rx modules
3. Co-Packaged optical IO with switching ASIC

800G pluggable optics necessitate a minimum space of two rack units to simply fit all 64 Tx/Rx modules. Host PCB transmission distance from ASIC to card edge pluggable transceivers is the most power demanding solution necessitating additional retiming components and/or use of high speed copper cabling in place of PCB traces. OBO modules have been used in many core routing and HPC applications over the last two decades and solve some challenges by placing the module closer to the ASIC on the host PCB. The question remains whether an OBO approach goes far enough to solve basic power and density challenges while eliminating the convenience and flexibility of card edge pluggable optics. Co-Packaging the optical IO with the switching ASIC is the optimal solution to overcome power and density hurdles. However, co-packaging introduces a new array of technical and logistical challenges to be solved prior to mainstream implementation. The timing of widespread adoption of co-packaged optics remains in question. However, a recent study commissioned by ARPA-e Enlitened Program suggests traditional Tx/Rx modules for high speed links will start to decline in favor of co-packaged optics by the end of the current decade[2].

A fundamental assumption for co-packaged Tx/Rx modules is that optical fibers must be separated from the ASIC for realistic manufacturability and logistics solutions. A separable optical fiber can be obtained by one of three primary approaches each with its own set of challenges:

1. Electrically separable Tx/Rx modules requiring compact, tight contact pitch, highly reliably socket technology.
2. Optically separable connections at the permanently attached Tx/Rx tiles utilizing new direct attach expanded beam interconnect technology.
3. Optically separable connections at the permanently attached Tx/Rx tiles utilizing new, solder reflow-capable terminated fiber stubs or short fiber pigtails.

This analysis is focused on solder reflow-capable fiber stubs and ferrule technology associated with the third option. This approach demands new levels of ferrule dimensional stability, epoxy stability, endface geometry stability as well as minimized CTE differences between fiber and ferrule.

Empirical Testing

Traditional multifiber (MT) ferrules have long been used in a variety of industries and applications within the MPO connector hardware and have passed standardized testing, including Telcordia GR-1435-CORE [3]. However, typical MT ferrules cannot survive solder reflow processes, which prevent use in fiber stub attach applications discussed above.

MT ferrules use guide pins and holes to align the two mating ferrules and ensure that the fibers mate properly. Therefore, a primary geometric concern for an MT ferrule is the fiber hole true position with respect to the guide pin holes which controls fiber alignment. For these permanent attach applications, the initial precision ferrule geometry must be maintained through solder reflow temperature exposure.

A new high temperature MT ferrule has been developed which significantly improves thermal stability over traditional MT ferrules. The new ferrule design enables applications requiring exposure to solder reflow processing. During material development, the focus was on increasing the glass transition temperature of the material (T_g), decreasing the coefficient of thermal expansion (CTE) above T_g, and maintaining a material that can be terminated, polished, and tested with industry-standard techniques for MT ferrules. Reducing the thermal expansion and Tg will help eliminate stress in epoxy/ferrule/fiber interfaces.

The new material was molded into standard MT geometry[4] for direct comparison to standard MPO MT ferrules. The solder reflow profile shown in Table 1 was used for testing.

Table 1: solder reflow recipe

Temp (℃)	25 to 150	150 to 182	182 to 220	220 to 255	255 to 220	220 to 20
Duration (sec)	80	95	55	30	20	60

Figure 1 shows empirically generated CTE curves from Thermo Mechanical Analysis (TMA) measurements, and Table 2 shows the quantitative results of the T_g and CTE analysis. The new material shows a substantial reduction in the CTE values, both below and above the glass transition temperature, along with a shift in the T_g of over 70℃. Between the improvements in all three criteria, the total thermal expansion the ferrule undergoes during solder reflow is reduced to only 40% of the original ferrule material expansion.

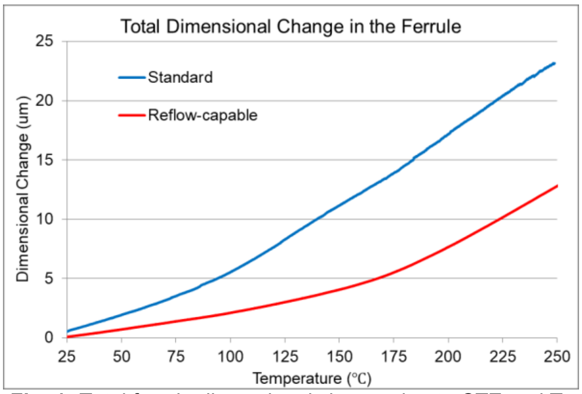

Fig. 1: Total ferrule dimensional change due to CTE and T_g

Table 2: CTE and Tg analysis results

	Standard	Reflow-capable
CTE (ppm/℃) below Tg	23	9
CTE (ppm/℃) above Tg	47	27
Tg (℃)	86	160

Standard MT ferrules and the new solder reflow-capable ferrules were compared for geometric stability through solder reflow. The fiber hole locations were measured with respect to the guide pin holes and the unterminated ferrules were then reflow cycled, remeasured, and then cycled and remeasued a second time. Figure 2 shows the radial change in fiber hole positions after two solder reflow cycles as compared to the initial measurements. While the standard MT ferrules show significant change, after two full solder reflow cycles the reflow-capable MT ferrules remain nearly unchanged. The average radial change of the reflow-capable MT ferrules was 0.11 microns, with the largest measured change among 60 fiber holes only 0.26 microns, indicating that the new material is capable of supporting single-mode and multimode connections through solder reflow without inherent structural changes.

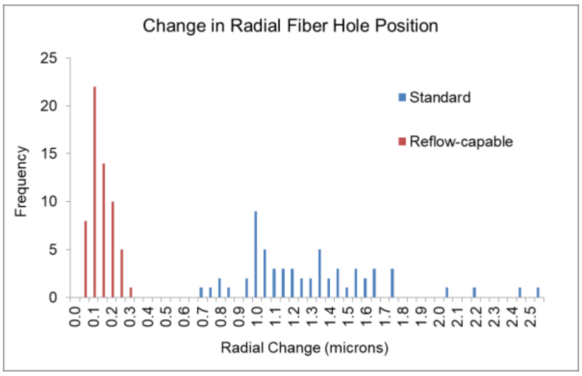

Fig. 2: Change in radial fiber hole position in ferrules after two solder reflow cycles (N=60 for each type)

Having validated that the ferrules can survive solder reflow, the next step was to terminate ferrules into MPO connectors using standard fiber and epoxies. Sets of MPO cable assemblies were built using standard single mode, ITU-T Recommendation G.652-D ribbon fiber, and terminated using industry-standard termination and polishing processes with standard fiber optic epoxy with both standard and reflow-capable MT ferrules.

Each set of cable assemblies was measured for insertion loss to establish baseline performance. The assemblies were then unmated and exposed to the reflow cycle of Table 1. After one reflow cycle the assemblies were then remeasured for insertion loss; results are shown in Table 3 with the average performance calculated for both ferrule types, as well as the number of fiber pairs that passed the 0.70dB GR-1435-CORE starting insertion loss spec.

The standard MPO MT Ferrule connectors showed a significant change of 2dB in performance, with almost all channels failing the insertion loss spec post-reflow. While the reflow-capable jumpers did show an average 0.3dB shift in performance, the first tests showed that most of the mated fiber pairs continued to pass GR-1435-CORE requirements. The impact of the reflow process with the new, high temperature MT ferrules was significantly smaller than the impact on traditional MPO MT ferrules.

In order to determine the root cause of the increased insertion losses, the assemblies were re-tested with index matching gel between fibers in the mated connection. If the ferrules suffered geometric deformation such that the fibers no longer aligned, index matching gel would not improve the performance. Conversely, if the end face geometry changed as a result of fiber pistoning axially within the ferrules due to epoxy stability, the index matching gel would negate the air gap and improve the performance. From Table 3, the all of reflow-capable assemblies returned to their original performance. This indicates an epoxy failure caused the performance change, and there was no shift in the fiber hole true position relative to the guide holes.

Table 3: Insertion loss results

		Average IL		
		Initials	Reflow	Gel
1310	Standard	0.10	2.14	2.16
	Reflow-capable	0.16	0.53	0.14
1550	Standard	0.08	1.93	1.93
	Reflow-capable	0.11	0.45	0.10

		Percent Fail (-0.7dB)		
		Initials	Reflow	Gel
1310	Standard	0%	96%	96%
	Reflow-capable	0%	23%	0%
1550	Standard	0%	96%	96%
	Reflow-capable	0%	12%	0%

The endface geometry of each MPO assembly was characterized at each step in the process. After the initial termination and testing process, the reflow-capable ferrules were all measured to industry standard endface geometry parameters. Table 4 shows the average ferrule angle and fiber height of the reflow-capable ferrules. The ferrule angles remain unchanged which indicates the ferrule body itself did not change through the reflow cycle, but the fibers moved due to the epoxy bond failure. This corroborates the conclusions about fiber alignment from the insertion loss testing. The assemblies were then repolished to re-establish acceptable endface geometry and cycled through a second reflow cycle to determine whether the jumper would remain constant after the first cycle or continue to change. Results in Table 4 show that the ferrule geometry remained stable and nominal, but the epoxy bond, once broken, continued to allow the fibers to move unacceptably. Based on these results, it is clear that the ferrule itself is solder-reflow capable, but more development work is needed to develop reflow-capable epoxy solutions for the application.

Table 4: Endface geometry results of the reflow-capable MPO connectors

	Ferrule X angle (°)	Ferrule Y angle (°)	Fiber Height (nm)
Before Reflow	0	8.35	1263
After Reflow	-0.04	8.32	-3019
After Repolish	-0.08	8.32	1262
After 2nd Reflow	-0.13	8.26	2540

Summary and Future Work

A material was selected and tested in the MT ferrule format using solder reflow requirements for permanent fiber stub attach applications. The new material showed a substantial reduction in the CTE coefficients, both below and above the glass transition temperature, along with a shift in the T_g of over 70 ℃. The total thermal expansion of the new ferrule during solder reflow was reduced to only 40% of the original ferrule material's expansion.

For the unterminated ferrules, the average fiber hole radial position change of the new, reflow-capable MT ferrules was 0.11 microns, with the largest measured change among 60 fiber holes only 0.26 microns. The new ferrule design is capable of supporting single-mode and multimode connections through solder reflow without inherent structural changes. Traditional MPO MT ferrules; however, showed significant geometric and performance degradation and are clearly not solder reflow-capable. Further investigation determined that the epoxy used for traditional MPO MT ferrule processing allowed axial fiber pistoning after solder reflow exposure. Future work will focus on epoxy process development for termination stability through reflow temperatures.

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