FURTHER ATTENUATION IMPROVEMENT OF A PURE SILICA CORE FIBER WITH LARGE EFFECTIVE AREA

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Abstract: With the growth of attention of digital coherent technique for ultrahigh-speed submarine cable systems, low optical attenuation and large Aeff PSCF "Z-PLUS Fiber®" is a possible candidate as a ready-made product. In this work, we succeeded in further improvement in its optical attenuation and achieved 0.162 dB/km with no change in other characteristics.

1. INTRODUCTION

Low attenuation optical fiber is highly important for long-haul transmission systems. Especially, with the growth of attention of digital coherent detection technique for ultrahigh-speed submarine cable systems, an optical fiber with low attenuation and low non-linearity is becoming more important than ever before.

Theoretical insight of low attenuation silica-glass optical fiber was shown in 1966 [1] and an optical fiber with 20 dB/km was proved by CVD method in 1970 [2]. After a lot of progress in production technology, attenuation of silica-glass based optical fiber with germanium-doped core reached 0.20 dB/km around 1980, and the optical fiber has been widely used as a standard single-mode optical fiber. On the other hand, further attenuation improvement has been studied and pure silica core fiber (PSCF) was found to have better attenuation characteristic because of no germanium in its core portion that behaves as an impurity and causes some Rayleigh scattering. PSCF was introduced to submarine cable systems late 1980', and an enhanced PSCF, Z-PLUS Fiber, was introduced with lower attenuation of 0.168 dB/km and larger effective area in 2000, then PSCF with much lower attenuation was demonstrated in 2002 [3].

In this work, we report attenuation improvement result on Z-PLUS Fiber in balance with its production efficiency, with no change in other characteristics utilizing some results of the demonstration.

2. ATTENUATION IMPROVEMENT OF OPTICAL FIBER

In general, attenuation of optical fiber consists of Rayleigh scattering, imperfection loss, hydroxyl (OH) absorption, infrared absorption and ultraviolet absorption as shown in Equation (1).

$$\alpha(\lambda) = \frac{A}{\lambda^4} + B + C(\lambda) + D(\lambda) \qquad (1)$$

, where A is a Rayleigh scattering coefficient, B is imperfection loss, C is OH absorption and D is infrared and ultraviolet absorption. Rayleigh scattering is caused by slight fluctuation in glass density, and the fluctuation is influenced by glass solidification temperature and concentration of impurities in core portion such as germanium which is generally doped in core portion. OH absorption has an absorption peak at 1383 nm, and infrared and ultraviolet absorption increase at longer and shorter wavelength respectively.

Since Rayleigh scattering is the dominant factor in the C-band wavelength region, it is effective to suppress Rayleigh scattering in order to improve the optical attenuation. From this point of view, PSCF is one of the most desirable optical fiber because of its pure silica core structure.

3. FABRICATION OF THE PSCF WITH LOW ATTENUATION

3-1. Refractive index profile

Figure 1 shows applied refractive index profile which is the same design as that of Z-PLUS Fiber.

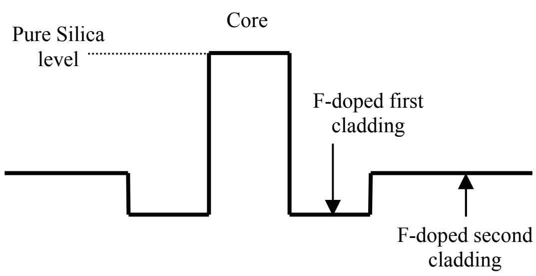

Figure 1: Schematic of Refractive index profile

3-2. Optical attenuation

Table 1 shows a production result of 1,100 km in comparison with current product.

Table 1: Production result

Items	Improved Z-PLUS	Current Z-PLUS
Optical attenuation* [dB/km]	0.162	0.168
Chromatic Dispersion* [ps/nm/km]	20.5	20.5
Dispersion slope* [ps/nm^2/km]	0.059	0.059
Aeff* [μm^2]	110	111

* Average values at 1550 nm

An average attenuation of the production is found to be 0.162 dB/km at 1550 nm that is lower than that of current product by 0.006dB/km. No significant change in other transmission characteristics is observed.

Figure 2 and Figure 3 show a distribution of attenuation and a typical attenuation spectrum of the improved Z-PLUS Fiber respectively. Low attenuation of less than 0.170 dB/km is achieved in a wide wavelength range due to successful reduction in Rayleigh scattering coefficient from 0.84 to 0.81.

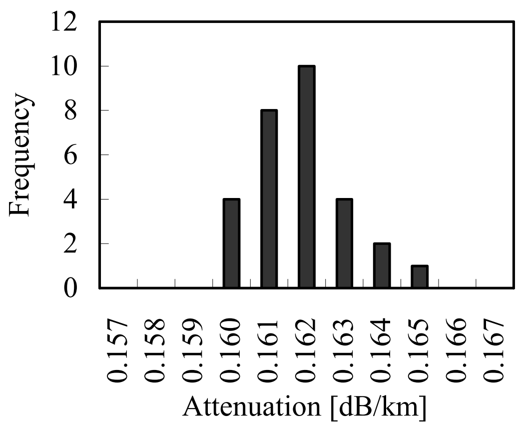

Figure 2: Distribution of attenuation of improved Z-PLUS Fiber

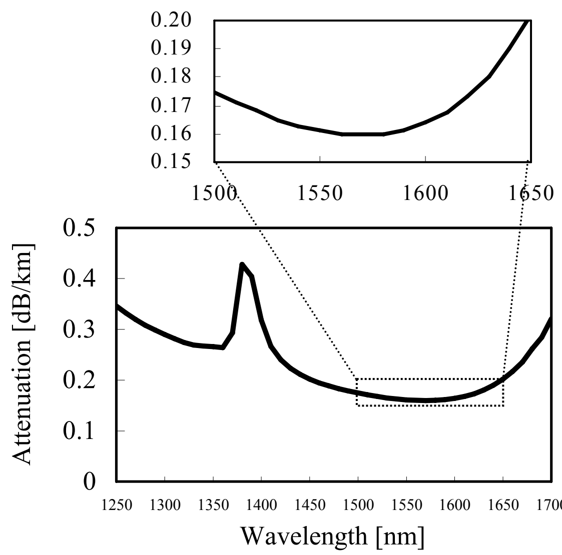

Figure 3: Typical attenuation spectrum of improved Z-PLUS Fiber

3-3. Reliability

Since long-term reliability is another important property for submarine cable system application, hydrogen test is performed on the improved Z-PLUS Fiber, and hydrogen induced attenuation after 25 years is estimated accordingly.

The reason of optical attenuation degradation due to hydrogen gas is divided into three factors as shown in equation (2) [4, 5], where $\Delta\alpha_{H2}$ is hydrogen molecular absorption which has an absorption peak at 1240nm, $\Delta\alpha_{OH}$ is OH absorption which has an absorption peak at 1383nm, and $\Delta\alpha_{SLE}$ is so called “SLE”, Short wavelength Loss Edge, which grows in short wavelength region.

$\Delta\alpha_{H2}$ does not depend on optical fiber, such as reflective index design or dopant for example, and is well formulated as equation (3) [5], where R is the gas constant and T is absolute temperature. However, $\Delta\alpha_{OH}$ and $\Delta\alpha_{SLE}$ strongly depend on optical fiber and have to be evaluated for every optical fiber type. The two factors can be treated in one term as a chemical reaction factor $\Delta\alpha_{CR}$ as in equation (2') to simplify the estimation.

$$\Delta\alpha_{1550nm} = \Delta\alpha_{H2} + \Delta\alpha_{OH} + \Delta\alpha_{SLE} \qquad (2)$$

$$= \Delta\alpha_{H2} + \Delta\alpha_{CR} \qquad (2')$$

$$\Delta\alpha_{H2} = 0.083 \times 0.57 \times P_{H2} \times \exp(1550 / RT) \qquad (3)$$

Since hydrogen test result in various temperatures shows no attenuation increase due to the chemical reaction, the hydrogen induced attenuation can be expressed as,

$$\Delta\alpha_{1550nm} = \Delta\alpha_{H2}. \qquad (4)$$

This is the same experimental result as previously reported on PSCF [6]. Assuming P_{H2} =0.001 atm and T = 276 K (3 ^{O}C), hydrogen induced attenuation after 25 years can be estimated by equation (3) and (4) as 0.0008 dB/km which is the same result as that of current Z-PLUS Fiber.

4. CONCLUSION

Optical attenuation of a large Aeff and low attenuation PSCF, Z-PLUS Fiber, is successfully improved by reduction of Rayleigh scattering with no change in other characteristics including long-term reliability.

5. REFERENCES

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