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Infrared optical properties of a LAS glass-ceramic capillary and application for an optical device

Akihiko Sakamoto & Shigeru Yamamoto

Nippon Electric Glass Co., Ltd. 2-7-1 Seiran, Otsu, Shiga, 520-8639 Japan

Introduction

The authors reported that precise glass-ceramic capillaries, which consist of Li_2O-Al_2O_3-SiO_2 (LAS) system, are obtained by redrawing crystallized preforms (1). The capillaries have good mechanical and chemical durability and are practically used for glass-ceramic ferrules (GCF) of optical fiber connectors (2-4).

In optical communication networks, fixed optical attenuators are widely used to control power level of optical signals. An attenuator employing a cobalt ion doped fiber (CoDF) has the advantage of excellent resistance to high optical power input. However, this attenuator has the disadvantage of instability of the attenuation level in operating wavelength range. This is due to the interference with optical signals (core mode) by leaked light into cladding of CoDF (cladding mode). In order to avoid this phenomenon, a method employing special CoDF with double cladding, which enables to trap the cladding mode, has been reported (5,6). However, even in this case, the interference by cladding mode is still the problem when higher power is input or larger attenuation level is needed.

In this study, infrared optical properties of GCF were investigated and the possibility of applying GCF to the CoDF attenuators was discussed for the purpose of increasing the stability of attenuator performance.

Reflectance at GCF / silica glass interface

The interference with the core mode by the cladding mode will be avoided if the cladding mode can be emitted out of CoDF. However, since CoDF is inserted into the ferrules, the cladding mode is reflected toward CoDF at the interface between CoDF and the ferrules. Therefore, the reflectance at the interface must be small to lower the interference. In order to know the reflectance of cladding mode, refractive indices of GCF in infrared region were measured by the minimum deviation angle method. The results are shown in Table 1 with those of silica glass, which is the material of CoDF.

Table 1. Refractive indices of GCF and silica glass

Wavelength (nm)	1014	1129	1367	1530	1711
GCF	1.5296	1.5276	1.5231	1.5197	1.5154
Silica glass*	1.4502	1.4489	1.4462	1.4443	1.4421

*American institute of physics handbook third edition 6-28

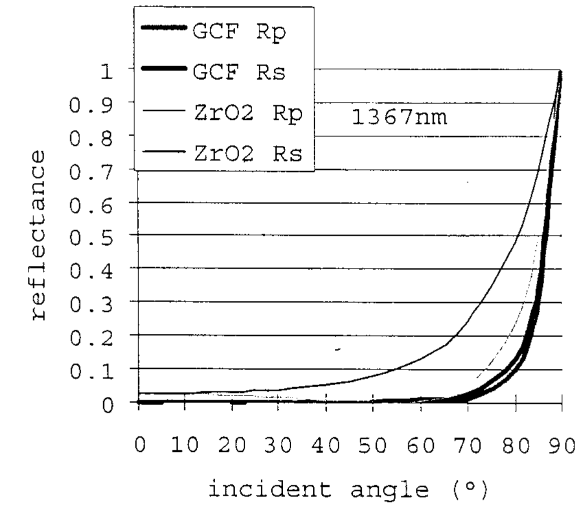

Fig.1 Reflectance of the incident beams from silica glass to GCF and ZrO_2 ferrule
Rp : parallel component, Rs : vertical component

Reflectance of incident beam from silica glass onto the surface of ferrules was calculated by Fresnel formulae using the refractive indices in Table 1. The results at 1367nm are shown in Fig.1. The results obtained with ZrO_2 ferrule, which has been conventionally used for CoDF attenuator, is also shown. It can be seen from the figure that the reflectance at GCF surface is much smaller than ZrO_2 ferrule and is almost zero with incident angle of 70 degree or less. It is also indicated the reflectance on GCF surface has no dependence on polarized direction. That is to say the cladding mode which incidents onto GCF with the incident angle of smaller than 70 degree is emitted into GCF without reflection. The same results were obtained at the other wavelengths shown in Table 1.

Scattering coefficient of GCF

The cladding mode emitted to GCF should be decayed out so that it does not return to CoDF. It is expected that the light in GCF is decayed by scattering, because GCF includes numerous crystals of ß-spodumene solid

Table 2 Scattering coefficients and losses of GCF

Wavelength (nm)	1000	1300	1550
Scattering coefficients (/mm)	0.623	0.217	0.115
Loss (dB)*	54	19	10

*optical distance : 20mm

solution with the grain size of 500nm. Scattering coefficients of GCF were calculated from Lambert's law through measurements of spectroscopic transmittance. The results are shown in Table 2. The table shows that the coefficients of GCF are quite larger than those of normal non-crystalline glasses. Losses in light intensity per 20 mm are also shown, because the ferrule length of CoDF attenuators is generally around 20 mm. It is shown that the light propagating in GCF is strongly decreased by scattering. The large scattering in GCF is considered to be effective to prevent the interference with the core mode by the cladding mode. The scattered light will not return to CoDF because of the greater refractive indices of GCF than those of silica glass (Table 1).

It was observed that the scattering coefficients of GCF vary in proportion to –3.7 power of wavelength. This behavior is very similar to that of Rayleigh scattering in spite of larger scatterer size (500nm) than normal Rayleigh scattering. The cause of this phenomenon is still under investigation.

Performance of CoDF attenuator with GCF

In order to confirm that the optical properties of GCF described above is useful for the stabilization of CoDF performance, a CoDF attenuator with GCF was fabricated. The dimensions of GCF used were 20 mm in length and 2.5 mm in diameter. CoDF with 0.125 mm in diameter was inserted into the center hole of GCF (0.126mm in diameter) and fixed by a epoxy adhesive with refractive index of 1.55.

The variations of attenuation level in the operating wavelength range of the attenuator are shown in Fig.2. It is obvious that the performance of the attenuator with GCF is much stable compared with the conventional attenuator with ZrO_2 ferrule. This means that the interference with the core mode by the cladding mode is effectively depressed by using

GCF instead of ZrO_2 ferrule. This effect is considered resulted from less reflection of the cladding mode at CoDF/GCF interface and large optical loss in GCF.

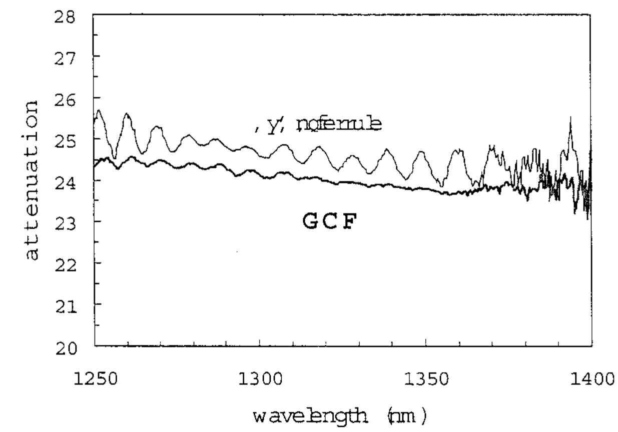

Fig.2 Wavelength characteristics of CoDF attenuator with GCF and ZrO_2

Conclusion

GCF, which consists of a LAS glass-ceramic, is non-reflective to the incident beams from silica glass with broad incident angle. It was also found that GCF has large scattering coefficient which leads to large optical loss. It was confirmed that these optical properties of GCF in infrared region were effective for stabilization of the performance of CoDF attenuators, because GCF decreases the interference with the core mode by the cladding mode. Since GCF has suitable mechanical and chemical durability for the ferrules of general optical connectors (1-3), it is expected that GCF can be widely applicable to the ferrules of CoDF attenuators.

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