Radiation-Resistant Single-Mode Optical Fibers

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Loss of silica-based optical fibers increases when they are exposed to radiation. We have developed a fluorine-doped core single-mode optical fiber, which complies with ITU-T G.652.B and has excellent radiation-resistant characteristics compared with pure silica core single-mode fiber. Although the increase in radiation-induced loss of the conventional pure silica core single-mode fibers with the condition 1×10^6 *R/h and 60 min is approximately 25 dB/km at 1310 nm wavelength, the loss of the fluorine-doped core single-mode fibers with the same condition is approximately 5 dB/km at 1310 nm wavelength. In addition to the excellent radiation-resistant characteristics, we have confirmed that the fiber has an excellent loss recovery characteristic after irradiation.*

1. Introduction

Optical fiber transmission systems are widely used in present telecommunications because optical fibers have a large bandwidth and low loss and are not influenced by the electromagnetic induction, and their use can reduce the size and weight of optical fiber cables. Moreover, the demand for data transmission in the high radiation environment is large. Therefore, research and development on radiation-resistant optical fibers has been conducted for more than 20 years[1]. When optical fiber is exposed to radiation, a colored center is formed because of the defect that exists in the fiber, there is absorption loss, and the transmission characteristic deteriorates. In particular, it is known to result in optical absorption in an ultraviolet and a visible region by defects that occur in the dopant such as germanium generally used to control the refractive index profile, the optical fiber manufacturing process, and the remaining impurities[2].

In the research of the radiation-resistant characteristics of silica-based optical fibers, research on large core optical fiber with step index profile and pure silica core glass was the main trend[3-5]. In large core fiber with pure silica core where the radiation-resistant characteristics of the silica glass optical fiber depend on the concentration of OH and chlorine content, and the process of manufacturing core glass, the radiation-resistant characteristics of the optical fiber with high OH content are reported to be excellent[6]. Nevertheless, further improvement of transmission capacity is needed when using it under the radiation environment in nuclear plants, reprocessing facilities, etc. The demand of large core optical fibers with the graded index (GI) profile and single-mode optical fibers for high capacity has become larger; thus the need for boron and fluorine co-doped fibers, fluorine-doped fibers, and germanium-doped fibers with GI profile has been reported[7]. Furthermore, pure silica core single-mode optical fibers with high transmission capacity and good radiation-resistant characteristics have also been reported.

However, in research fields such as accelerators where in recent years the aim has been to experiment on high-energy physics, there is an increasing demand for optical fibers with a large transmission capacity and an improved radiation-resistant characteristic. The fibers are 1.3-μm optimized optical fibers that have excellent radiation-resistant characteristics and are compliant with the international standard ITU-T G.652.B. Although OH content is effective for the improvement of the radiation-resistant characteristics, the concentration of OH content in 1.3-μm optimized optical fibers should be low, the so-called "low-OH type," because OH content has a very large absorption loss at 1.38 μm wavelength. However, the fiber with low-OH core glass is inferior to the fiber with high-OH content, the so-called "high-OH type," in terms of radiation-resistant characteristics. It has been reported that radiation resistance was improved by fluorine doping to the core by the evaluation of a large core fiber[8].

In this paper, we report that the radiation-resistant characteristic of single-mode optical fibers is greatly improved by optimizing the fluorine concentration added to the core glass.

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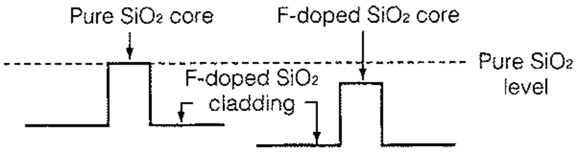
Table 1. Parameters of sample fibers.

Fiber No.	Material		OH content of core glass (ppm)	Manufacturing process for core glass	Fluorine content (wt%)		Δn* (%)	Core diameter (μm)	Cladding diameter (μm)
	Core	Cladding			Core	Cladding			
A	SiO_2	F-SiO_2	< 1	Plasma method	0	1.4	0.35	8.3	125
B	F-SiO_2	F-SiO_2	< 1	VAD method	0.2	1.6	0.35	8.3	125
C	F-SiO_2	F-SiO_2	< 1	VAD method	0.8	2.2	0.35	8.3	125

*: Relative refractive index difference



a: Fiber A b: Fiber B and C

Fig. 1. Refractive index profiles of sample fibers.

2. Design and characteristics

2.1. Fiber design

Figure 1 shows the refractive index profiles of the fibers that we fabricated. Figure 1(a) shows the refractive index profile of Fiber A with pure silica core glass, Fig. 1(b) shows that of Fibers B and C with fluorine-doped core glass. The parameters of all fibers are shown in Table 1.

The OH content of the core glass for Fiber A is less than 1 ppm, the core glass is fabricated by the plasma method, and fluorine is not added to the core glass. The OH contents of core glass for Fibers B and C are less than 1 ppm, and fluorine concentrations are adjusted by the amount of the fluorine in Vapor Axial Deposition (VAD) method. The fluorine concentrations of Fibers B and C are 0.2 wt% and 0.8 wt%, respectively. The three optical fiber preforms are fabricated using the Outside Vapor Deposition (OVD) method. High concentration fluorine was added to the cladding of Fibers B and C as compared to Fiber A, as shown in Table 1, to keep the relative refractive index difference between the core and cladding of all fibers similar.

2.2. Fiber characteristics

The characteristics of the fibers fabricated for trial purposes and the loss spectra of the fibers are shown in Table 2 and Fig. 2. All characteristics of the three fibers are similar except for transmission loss. The transmission loss at 1.31 μm wavelength of Fibers B and C are slightly higher than that of Fiber A. In particular, increased loss of Fiber B, influenced by the tail of the OH absorption loss at 1.38 μm wavelength, is observed. The loss increases with little wavelength dependency, which is a dominant factor of the transmission loss of Fibers B and C, and thus it is thought that the main cause of the loss increase is a structural imperfection loss. An influence of the fluorine-doping process to the core glass is thought to be the cause.

Table 2. Characteristics of sample fibers.

Characteristic	Recommended value in ITU-T G.652.B	Fiber A	Fiber B	Fiber C
Loss (dB/km) @1310 nm	≦0.4	0.33	0.35	0.38
Loss (dB/km) @1550 nm	≦0.35	0.18	0.21	0.25
PMD (ps/$\sqrt{\ }$km)	≦0.2	0.1	0.1	0.1
MFD (μm) @1310 nm	8.6-9.5 ± 0.7	8.6	8.6	8.7
Cladding diameter (μm)	125.0 ± 1.0	125.0	125.0	125.0
Core concentricity error (μm)	≦0.8	0.2	0.3	0.2
Cladding noncircularity (%)	≦2.0	0.5	0.4	0.4
Cutoff wavelength (μm)	≦1.26	1.24	1.24	1.22
Zero-dispersion wavelength (nm)	1300-1324	1308	1308	1309
Zero-dispersion slope (ps/nm²/km)	≦0.093	0.081	0.081	0.079

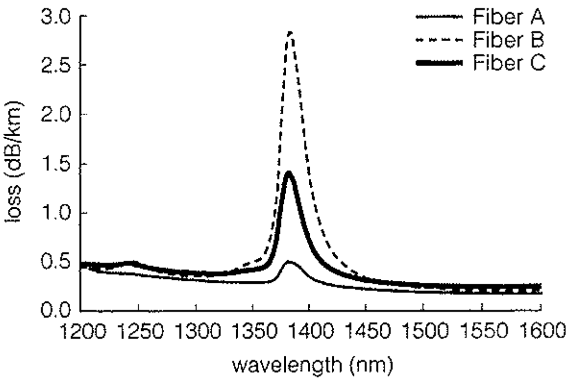


Fig. 2. Loss spectra of sample fibers.