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Durability of glass ceramic jacketted optical fibre

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A novel optical fibre connecting component was fabricated by direct jacketting of silica glass single mode optical fibre (SMF) with a low expansion Li_2O–Al_2O_3–SiO_2 (LAS) glass ceramic. The durability of the glass ceramic jacketted SMF (GC-SMF) was evaluated by immersion, high temperature and damp heat tests. The GC-SMF displayed excellent stability in the configuration of its optical connecting endfaces in both the immersion test in hot (90°C) acidic water and the high temperature endurance test at 500°C for 1 h. The change in optical connection loss of the GC-SMF was within the range of 0·2 dB during the damp heat test at 85°C, 85% relative humidity for 2000 h. It was confirmed that the GC-SMF is suitable for high power optical communication systems as a durable optical connecting component.

Single mode optical fibres (SMFs) inserted into precision capillaries are widely used as optical connecting components in telecommunication networks. Recently, the optical power in the networks has tended to increase for dense, long distance optical transmission systems. The increase in optical power causes elevation in the temperature of the SMF components. As the SMF components are also used in an external environments, they may be accidentally immersed in rainwater that occasionally might be acidic, and may be placed in hot and humid environments as well. Therefore, SMF components used in high power optical systems have to be able to withstand high temperatures, rainwater and hot, humid atmospheres. In conventional SMF components, a fibre is inserted into a capillary and fixed using an organic adhesive. At high temperatures, however, the organic adhesives cannot maintain the fibre in the correct position in the capillary. If the SMF is out of position, large amounts of optical power are lost at the connecting interface, which causes further elevations in temperature and results in the fusion of the SMF core.(1,2) The authors have, therefore, developed a novel SMF component by precision direct jacketting of SMF with a glass ceramic, which does not require the use of any adhesives. A Li_2O–Al_2O_3–SiO_2 (LAS) glass ceramic was selected for the jacketting material because it possesses precision formability by drawing, suitable mechanical properties and a small thermal expansion coefficient.(3) We have already reported the mechanical and optical performances of this SMF component.(4) This paper reports studies on the high temperature and chemical durabilities of this newly developed SMF component with a LAS glass ceramic jacket.

Table 1. *Composition and characteristics of the glass ceramic for jacketting single mode optical fibres*

Composition (mol%) SiO_2	Al_2O_3	Li_2O	*MgO*	TiO_2	ZrO_2	K_2O	*ZnO*	*BaO*	*Total*
73·0	11·9	5·2	1·7	2·5	1·0	1·7	2·6	0·4	100·0

Crystalline phase	*Thermal expansion coeff., 30–1000°C* ($\times10^{-7}$/°C)	*Softening point (°C)*	*Melting point of (°C)*	*Young's modulus (GPa)*
β-spodumene solid solution	30	1135	1220	80

Experimental

Glass ceramic preparation

A LAS glass ceramic with the composition given in Table 1 was prepared by melting the raw materials in a platinum crucible at 1600°C for 12 h in an electric furnace. A two-stage crystallisation heat treatment was used with a 3 h nucleation step at 790°C and a 2 h crystal growth step at 1000°C. A glass ceramic containing approximately 50 mass% of β-spodumene solid solution was obtained from the heat treatment. Table 1 shows some of the characteristics of the glass ceramic obtained. The thermal expansion coefficient of the glass ceramic was 30×10^{-7}/°C. This value is closer to that of SMF (6×10^{-7}/°C) than other multicomponent glasses. As the softening point of the glass ceramic is lower than the melting point of the crystalline phase, this glass ceramic can be elongated by drawing without melting of the crystalline phase.(3)

Jacketting of SMF with LAS glass ceramic

A glass ceramic preform, 12·5 mm outer diameter, 1·0 mm inner diameter and 200 mm in length, was prepared for jacketting. The jacketting was performed by drawing the preform at 1200°C after inserting a bare SMF into the centre hole of the preform as shown in Figure 1. The lower end of the preform was clamped and drawn by a pair of rollers. The drawn product was cut into prescribed lengths and the glass ceramic jacketted SMFs (GC-SMFs) were completed by polishing both endfaces using a convex spherical polishing technique.(5) Conventional SMF components, in

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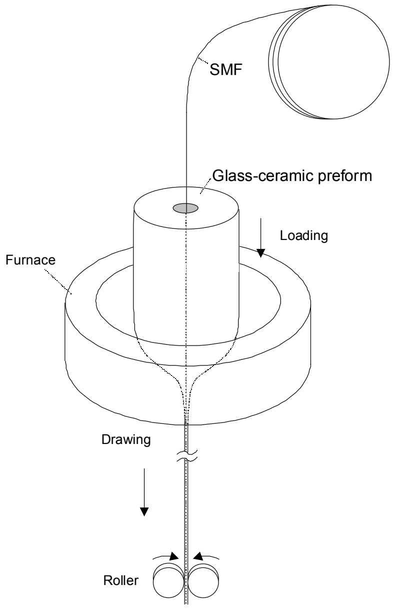


Figure 1. *Schematic diagram of jacketting process.*

which the SMF was fixed to the glass ceramic capillary using an epoxy adhesive (EPO-TEK 353ND), were also prepared for comparison. The adhesive was cured at a recommended temperature of 100°C for 1 h.

Durability tests

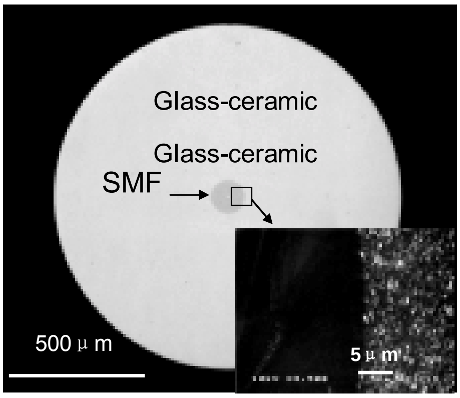
First, the durability of the glass ceramic itself was examined by immersion tests in distilled water and 1 mass% H_2SO_4 solution (pH=0·7). A polished platelike specimen of the glass ceramic (25×25×5 mm) was immersed into each liquid at 90°C for 24 h. Weight loss per unit surface area and changes in the density and the surface roughness (R_a) were measured. The experimental error ranges were within 10 µg/cm^2, 0·001 g/cm^3 and 0·02 µm, respectively. The dimensional stability of the glass ceramic was investigated by the measurement of density change during a long term damp heat test at 85°C, 85% relative humidity (RH) for 14 000 h.

The durability of the GC-SMF was studied by observing the configuration of its optical connecting endfaces. The observation was carried out using a three-dimensional interferometer (Model: ACCIS NC-2800, Norland) before and after the immersion and high temperature endurance tests. In the high temperature test, specimens were heated at a prescribed temperature in an electric furnace for 1 h. The long term stability of the optical connecting performance of the GC-SMF was investigated by a damp heat test at 85°C, 85% RH. In the test, one end of the GC-SMF (7 mm in length) was connected to a light source with a wavelength of 1·55 µm using a commercial MU-type connector(6) and the other end was connected to an optical power meter using the same connector. The optical connection loss was continuously monitored for 2000h.

Results and discussion

Geometry of GC-SMF

Figure 2 shows a cross-sectional view of a fabricated GC-SMF with a diameter of 1·25 mm. There is no need to recrystallise the drawn products, as the jacket has already been crystallised. One can see the SMF at the exact centre of the glass ceramic jacket. No deformation was observed in the SMF, since the jacketting was carried out at a lower temperature than the softening point of the SMF (approximately 1800°C). It was confirmed that the SMF was directly bonded to the jacket along its circumference, as shown in the inset of the figure. The dimensional accuracy in the eccentricity and outer diameter were both within 1·0 µm, which satisfies the dimensional requirements for single mode optical connecting components. It has already been confirmed(4) that the thermal stress in the GC-SMF is sufficiently small for the present application because of the small difference in thermal expansion between the glass ceramic and the SMF. The GC-SMF was cut into a length of 7 mm and both endfaces were polished into a smooth convex spherical shape. A typical shape of the polished endface is shown in Figure 3 (vertical scale of the figure is emphasised). The radius of curvature of the endface was between 10 and 20 mm.

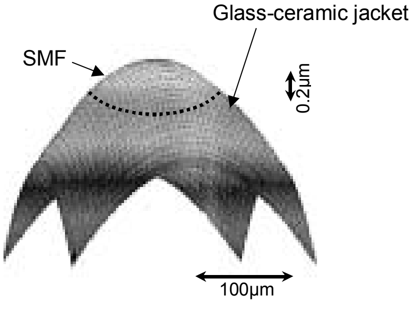


Roundness<1·0 µm, Eccentricity<0·7 µm

Figure 2. *Cross sectional view of the single mode optical fibre jacketted with Li_2O–Al_2O_3–SiO_2 glass ceramic*

Durability of LAS glass ceramic

Table 2 shows the durability test results for the LAS glass ceramic. In the immersion tests, all the changes in weight, density and surface roughness of the LAS glass ceramic were very small, being within the experi-



Radius of curvature: 12mm

Figure 3. *Typical configuration of polished endface of a single mode optical fibre component jacketted with the glass ceramic. Vertical scale of the figure is emphasised. Dotted line in the figure indicates the boundary between the SMF and glass ceramic jacket*

Table 2. *Results of durability tests of the glass ceramic for jacketting*

Property	Change of value		
	Water immersion (90°C, 24 h)	Acid immersion (1 mass% H_2SO_4, 90°C, 24 h)	Damp heat (85°C, 85%RH, 14000 h)
Weight (µg/cm^2)	−4	−4	0
Density (g/cm^3)	−0·0001	0·0000	0·0004
Surface roughness /Ra (µm)	−0·01	−0·01	–

mental error range, indicating the excellent stability of this material. Therefore, it is expected that the LAS glass ceramic can be applied to optical components used in an external environment. The dimensional stability of the jacket material under hot and humid conditions is important for precision alignment of the optical components. The LAS glass ceramic used in the present study showed no density change in the damp heat test for 14000 h (more than 1·5 years), indicating its excellent dimensional stability. It is superior to the conventional ZrO_2 capillaries being used for SMF components, which undergo a volume change and microcracking due to a phase transformation in the presence of water.$^{(7)}$

Durability of GC-SMF

Figure 4 shows the three-dimensional configuration of the endface of the SMF components after the immersion tests. Changes in the relative vertical position of the SMF to the jacket before and after the tests are indicated as Δ*h*. No significant change was observed in the endface configuration of the GC-SMF. On the other hand, in the specimens fabricated using the epoxy adhesive (epoxy–SMF), the SMF protruded from the jacket surface in both the water and acid immersion tests as shown in Figure 4 (c) and (d). This protrusion is regarded as the displacement of the SMF due to the degradation of the adhesive, because the glass ceramic jacket itself is not etched under these conditions as shown in Figure 4(a) and (b). When the epoxy–SMF was stored in dry air (18% RH) at 90°C for 24 h, no protrusion was observed, thus the degradation of the adhesive is believed to be caused by a reaction with water.

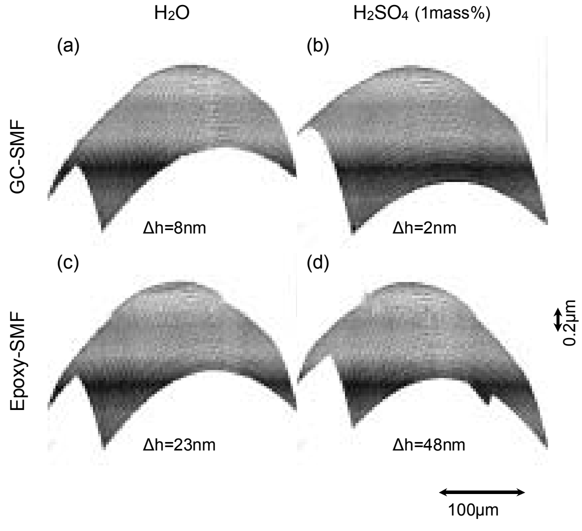


Figure 4. *Configuration of the endfaces of single mode optical fibre components after immersion tests. Vertical scale of the figure is emphasised. Δ*h *is the difference in vertical position of the optical fibre before and after the tests: (a) with glass ceramic jacket, water immersion, 90°C, 24 h; (b) with glass ceramic jacket, acid immersion, 90°C, 24 h; (c) fixed by epoxy, water immersion, 90°C, 24 h; (d) fixed by epoxy, acid immersion, 90°C, 24 h*

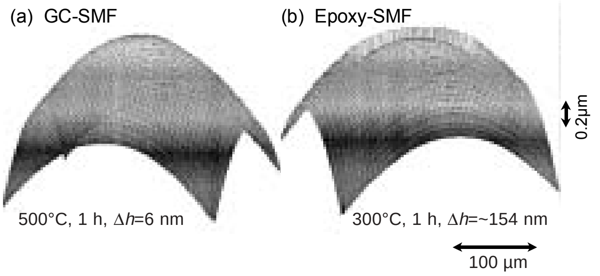


Figure 5. *Configuration of the endfaces of single mode optical fibre components after high temperature endurance tests. Vertical scale of the figure is emphasised. Δ*h *is the difference in vertical position of the optical fibre before and after the tests: (a) with glass ceramic jacket, 500°C, 1 h; (b) fixed by epoxy, 300°C, 1 h*

According to a recent study$^{(8)}$ the temperature of the SMF components such as optical attenuators reaches 300°C when an optical power of 2 W is used. Figure 5 shows the results of high temperature endurance tests. In the case of GC-SMF, the SMF was in position even after heating to 500°C, exhibiting excellent thermal durability. In the case of epoxy–SMF, the SMF was significantly sunk from the spherical surface of the glass ceramic jacket after heating to 300°C. The displacement of the SMF (Δ*h*) reached more than −150 nm, which does not meet the requirements for single mode optical connection.$^{(9)}$ These results indicate that the direct bonding of the SMF to the glass ceramic is a significant factor in realising excellent chemical and thermal durabilities in these components.

The long term stability of the optical connection performance of the GC-SMF under hot and humid conditions was evaluated using four specimens connected to a light source. The changes in total optical loss, which is the sum of the losses at both endfaces, were less than 0·2 dB throughout the test for 2000 h. This means that the change was less than 0·1 dB for each endface. It has been reported that the change in the optical loss of a standard optical connector fabricated by fixing an SMF to a ZrO_2 capillary using an epoxy adhesive can be up to approximately 0·2 dB for one endface during the same damp heat test after only 960 h.$^{(10)}$ This suggests that the optical connection stability of the GC-SMF under hot and humid conditions is superior to that of conventional optical connectors. The improved stability of the optical connection performance of the GC-SMF is regarded as a result of both the excellent dimensional stability of the glass ceramic jacket as a precision alignment part and the direct bonding of the SMF to the jacket.

Conclusion

The thermal and chemical durabilities of a GC-SMF component, in which the SMF is directly bonded to a low expansion LAS glass ceramic jacket, were investigated. The LAS glass ceramic displayed excellent durability in immersion tests in hot distilled and acidic water, and a long term damp heat test. The GC-SMF fabricated by jacketting the SMF with the glass ceramic exhibited excellent stability in the configuration of its optical connecting endfaces in both immersion and high temperature endurance tests. It was also found that the GC-SMF maintains good optical performance during the long term damp heat test. It has been confirmed that the use of the durable glass ceramic jacket and the direct bonded structure of the GC-SMF enables the realisation of an optical connecting component with excellent high temperature and chemical durabilities. The GC-SMF is a promising candidate for durable optical components in high power communication systems.

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