The Reliability of Optical Fiber Assembly Using Glass Solder

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Abstract

In this study, an optical fiber assembly directly coupled with a laser diode or a photo diode is designed to confirm high reliable optical coupling efficiency of optical transmitter(Tx) and receiver(Rx). The optical fiber assembly is fabricated by soldering an optical fiber and a Kovar ferrule using a glass solder after inserting an optical fiber through a Kovar ferrule. The Kovar which has good welding characteristics is applied to introduce laser welding technique. The glass solder has excellent thermal characteristics such as thermal shift, delamination compared with PbSn, AuSn solder previously used usually. Furthermore, the glass solder doesn't need fiber metalization and this enables low cost fabrication. However, the glass soldering is high temperature process over 350℃ and the convex shape after solidification due to surface tension causes the stress concentration on optical fiber. The stress concentration on the optical fiber increases the optical insertion loss and possibility of crack formation. The shape of glass solder was designed referring to 2-D Axi-symmetric FEM simulation. To test the mechanical reliability, mechanical vibration test and shock test were done according to Telcorida GR-468-Core protocol.

After each test, the optical loss of the stress distributed fiber assembly didn't exceed 0.5 dB, which passes the test.

1.Introduction

The optical alignment is the key technology in terms of the packaging to determine the performance and cost of optical Tx and Rx. The passive alignment technology has been considered as promising low cost packaging solution but still far from being commercialized.

Meanwhile, the active alignment technology using high reliable laser welding is still the main stream and will last longer than expected when it comes to fiber and lens system attachment shown in Fig 1[1]. To apply laser welding technique, the optical fiber is fixed inside metal ferrule using PbSn or AuSn solder[3]. Both the optical fiber and metal ferrule were metalized with Au to enhance the solderability. However, the temperature change causes the critical damage such as thermal shift, metal delamination, fiber pistoning and crack, which may cause leakage of hermetically sealed package, defocusing of beam and optical fiber breakage. In addition to that, the cost and the reliability of metalization on fiber are another challenge to low cost. To solve the above problem, a glass solder is introduced for an optical fiber assembly which consists of SMF(Single Mode Fiber) and Kovar ferrule which has good laser welding characteristic. The combination of SMF, glass solder and Kovar ferrule induce the lower stress on each material interface, lower thermal shift, lower leakage, lower delamination than any other materials commercially available.[3] Besides that, the glass solder doesn't need fiber metalization and ferrule metalization, which enables low cost packaging solution.

During the glass soldering process the

extreme stress concentration which exceed the yield stress on the optical fiber occurs from high temperature soldering process over 350°C and CTE(Coefficient of Thermal Expansion) mismatch[3].

The reliable optical fiber assembly was designed to apply glass solder by distributing concentrated stress which depends on the solidified shape. To verify the relation between stress concentration and shape formation, Axi-symmetric 2-D FEM simulation which can replace the 3-D FEM simulation was done to reduce the amount of calculation process.

SMF is composed of a core(9μm diameter) centered in SMF and a clad(125μm diameter) covering the core. Beam mainly propagates through core and has gaussian intensity profile.[4] When the SMF get stressed a certain portion of beam deviate from core and propagate through clad proportional to the stress. Supposing that the crack occur

Supposing that the crack occurs on the clad, the beam propagating through the clad leaks out, which causes the optical coupling loss. To evaluate the reliability of newly designed fiber assembly, the mechanical integrity test such as mechanical shock and mechanical vibration test were done based on Telcordia GR-468-CORE test protocol. [5]

2. The stress concentration on the optical fiber assembly.

Fig 2 shows the optical fiber assembly applying glass solder to fix the fiber inside the metal ferrule. Without intentional shape control, the glass solder forms dome due to surface tension at 350°C melting point after solidified. After process, the optical fiber assembly is then cooled at ambient temperature 25°C. The solidified shape of glass solder was assumed as a quadrant that contour is perpendicular to the fiber axis at the interface.

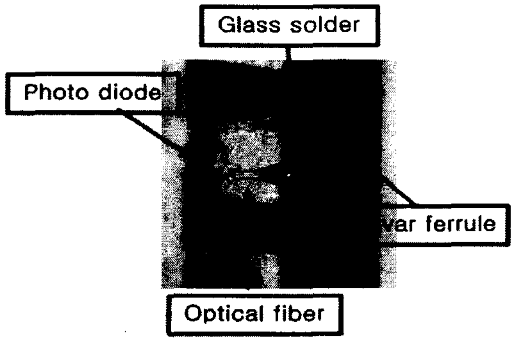

Fig 1. Optical coupling applying laser welding.

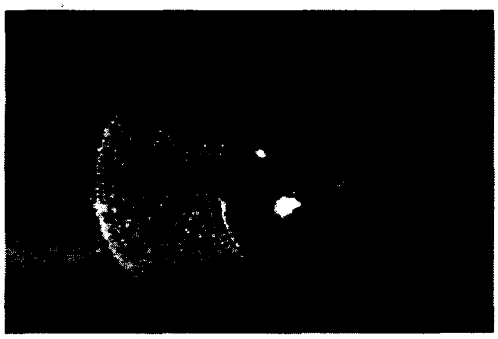

Fig 2. Fiber assembly using glass soldering(Stress concentrated type)

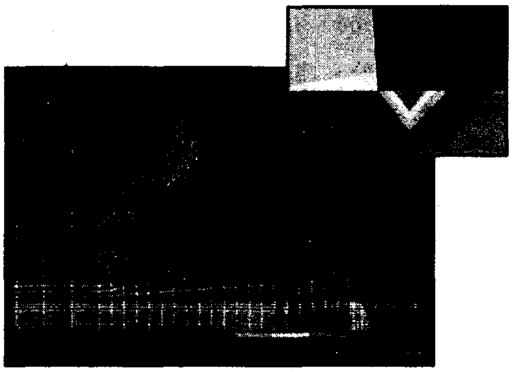

Fig 3. 2-D Axi-symmetric FEM analysis of stress concentration due to high temperature glass soldering

Table 1. Material property of optical fiber assembly

	E	σ_y	υ	CTE
Kovar	141	517	0.3	5.1
Glass solder	63.3	550	0.25	7.7
Optical Fiber	73	234.4	0.23	0.55

E:Young's modulus(GPa),
σ_y:Yield strength(MPa),
υ:Poisson's ratio, CTE: 10^{-6}m/K

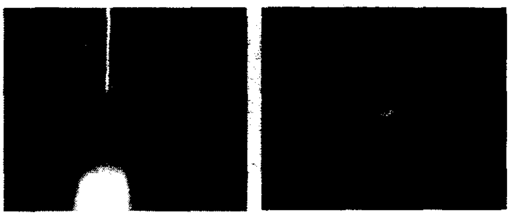

Fig 4. Visible inspection of stress induced optical loss using 633nm Visible HeNe lase(1mW) for stress concentrated type

3. The stress distribution on the optical fiber assembly.

To reduce the stress, the stress distributed shape was designed as shown in Fig 5. The result shows that the stress on the solder itself is 230MPa which is smaller than the yield stress. And also the stress on the fiber is under 200MPa which doesn't exceed the yield stress. Fig 6. shows the stress distributed optical fiber assembly and Fig 7 shows the visible inspection result which shows the less severe and intensive optical loss than that of stress concentrated type.

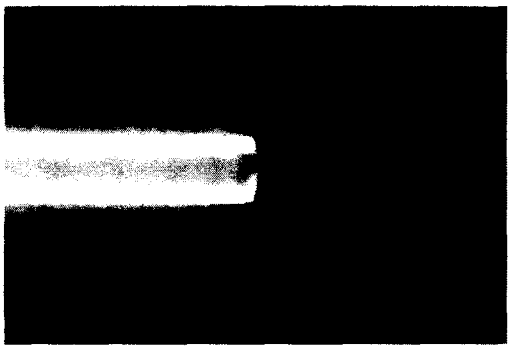

Fig 6. Stress distributed optical fiber assembly.

Fig 7. Visible inspection of stress induced optical loss using 633nm Visible HeNe lase(1mW) for stress distributed type

4.Reliability test of optical fiber assembly

For reliability test, the test procedure of optical transmitter in Telcordia GR-468-CORE was applied. In particular, the mechanical shock and vibration test is done to ensure the initial mechanical stability of the optical components such as laser diode and photodiode. To ensure mechanical stability of optical fiber assembly, the same test was done in terms of initial mechanical stability. The sampling method follows the LTPD 20% and the minimum sample size is 11. All samples should pass the test, or the acceptable failure sample size is 0.[5] The NA(Numerical Aperture) in Fig 8 is determined as $\sin\theta$ and the NA of cleaved fiber is 0.2. Far field pattern propagating to the air from fiber maintains gaussian profile with divergence angle 6^0 concerning the definition of NA. The optical power output through core is measured by removing the diverging beam from clad. The pass/fail determined by comparing the output power before and after the test. The distance(L) between fiber end and integrating sphere which has 5mm window is set for 2.4mm to remove the clad mode beam. The opposite end of optical fiber in Fig 8 is connected to 1550nm 1.88dBm optical source with FC/PC connector. Over 0.5dB optical loss is considered as fail.

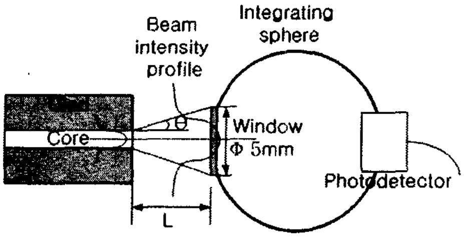

Fig 8. Optical power measurement setup using integrated sphere

4.1 Mechanical vibration test

The vibration test is done to evaluate initial failure affected by external vibration transmitting to the optical fiber assembly.

Table 2. Mechanical shock test condition

Test protocol	MIL-STD-883, Method 2002
Condition	Pulse peak : 1500G Duration : 0.5ms 6 axis, 5 times/axis
Sampling (LTPD 20%)	Sample size : 11ea Accepted failure : 0 ea

Table 3. Optical power change after shock test(unit:dBm)

#DUT	SC			SD		
	P_0	P_1	dP	P_0	P_1	dP
1	1.67	1.62	0.05	1.78	1.75	0.03
2	1.5	1.58	-0.08	1.62	1.6	0.02
3	1.49	1.29	0.2	1.6	1.6	0
4	1.53	1.42	0.11	1.4	1.38	0.02
5	1.32	1.3	0.02	1.65	1.65	0
6	1.7	1.7	0	1.62	1.62	0
7	1.42	1.35	0.07	1.69	1.61	0.08
8	1.7	1.72	-0.02	1.69	1.69	0
9	1.64	1.6	0.04	1.63	1.63	0
10	1.53	1.55	-0.02	1.62	1.64	0.02
11	1.34	1.3	0.04	1.61	1.71	-0.1

SC:Stress Concentrated type
SD:Stress Distributed type
P_0:Initial output power
P_1:Output power after test
$dP=P_0 - P_1$

The test condition was given in Table 2 following Telcoridia GR-468-CORE. The average optical output power of the stress concentrated type is 1.54dBm and stress distributed type is 1.66dBm. The initial optical power loss of stress concentrated type is two times larger than that of stress distributed type. As a result all samples of both types pass the test. The measurement error is ranging +0.1 to -0.1dB.

4.2 Mechanical shock test

According to the Telcoridia GR-468-CORE, the same samples are used for vibration test and shock test. The amount of stress of vibration test is larger than that of shock test. Thus, the shock test was done prior to the vibration test to reduce the dependence of each test.

Table 4. Mechanical vibration test condition

Test protocol	MIL-STD-883, Method 2007 Condition A
Condition	Peak acceleration : 20G Frequency : 20~2K Hz 3 axis/4min, 4time/axis
Sampling (LTPD 20%)	Sample size : 11ea Accepted failure : 0 ea

Table 5. Optical power change after shock test(unit:dBm)

#DUT	SC			SD		
	P_0	P_1	dP	P_0	P_1	dP
1	1.62	-0.28	1.9	1.75	1.7	0.05
2	1.58	1.34	0.24	1.6	1.6	0
3	1.29	1.172	0.118	1.6	1.61	-0.01
4	1.42	1.32	0.1	1.38	1.35	0.03
5	1.3	1.3	0	1.65	1.56	0.09
6	1.7	1.56	0.14	1.62	1.72	-0.1
7	1.35	1.37	-0.02	1.61	1.58	0.03
8	1.72	-0.03	1.75	1.69	1.65	0.04
9	1.6	1.25	0.35	1.63	1.66	-0.03
10	1.55	1.46	0.09	1.64	1.62	0.02
11	1.3	1.23	0.07	1.71	1.7	0.01

SC:Stress Concentrated type
SD:Stress Distributed type

P_0:Initial output power
P_1:Output power after test
$dP=P_0 - P_1$

For stress concentrated type in Table 5, the optical loss of sample number 1 and 8 exceed the 0.5dB and sample number 2 and 9 show relatively high optical loss. Meanwhile, all samples of stress distributed type passed the test.

5. Conclusion

The optical fiber assembly was designed to apply glass solder as a low cost packaging solution. High temperature soldering process over 350 caused stress concentration due to solidified shape affected by surface tension without shape control. The stress distributed type was designed using 2-D axi-symmetric FEM simulation to reduce the amount of calculation. To evaluate the reliability, the test samples of stress concentrated and distributed type were tested under mechanical vibration and shock condition referring to Telcordia GR-468-CORE. The optical loss of stress distributed type is less than 0.5dB, which passed the test.

Reference

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