

GLASS-CERAMIC FERRULE FOR OPTICAL CONNECTOR FABRICATED BY REDRAWING THE CERAMMED PREFORM

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ABSTRACT

A glass-ceramic ferrule for optical connectors has been developed by redrawing a cerammed preform of $\text{Li}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ glass-ceramic. The cerammed preform contains about 50wt% β -spodumene solid solution and a residual glass matrix. The preform was redrawn into micro-capillaries with sub-micron accuracy, then the micro-capillaries were processed to the net shape of the ferrule. The glass-ceramic ferrule showed excellent scratch resistance, durability in outdoor environments and a higher rubbing rate than that of conventional zirconia ferrules.

INTRODUCTION

Ferrules used in the connection of single mode optical fibers require very accurate dimensions. The accuracy of their diameters (inner and outer) and their concentricity must be within less than 1 μm so that optical connection loss can be minimized. In this field, precise zirconia micro-capillaries are currently used because of their excellent mechanical properties. However, zirconia capillaries require precise grinding for outer and inner diameters to obtain the precise dimensions mentioned above. Glass is seen as a low cost alternative material for ferrules [1], because it can be continuously formed into precise micro-capillaries by the redrawing method. However, glass ferrules are only used in some limited applications, because their scratch resistance is not adequate for general applications.

Since the glass-ceramic is considered an ideal material with superb mechanical properties for optical connector ferrule, the redrawing of their mother glass tubing has been proposed [2,3]. However, the redrawing of the mother glass tubing of glass-ceramics into the micro-capillaries has not been realized, because of uncontrollable crystallization during heating for redrawing.

To solve the above problem, the authors have developed a novel glass-ceramic material which can be redrawn after ceramming. The cerammed glass-ceramic preform was successfully redrawn into micro-capillaries without any deterioration of the crystalline structure. Glass-ceramic ferrules (GCFs) were fabricated from the obtained micro-capillaries. In this paper, the concept of this novel glass-ceramic material which can be redrawn after ceramming and the properties of GCFs such as the scratch resistance, the rubbing rate and the durability in outdoor environments, are described.

EXPERIMENTAL

A batch mixture of glass raw material was melted at 1600°C for 24 hours in a platinum pot with stirring, then the melt was cast into a cylindrical ingot. The ingot was cerammed under a controlled heating schedule in such a way that it was nucleated at 780°C for 12 hours and cerammed at 1000°C for 8 hours. The cerammed ingot was machined to the net shape of the preform with a center hole. Then the cerammed preform was redrawn into micro-capillaries with a drawing apparatus having a highly controlled electric furnace. The micro-capillaries were processed into GCFs.

The apparent viscosity of the cerammed preform was measured with a parallel plate viscometer [4,5]. The properties of the micro-capillaries were evaluated with respect to thermal, mechanical and chemical characteristics. The scratch resistance as well as the rubbing rate of GCFs were evaluated. The crystalline structure of the cerammed preform and the texture of GCFs were observed under SEM. The crystalline phase and crystallinity were analyzed by XRD.

RESULTS AND DISCUSSIONS

1) Redrawing of the cerammed preform

Li₂O-Al₂O₃-SiO₂ (LAS) system was selected as the base composition of the glass-ceramic preform, because the LAS glass-ceramic system has useful characteristics such as low thermal expansion, superior mechanical properties and good chemical durability for ferrules. Figure 1 shows the crystalline structure of the glass-ceramic preform, containing β -spodumene s.s. (ca.50 wt %) and a glass matrix (ca.50 wt %) with traces of gahnite crystals. The fine crystal grains are essential to realize high precision redrawing.

Figure 2 shows the DTA characteristic and the apparent viscosity of the cerammed preform. For redrawing the preform into precise micro-capillaries, the viscosity of the preform at the neck down area is kept at about 10^6 Pa · s. It can be seen from the figure that the viscosity of the cerammed preform reaches the value of 10^6 Pa · s at the temperature of 1150°C, much lower than the melting temperature (T_m) of the precipitated crystals.

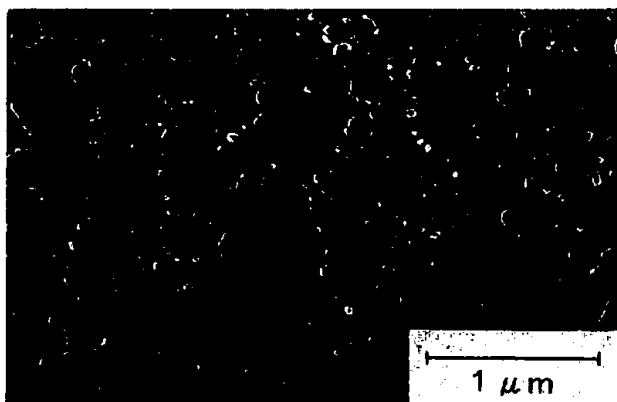


Fig.1 Crystalline structure of the cerammed preform

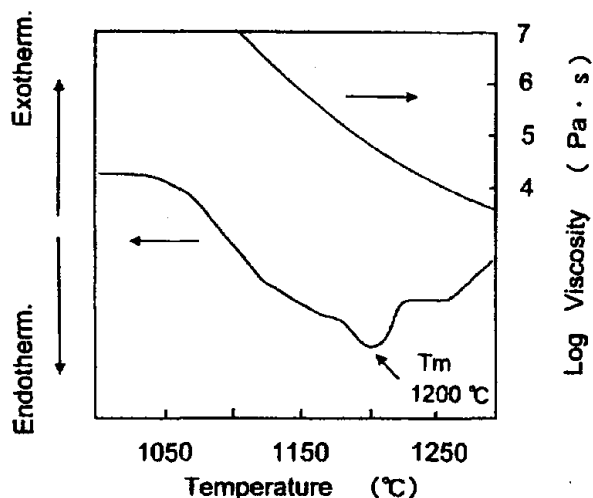


Fig.2 DTA behavior and apparent viscosity of the cerammed preform

The cerammed preform was redrawn into micro-capillaries at 1150°C. The neck down area of the preform is shown in Fig. 3a. The uniform deformation of the preform and the scratch resistant texture of the micro-capillaries were obtained by adopting a specified glass-ceramic composition. The glass-matrix of the preform has a high stability against crystallization so that no undesirable crystals were precipitated even if the surface area of the preform was extended by redrawing. No precipitation of undesirable crystals during redrawing was confirmed by comparing the crystalline structures between the preform and the micro-capillaries.

A cross-section of the redrawn glass-ceramic micro-capillary is shown in Fig.3b. The center hole of the micro-capillary is for the insertion of optical fibers. The surface of the hole had a smoothness suitable for the insertion of optical fibers. The outer surface of the micro-capillaries had a fine texture with numerous crystals. The precision of the micro-capillaries was accurate enough for single mode optical connectors [6] as shown in Table 1.



Fig.3 Outlook of cerammed preform redrawing
a) : Neck down area b) : Cross-section of the micro-capillary

Table 1 . Size precision of the micro-capillary fabricated by the redrawing

	Type A	Type B
outer diameter (mm)	2.499 ± 0.0005	1.249 ± 0.0005
inner diameter (mm)	0.125 to 0.126	0.125 to 0.126
concentricity (mm)	< 0.001	< 0.001

2) Properties of Glass-ceramic Ferrule

The micro-capillaries were processed to the net shape of GCFs as shown in Fig.4 by cutting , chamfering and fixing to metal flanges. Since the ferrules are mated repeatedly with each other in a zirconia alignment sleeve, the scratch resistance of the outer surface of the ferrules against the

zirconia material is an important consideration. Without sufficient scratch resistance, no desirable optical connection can be obtained because the abraded powders inhibit the contact of ferrule endfaces. Using an SC adaptor [6] with a zirconia alignment sleeve, the number of matings which can be repeated without scratching were examined with respect to GCFs and glass ferrules. No scratching was observed in GCFs during 500 times matings in contrast to conventional glass ferrules, as shown in Fig. 5. GCF's excellent scratch resistance is considered to be due to the fine texture with numerous crystals. The scratch resistance of GCFs was also confirmed by Nagase et al. [7] on the reliability of optical connection under the 500 cycle-mating test.

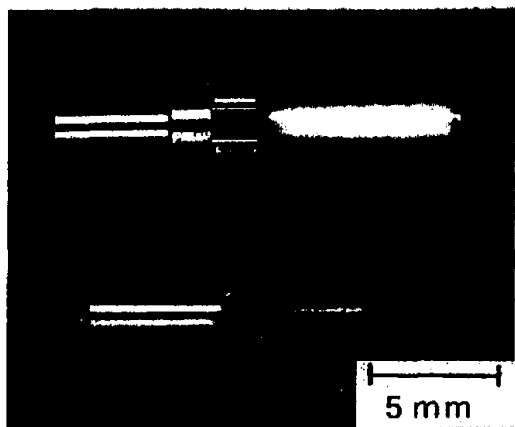


Fig. 4 Appearance of GCF

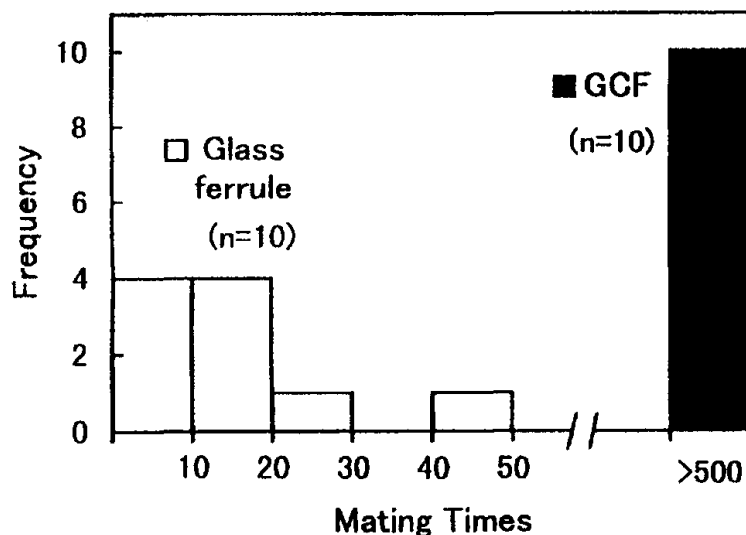


Fig. 5 Scratch resistance of GCF

Table II shows the bending strength and specific volume of GCF, which were measured before and after the exposure to high temperature and humidity (85°C, 90% R.H.). It can be seen from the table that GCF has excellent characteristics in the bending strength and the volume stability even after the exposure for 1000 hours. The increased bending strength after the exposure is considered to be due to the blunting of surface fine flaws by the presence of H₂O. In fact, it is proved by Mitachi et al. [8] that GCF is applicable to usage in outdoor environments. This is an advantage of GCF over zirconia material, which induces volume changes under high temperature and high humidity conditions [9]. For applications in which higher bending strength is requested, GCFs are capable of being strengthened by ion exchange. The mechanical properties of ion exchanged GCF have been reported by Takeuchi et al. [10]. They reported that ion exchanged GCF shows high bending strength even after scratching test.

Table II. Bending strength and specific volume of GCF

	Before exposure*	After exposure
Bending strength (MPa)	550	700
Specific volume ($\times 10^{-4} \text{m}^3/\text{kg}$)	3.94	3.94

* 85°C, 90% R.H., 1000h

The ease of polishing the ferrule-ends with silica glass fibers in the center holes is one of the most important issues for the ferrule material, because of the economical processing for the optical connection. Table III compares the characteristics of the glass-ceramic material for GCFs with zirconia and silica glass, in the rubbing rate, the coefficient of thermal expansion and Young's modulus. The glass-ceramic shows almost the same rubbing rate as that of silica glass, which is ten times faster than that of zirconia. Yoshino et al.[11] reported that GCF's endfaces can be polished faster than those of zirconia ferrules. There is also a close resemblance between the glass-ceramic and silica glass in the coefficient of thermal expansion and Young's modulus. Hence, it is expected that these characteristics of the glass-ceramic for GCF will contribute to the improvement of the thermal stability of the optical connection as well as the reduction of the axial compressive force between the ferrule endfaces. GCF's excellent stability in optical connection under a temperature and humidity cycling condition has been reported on, by Nagase et al.[7].

Table III. Characteristics of the glass-ceramic for GCFs

	Glass-ceramic	ZrO ₂	Silica glass
Rubbing rate ** ($\mu\text{m}/\text{min}$)	21	2	26
CTE ($\times 10^{-7} / \text{K}$)	30	80	6
Young's Modulus (GPa)	80	190	70

** Al₂O₃ #1200, 24.5 kPa

As mentioned above, it was found that GCF has an excellent scratch resistance, durability in outdoor environments, higher rubbing rate and smaller thermal expansion and lower Young's Modulus than zirconia. These characteristics are suitable for general optical connectors.

CONCLUSION

A novel Li₂O-Al₂O₃-SiO₂ glass-ceramic for the optical fiber connecting ferrules was developed. The glass-ceramic preform having about 50 wt% β -spodumene s.s. as the major crystalline phase was redrawn into micro-capillaries with sub-micron accuracy. The glass-ceramic ferrules (GCFs) were obtained from the micro-capillaries by cutting, chamfering and finally by bonding to metal flanges.

It was confirmed that GCFs have the size precision adequate for single mode optical connectors and excellent characteristics such as scratch resistance, durability in outdoor environments and a much higher rubbing rate, superior to that of zirconia.

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