

SEALING OPTICAL FIBERS WITHOUT METALLIZATION: DESIGN GUIDELINES

Raymond L. Dietz - Diemat, Inc.
19 Central St. Byfield, MA 01922 USA 1-978-499-0900

ABSTRACT

This paper describes an alternative way of sealing an optical fiber at a much lower cost than soldering, with an equal to or lower susceptibility to creep and misalignment of the fiber, and higher reliability. It involves the use of a low temperature (320°C) glass preform which seals directly to the bare fiber without the need for the costly metallization required for soldering. Various processing methods are outlined, along with cross sections of the sealed fiber in a ferrule. The key variables of the seal length, inside diameter of the tube, and the tube material itself are discussed in reference to their impact on designing a reliable, stress controlled hermetic seal. Reliability information is presented to demonstrate the viability of this technique for hermetically sealing optical fibers in a package feed-through tube.

Keywords: Solder glass, hermetic seals, sealing glass, low temperature optical fiber seals

1. INTRODUCTION

The demand for hermetically sealed optical fibers continues to increase due to the more stringent performance and reliability requirements of the telecommunications industry. The largest application for hermetically sealed fibers is through the cavity wall of an optoelectronic package, most common of which is the butterfly package. Coupling the light emitted from a semiconductor laser requires a method of fixing the fiber in precise alignment with the laser over the life of the optical device. Even a movement of a fraction of a micron can decrease the coupled power significantly (1). Reliability requirements preclude the use of epoxy because of the creep, outgassing, and the susceptibility to degradation over time. The standard method has been to metallize the fiber and hard solder it into a metal tube that is subsequently solder sealed in the package wall. Although this method overcomes many of the reliability problems of the epoxy method, the solder method has other disadvantages. The requirement for metallization of the fiber is not only expensive, but introduces other reliability concerns. (1) Clearly, an alternate method is needed for sealing fibers that overcomes the deficiencies of the epoxy and/or hard solder methods. This paper describes a low temperature solder glass and the process for sealing optical fibers reliably and at a significant cost savings over the solder sealing method. Compared to the solder method of sealing, low temperature glass sealing eliminates the costly need of metallization and all the associated problems of atmosphere, delivery, and inventory. In addition, glass offers the advantage of high corrosion resistance and positional stability associated with high creep resistance. Another key advantage is that glass does not require a non-oxidizing atmosphere which solders require. From a practical standpoint, this means sealing can be performed in an open air environment, as opposed to a dry box – a major plus.

2. REQUIREMENTS OF A SEALED JOINT

Aside from the hermetic requirement as specified by Telcordia, the optical fiber seal in the feed-through of the cavity wall of a package has several other requirements:

- Mechanical strength maintained through the reliability testing of Telcordia
- Corrosion resistance to different environments, such as temperature/humidity conditions
- High creep resistance to avoid degrading the fiber alignment technique within the package
- Ease of assembly, preferably with no special processing parameters
- Cost effective in materials, inventory, and process of assembly
- Low residual stress on the fiber

Epoxy or other polymer seals have been used, but do not meet the hermeticity requirements after longer-term exposure to damp heat tests (2). They are also susceptible to creep and mechanical degradation. For the high reliability end of the market, epoxy has been replaced by hard solder sealing, such as AuSn. Although this method overcomes most of the shortcomings of epoxy seals, solder sealing has several disadvantages. Probably the biggest disadvantage is the requirement for metallizing the fiber to achieve solder wetting. The metallization process is very costly consisting of the deposition of layers of metal on the fiber using sputtering or evaporation techniques. The adhesion of these layers over the life of the components is critical. Delamination of the metallization from the fiber has been observed after temperature cycling (-40°C to +85°C) at the point the fiber exits the metallization (1). The delivery times and inventory requirements are other disadvantages of using the solder method for attaching fibers.

3. WHAT IS A SOLDER GLASS?

Perhaps a better question is, "What isn't a solder-glass?" There is a large misconception that solder glass is some mixture of solder and glass – solder with glass or glass with solder. It is neither. The name "solder glass" originated when a high Pb, low temperature glass was used to join, or "solder", two glass substrates together. These are the key differences between solder and solder glass:

1. Solder glass is a solution of metal oxides, whereas solder is a solution of alloy or metals. Solder glass contains no metal, nor does solder contain any oxides.
2. Solder glass will wet oxide surfaces and some metallic surfaces, depending on the surface energy. Solder wets metallic surfaces, but not oxide surfaces.
3. Solder has an abrupt change in viscosity at the melt temperature. Solder glass has a more controlled viscosity with temperature, and hence, more controlled wetting.
4. Solder glasses are generally harder with a high modulus of elasticity and greater creep resistance. However, AuSn solders have comparable modulus as a low temperature solder glass.
5. Solder glass can be processed in air atmosphere, whereas solder requires a slightly reducing atmosphere or flux to provide an oxide-free surface for wetting.

4. SOLDER GLASS PROPERTIES

Designated as DM2700PF, the glass has the following key properties:

CTE (ppm/C) 7.5 ppm/°C
Density 4.5 g/cc
T_g 215°C
FSP 280°C
Seal Temperature 320-350°C

Typically, the DM2700PF is offered in a variety of shapes and sizes in preforms for sealing a variety of components such as optical fibers, lenses, ferrules, feedthrough pins, lids, etc. The preforms are pressed from the powder and sintered into a variety of shapes. The sintering process leaves no residue and there is no outgassing when melted.

5. GLASS SEAL PROCESS

Sealing of optical fibers (4) will be the focus of this paper. Usually, this is accomplished by presealing the fiber into a feed-through tube or ferrule, creating a "pig tail" assembly. The fiber is first stripped of the organic jacket in the immediate seal area and fed through the ferrule leaving a stripped or bare fiber of sufficient length for alignment inside the package later. A solder glass preform is then placed over the stripped fiber to rest on the top surface of the ferrule. Localized heating of the ferrule can be accomplished by several methods described later. To prevent thermal damage to the organic jacket, localized heating is usually in combination with some heat sinking of the opposite end of the ferrule where the organic jacket remains. This pigtail assembly is subsequently sealed into the package wall with a hard solder such as Au/Sn. These steps are illustrated below.

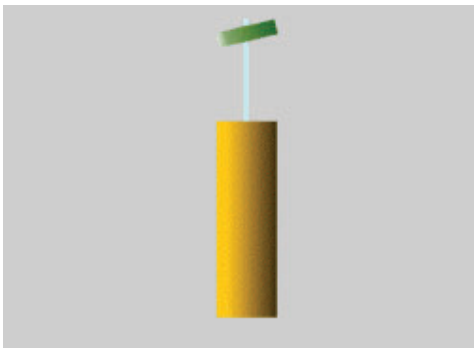


Figure 1. After the fiber is stripped and cleaned, the preform is placed over the fiber and dropped down to rest on the top surface of the ferrule.

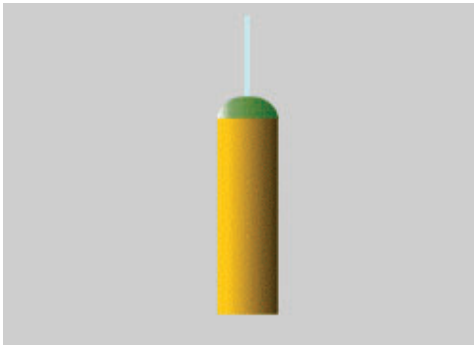


Figure 2. The preform is heated to the melting temperature of the glass preform, which in turn collapses around the fiber and wets down the inside diameter of the ferrule.

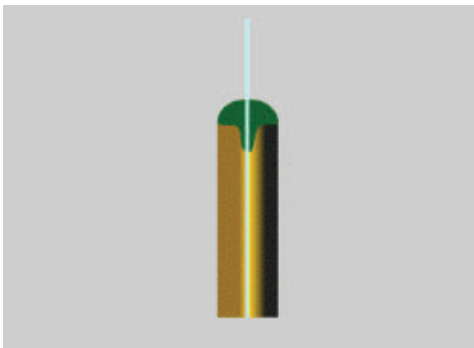


Figure 3. Cross section showing the glass wetting down the inside diameter of the ferrule around the fiber.

6. METHODS OF HEATING TO FORM A SEAL

There are several methods for melting the glass to form a hermetic seal:

1. The most common is heating the ferrule by RF induction heating. This method has the advantages of localized heating in a very short time. Small induction coils are designed to fit closely around the metal ferrule which is heated by the RF field. The heated ferrule in turn heats and melts the glass. Ferrules have to be RF energy absorbent.
2. Resistance heating can be with electrodes, which contact the ferrule. This method is also localized and fast, but requires an electrically conductive ferrule.
3. Radiant heating, using a filament, in close proximity to the seal joint is very effective and independent of the ferrule type. For example, ceramic or quartz ferrule could be used by this method.
4. Hot air or gas can be used effectively in applications that do not require the ferrule to be metal. In particular, the microflame generator is excellent in creating very localized heating without damaging heat sensitive components in close proximity.
5. Laser heating is also very effective at localized heating of the ferrule and is independent of ferrule type. The solder glass is absorbent to CO₂ laser energy.
6. Conduction heating places the heat source in contact with the work piece, much like a soldering iron. The disadvantage of this method is the heating rate is dependent on the mass and thermal conductivity of the ferrule.

7. STRESS WITHIN A GLASS SEAL

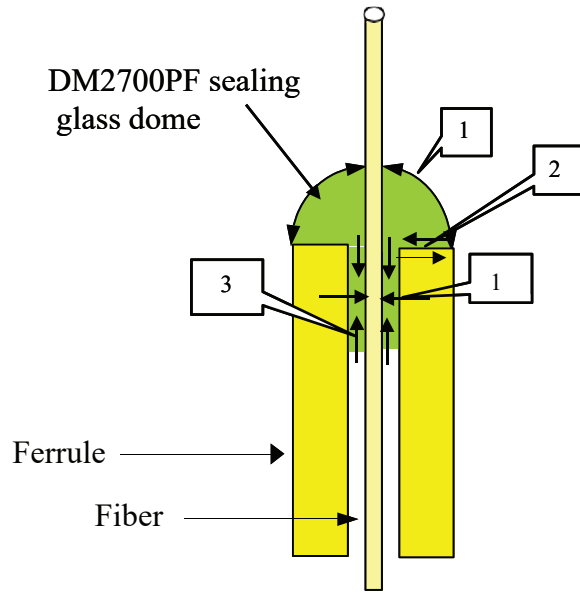


Figure 4. Stress analysis within a seal

The radial stress **1** within the dome is controlled by the expansion of the glass, which is higher than the ferrule or the fiber and results in a compression stress at the fiber interface. This facilitates a hermetic seal at the fiber in the dome. However, if this stress is excessive, embrittlement of the fiber can result. Shear stress **2** at the top surface of the ferrule will depend on the relative coefficient of temperature expansions (CTE) of the sealing glass and the ferrule. Axial shear stresses along the inside wall of the ferrule **3** will also result from the CTE mismatch of glass and ferrule.

Larger size domes will result in higher compressive stress **1** on the fiber. The size of the dome is controlled by the outside diameter of the ferrule. Glass will not flow down the inside diameter of the ferrule until a dome is created by the glass on the top surface of the ferrule. Instead, it will flow out on the top surface of the dome before it will wet down the bore. Unless a thicker, higher volume preform is used, insufficient seal length could result in poor hermeticity. Ideally, the glass would wet down the bore to create a hermetic seal, as well as providing mechanical strength of the seal, as indicated by a tensile pull of the fiber in the direction of the axis. Also, for low or medium expansion ferrules, excessive shear stresses on the top surface could result due to the Δ CTE of the glass and the ferrule. The glass wetting behavior with a large outside diameter (OD) ferrules is indicated below in Figure 5.

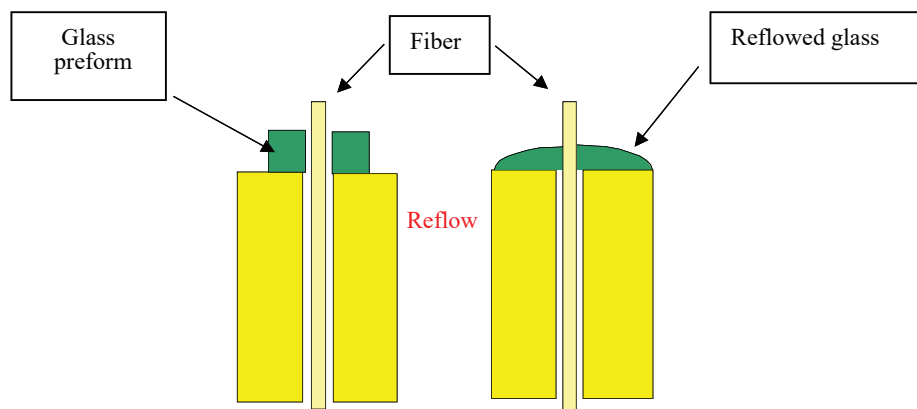


Figure 5. Glass wetting behavior with large surface area on top of ferrule

For ferrules of larger diameter, one can control the wetting on the top surface by creating a discontinuity such as a chamber depicted in Figure 6 below.

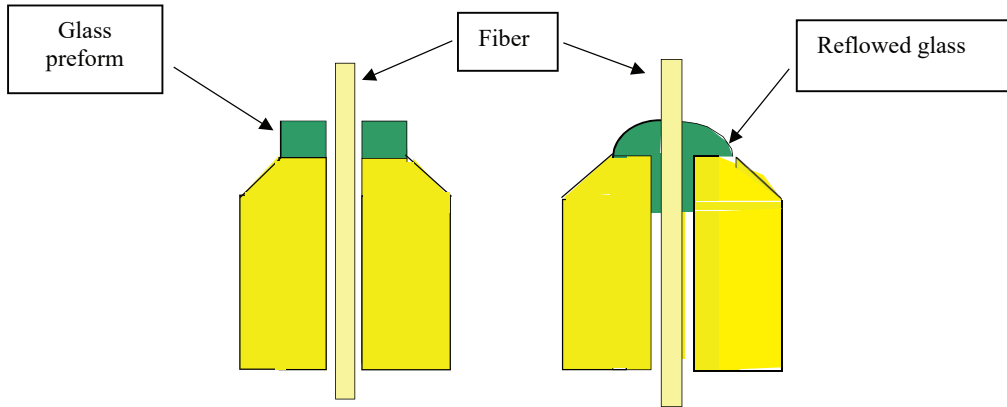


Figure 6. Volume of preform matched to top surface area of ferrule to allow wetting down the inside diameter.

Within the inside diameter of the ferrule (figure 7), a compressive stress against the fiber results that is a function of the inside diameter (ID) of the ferrule the ferrule material or expansion, and the wall thickness (W) of the tube. The glass properties of transformation temperature (T_g), Young's modulus (E), and the coefficient of thermal expansion (α), as expected, would also impact the radial stress in the glass (S_g) as illustrated in Figure 7 below.

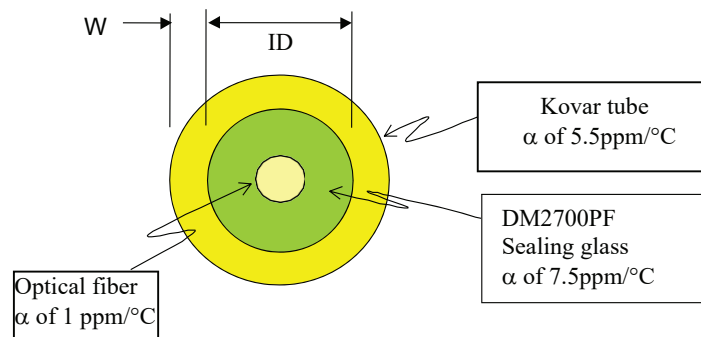


Figure 7. Section of ferrule with fiber sealed with solder glass

$$S_g = \frac{2a}{1+2ab} \frac{E_m(\Delta CTE)\Delta T}{E_g} \quad (3)$$

Where

$$a = ID/W \quad b = E_m/E_g$$

$$\Delta CTE = CTE_m - CTE_g$$

$$\Delta T = T_g - \text{room temp}$$

$$E_m = \text{Young's modulus of metal ferrule} \quad E_g = \text{Young's modulus of glass}$$

As the inside diameter is increased, the stress in the glass (S_g) results in a tensile stress until eventually the glass separates from the inside wall of the ferrule. From cross sections of the sealed ferrule, this maximum diameter was observed to be about 1mm with an outside diameter of 1.4mm. Note from the formula that increased wall thickness will reduce (S_g), as will decreasing the E (Young's modulus) of either the glass (E_g) or ferrule material (E_m).

For a higher expansion tube or ferrule, such as stainless steel, the glass will always be in compression because the stainless steel tube has a higher coefficient of expansion/compression than the DM2700PF glass. Thus, the allowable inside diameter of higher expansion tubes would only be limited by what is a practical volume of glass needed, as well as the sensitivity of the fiber to compressive stresses. However, a large outside diameter will create a large dome of glass on the top surface of the ferrule causing excessive compressive stress on the fiber, resulting in embrittlement. Conversely, the maximum diameter of lower expansion tube, such as quartz, would be smaller to prevent the glass from dewetting the inside diameter from the tensile forces generated from the difference in expansion (ΔCTE) of the glass and ferrule material.

One method of controlling the tensile stress for low expansion ferrules, such as quartz, is to employ counter bores with small diameters to allow for the glass to seal while controlling the tensile stresses on the inside walls of the counterbore. This is depicted in Figure 8 below. For a ferrule such as fused quartz, the maximum diameter should be about 0.25mm.

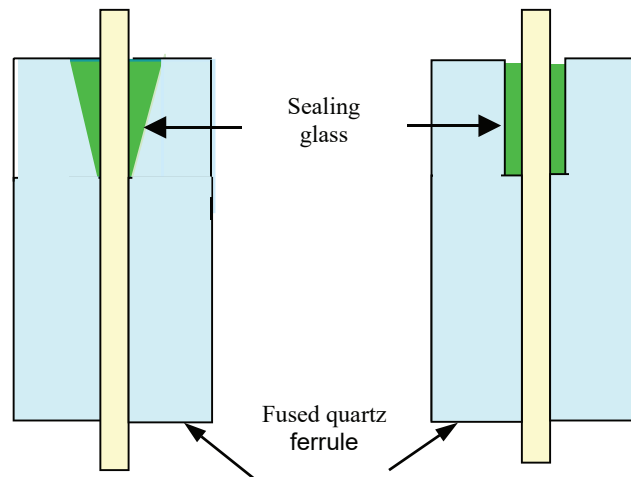


Figure 8. Small-bore, low-expansion fused quartz ferrule with counterbores to control the radial stress

8. ASYMMETRICAL STRESS

When the bore size of the ferrule is significantly larger than the bare fiber, the stress on the fiber becomes asymmetrical as a result of the fiber being off center in the bore. The impact of this type of stress on the fiber was studied by holding the fiber to one side while sealing the fiber and performing a fiber bend test as shown below.

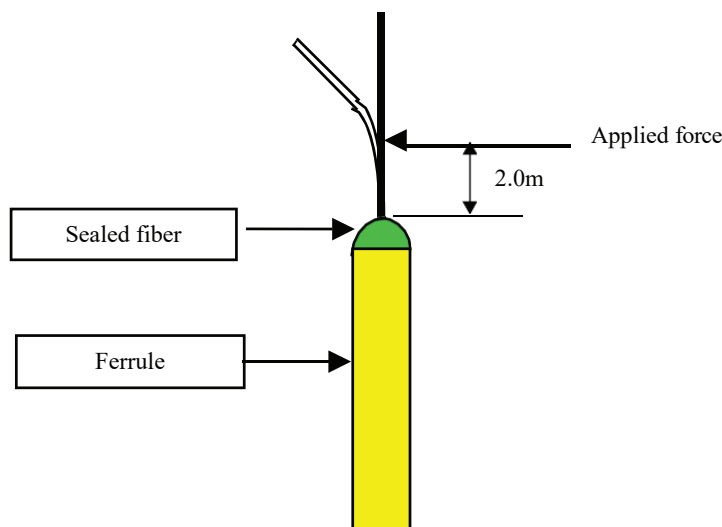


Figure 9. Fiber bend test to measure the resistance to fiber breakage (4)

The amount of fiber deflection before breakage is an indication of residual stress on the fiber. The difference in this deflection due to the asymmetry of the fiber location is illustrated below.

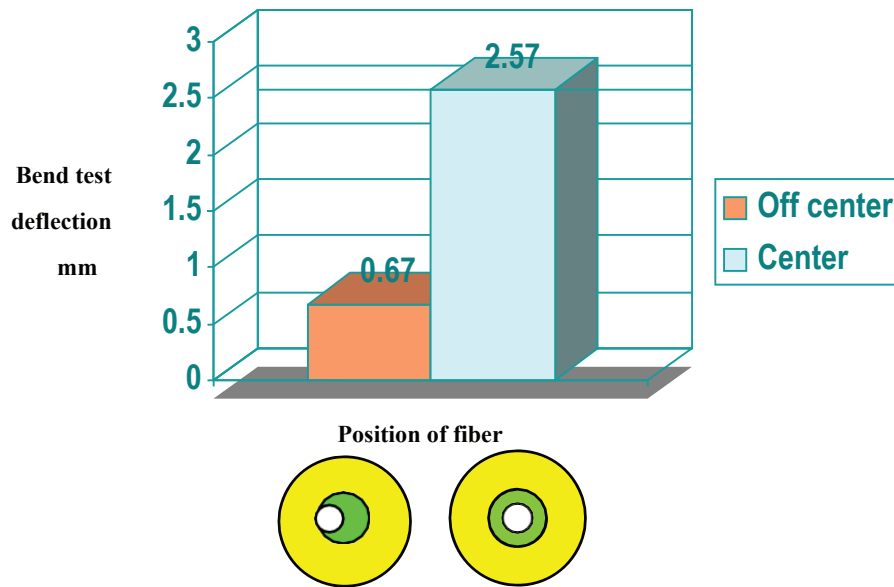


Figure 10. Impact on fiber bend test due to the asymmetry of the fiber location within the inside diameter of ferrule

This increase in stress, as measured by the amount of deflection before the fiber breaks, was also shown in finite element analysis (1). Although the deflection shows a significant difference in the residual stress due to the asymmetry, it should be pointed out that this difference does not appear to be significant unless the fiber is near the wall of the bore and also asymmetrical in the dome. Many sections of low bend vs. high bend deflections were observed with no real correlation with the location of the fiber at the top surface of the ferrule. The direction of the push may be a significant variable that wasn't monitored in these tests. Thus, asymmetry of the fiber location is something to be aware of, but only in extreme cases does it impact stress on the fiber as measured by the fiber bend test. One way to control this variable is to use small-bore ferrules with a counterbore, as illustrated below. The small bore serves to center the fiber, while the counterbore allows the necessary seal length.

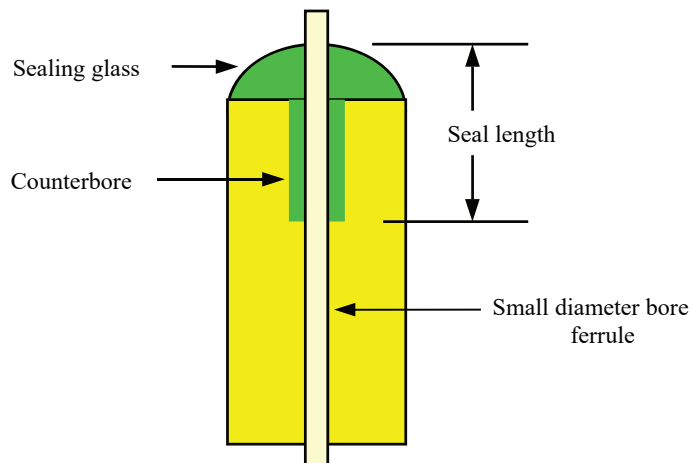


Figure 11. Centering fiber with a small bore and sealing with a counterbore

9. DESIGN GUIDELINES

The design guidelines for using a solder glass and controlling the stresses can be summarized as follows:

1. Choose the proper volume preform that will result in a seal length that includes the wetting by capillary action of the glass down inside diameter of the tube or ferrule. The actual dimensions of the preform are not as critical as the volume of the reflowed preform. The volume is controlled, of course, by the outside diameter, inside diameter, and length or thickness of the preform. Generally the thickness can be tailored to the particular application without necessitating new tooling. For thicker preforms, additional glass powder is added to the die. The outside and inside diameters can vary and are not critical, as the preform when melted will collapse around the fiber. Allow about a 15% reduction in volume from the sintered preform as received to the melted glass.
2. Choose the ferrule dimensions to control the axial and radial stresses as discussed. This depends on the ferrule material and associated CTE.

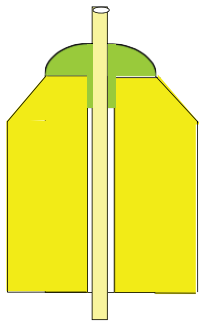
Ferrule material	Maximum ID (mm)
High expansion (Stainless steel)	1
Medium expansion (Kovar)	0.65
Low expansion (Fused quartz)	0.25

3. Minimize the ferrule's top surface wetting area to allow solder glass to form a dome and wet the inside diameter or counterbore of the ferrule. Keeping the outside diameter or diameter of top wetting surface under 1mm should accomplish this in most cases. This outside diameter is more critical for the high expansion ferrules to prevent excessive compressive stresses which result in fiber embrittlement.
4. Heat the ferrule by one of the methods described to reach an interface temperature of at least 320°C. Avoid heating above a peak of 400°C. A fast ramp rate of heating is recommended to avoid the CTE modifiers from partially dissolving in the glass matrix and raising the viscosity and seal temperature. Time at temperature is dependent on the peak temperature and could typically range from 1-15 seconds.

10. RELIABILITY OF A SOLDER SEALED FIBER

10.1 Hermeticity

Assuming the guidelines are adhered to, the glass sealed fiber assembly is very reliable, passing Telcordia specifications (4). Compared to the solder sealed method, the solder glass has generally less stress and a greater reliability (1). Hermeticity is maintained through environmental exposure. This was demonstrated in-house by measuring leak rates with an open face method using a Kovar ferrule. Leak rates were measured before and after liquid to liquid thermal shock.



Open face leak rate

	<u>As sealed</u>	<u>After thermal shock*</u>
1	1.0x10 ⁻⁹	1.0x10 ⁻⁹
2	1.0x10 ⁻⁹	1.0x10 ⁻⁹
3	1.2x10 ⁻⁹	1.2x10 ⁻⁹
4	1.0x10 ⁻⁹	1.2x10 ⁻⁹
5	1.0x10 ⁻⁹	1.0x10 ⁻⁹

*Boiling water to ice water – 5x

Table 1. Leak rate of fiber sealed in Kovar ferrule (ATM-cc/sec)

10.2 Corrosion resistance

Corrosion resistance was demonstrated by 85°C/85% relative humidity exposure of the solder glass before and after sealing and monitoring the impact on the fiber bend test. Results are demonstrated in the chart below.

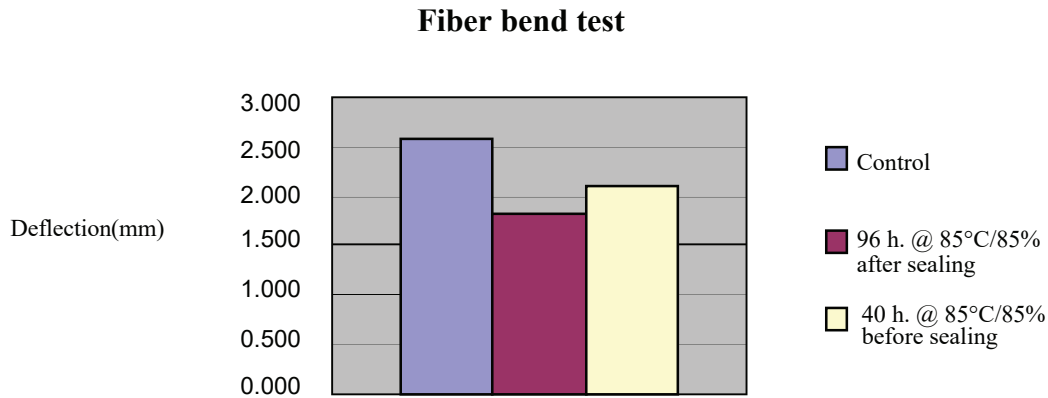


Figure 12. Impact of 85°C/85% relative humidity exposure on the fiber bend test

Exposing the preform to 40 hours of 85°C/85% before sealing and the sealed joint to 96 hours of 85°C/85% had minimal impact on the fiber bend test results.

11. CONCLUSIONS

Referring back to the requirements of a sealed fiber joint, one can conclude that a low temperature solder glass (DM2700PF) has proven to be a viable alternative to solder seal in hermetic optoelectronic packaging applications. By eliminating requirements of fiber metallization on and the associated atmosphere requirements of solder sealing, the cost for manufacturing a sealed assembly is reduced significantly. Design guidelines were presented to ensure stress management for a reliable joint. The low stress nature of the fiber assembly sealed with glass makes it suitable for use with Polarization Maintaining Fiber (1). Reliability was shown through customer testing to Telcordia specifications (4), as well as some in-house data.

REFERENCES

1. Mark Shaw, Robert Galeotti, Giacomo Coppo, "Method of Fixing an Optical Fibre in a Laser Package," Electronic Components and Technology Conference, 2001.
2. Fred Bushroe, "Getting Light in and out of Hermetic Optical Packages," Optical Manufacturing, November/December, 2000.
3. Richard M. Rulon, "Glass to Metal Seals" in Introduction to Glass Science, L.D. Pye, H.J. Stevens, and W.C. La LaCourse, eds., pp. 661-703, Plenum Press, New York, 1972.
4. Developed and tested in conjunction with Bookham Technology.

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NAMICS Corporation, 3993 Nigorikawa, Kita-ku, Niigata City, 950-3131, Japan

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Taiwan NAMICS Electronics Co., Ltd., Rm. 3, 10F., No. 360, Sec. 2, Taiwan Blvd, North Dist., Taichung City 40453, Taiwan (R.O.C.)

Phone +886-4-2329-2158 Fax +886-4-2329-2155 sales@namics-tw.com

Korea NAMICS Co., LTD, 2301 Trade Tower, 511, Yeongdong-daero, Gangnam-gu, Seoul Korea, 06164

Phone +82-02-562-2812 Fax +82-02-562-2814 sales@namics-kr.com

Shanghai NAMICS Co., LTD., Room#610, No. 458, Fushan Rd, Tongsheng Tower, Shanghai, P.R.C. 200120

Phone +86-21-20246358 Fax +86-21-20247808 sales@namics-cn.com

Hong Kong NAMICS Co., LTD., Room 910-911, 9/F, Two The Harbour Front, 22 Tak Fung Street, Hung-Hom, Kowloon Hong Kong

Phone +852-3691-8472 Fax +852-3691-8475 sales@namics-hk.com

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