Ultralow-Loss Large-Core Fiber for Submarine Cables

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Reduction in the transmission loss and nonlinearity of optical fibers used for submarine cables is important for meeting the ever-growing demand for telecommunication traffic. Pure silica core fiber (PSCF) has substantial advantages of low transmission loss and low nonlinearity because no dopant is added in its core. We have developed a PSCF having the highest transmission performance among commercialized optical fibers. The fiber, Z-PLUS Fiber 150 (Z+150), has been realized by improving our previous Z-PLUS Fiber 130 ULL (Z+130) in terms of both the glass quality and the mechanical performance of the protective coating. As a result, the transmission loss reduced form 0.154 dB/km to 0.152 dB/km, and the effective core area enlarged from 130 μm^2 to 150 μm^2. We have further confirmed an excellent manufacturability of Z+150 by the trial mass production of about 4,000 km fibers.

Keywords: optical fiber, optical communication, low loss, high-capacity transmission, long distance transmission

1. Introduction

The wide-spread usage of mobile communication devices and the increasing variety in the mobile services have led to exponential growth in demand for data communication capacity, and the growth is expected to continue. To meet this demand, the fiber-optic communication systems need to evolve to provide ever higher information-carrying capacity. In order to expand the capacity of the submarine communication cables in particular, it is essential to increase the amount of information that a single optical fiber can carry, because there are limitations in increasing the number of deployment of submarine cables or the number of optical fibers integrated in a single cable. The capacity of the submarine communication systems typically depends on digital coherent technology, where the intensity and phase of the light are captured by coherent detection and the detected waveform of the light is processed in digital manner for correcting the distortion caused by the transmission medium, such as chromatic dispersion and polarization mode dispersion of the optical fiber. As a result, the loss and the nonlinearity of the optical fiber become dominant on the quantity of information that can be transmitted. The theoretical maximum amount of information that can be carried by a single optical fiber with a finite frequency bandwidth is known to be given by the nonlinear Shannon limit.(1) According to the theory, the maximum information capacity increases monotonically with the optical signal-to-noise ratio (OSNR), so that the amount of information that can be carried by a single optical fiber can be increased by improving the OSNR. The OSNR is dominated by two types of noise: amplifier noise generated by the optical amplifier that compensates transmission loss, and nonlinear noise generated by nonlinear optical phenomena in the optical fiber. Consequently, it is important to reduce the transmission loss and nonlinearity of optical fibers to be used in submarine communication cables.

To meet this need, pure silica core fiber (PSCF)*1 is useful due to its inherent low loss and low nonlinearity. The core of a PSCF, through which light signals propagate, contains no dopants to adjust the refractive index. Sumitomo Electric Industries, Ltd. was the first in the industry to commercialize the PSCF and has been working on improvement of its quality. Whereas the typical transmission loss of the standard single-mode fibers (SMFs) is 0.19 dB/km at a wavelength of 1550 nm, Sumitomo Electric launched Z Fiber (0.170 dB/km) in 1988, Z-PLUS Fiber (0.168 dB/km) in 2002, Z-PLUS Fiber LL (0.162 dB/km) in 2011, and Z-PLUS Fiber ULL/Z-PLUS Fiber 130 ULL (Z+130) (0.154 dB/km) in 2013.(2),(3) These PSCFs have been selected for many long-distance submarine cables for their excellent performance. Among them, Z+130 was the first fiber designed especially for digital coherent applications, and has been the best-selling product with the total length of shipment exceeding 500,000 km. This fiber has greatly contributed to the construction of global high-capacity optical communication networks.

In this paper, we present Z-PLUS Fiber 150 (Z+150), which has been newly developed and delivers even better performance than Z+130, the previous highest-performance fiber. The transmission loss of Z+150 is 0.152 dB/km, improved from that of Z+130, 0.154 dB/km. In addition, the effective area (Aeff),*2 an indicator of low nonlinearity, of Z+150 is 150 μm^2, also improved from that of Z+130, 130 μm^2. These improvements have been achieved by improving the quality of the core glass through which the light propagates, and the mechanical performance of the polymer coating surrounding the glass fiber. The excellent characteristics of Z+150 have also been reproduced stably by trial mass production. This paper reports on these development results.

2. Excellent Properties of Z+150

Figure 1 shows the typical structure of Z+150 fiber. It has a ring-core structure, where the central part is made of silica glass (SiO_2) slightly doped with fluorine (F), and the peripheral part surrounding the central part is made of pure silica glass. The cladding surrounding the ring core is made of fluorine-doped silica glass, and has a W-shaped structure, where the inner cladding has a lower refractive index than the outer cladding. Whereas the structure of Z+150 is basically similar to that of Z+130,(2) accurate optimization of the structure has enabled a large Aeff (150 μm^2) and low bending losses. Larger Aeff may increase splicing loss when spliced with a standard SMF that is typically used in an optical amplifier and has an Aeff of 80 μm^2 or less. However, the ring-core structure is effective to reduce the splicing loss because it causes large Aeff while keeping small mode field diameter (MFD),(2) whose mismatch determines the splicing loss. We showed that an optical fiber having a ring-core structure and an Aeff of 150 μm^2 could be spliced with a standard SMF at a low loss of 0.18 dB per splice.(4) This is a significant improvement of 0.12 dB compared with a conventional optical fiber having an Aeff of 150 μm^2 whose reported splicing loss to a standard SMF is 0.30 dB.

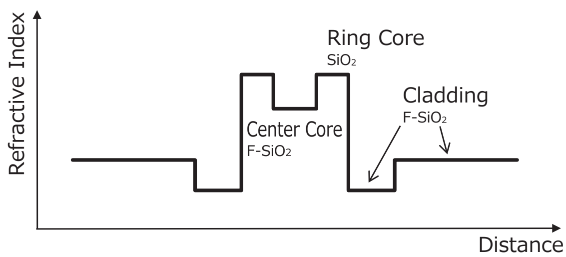

Fig.1. Refractive index profile of Z+150

Figure 2 illustrates the typical transmission loss spectrum of Z+150. The loss at a wavelength of 1550 nm is 0.152 dB/km, which is the lowest among the commercial products at the time of writing (July 2017).

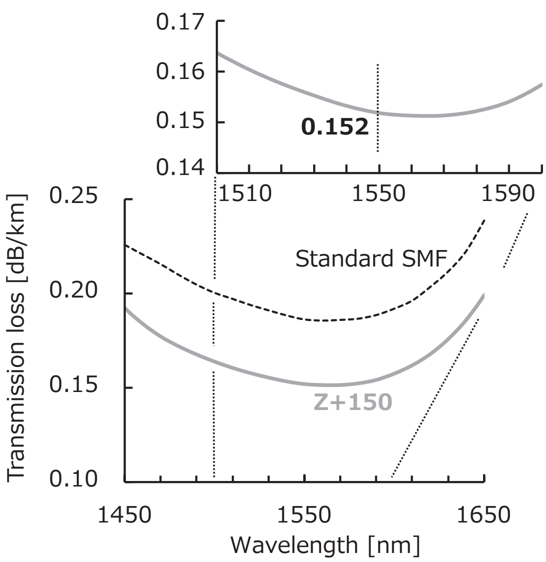

Fig.2. Transmission loss spectrum of Z+150

In the wavelength range of 1530–1610 nm commonly used for optical communications, the transmission loss of Z+150 is significantly lower than that of standard SMF, as shown in Fig. 2. In order to achieve this significant reduction in transmission loss, it is important to reduce Rayleigh scattering loss that accounts for approximately 80% of transmission loss at a wavelength of 1550 nm. Rayleigh scattering is a phenomenon of light scattering caused by wavelength-order fluctuations in the density of silica glass. These density fluctuations originate in the melted glass at a high temperature and are frozen while the fiber is cooled down. Such fluctuations in density have been reduced as the manufacturing techniques get matured.

Table 1 shows typical optical properties of Z+150. In addition to low transmission loss and large Aeff, the fiber exhibits large chromatic dispersion of 21 ps/nm/km, which implies that the velocities of optical signals in different wavelength channels differ largely so that nonlinear noise arising from adjacent wavelength channels is effectively reduced even in the case of dense wavelength division multiplexing transmission. Moreover, the bending loss of Z+150 is kept low, and consequently the transmission loss spectrum of a fiber wound on a 170 mm diameter standard drum is free from an increase in transmission loss due to bending, as shown in Fig. 2. The transmission loss at an L-band wavelength of 1610 nm is as low as 0.162 dB/km.

Table 1. Typical optical properties

	Z+150	SMF
Transmission loss [dB/km]	0.152	0.186
Aeff [μm^2]	150	80
Dispersion [ps/(nm•km)]	21	17
Dispersion slope [ps/(nm^2•km)]	0.06	0.06
Cable cut-off wavelength [nm]	≤ 1530	≤ 1260

*All property values except for cable cut-off wavelength are at 1550 nm

To enlarge the Aeff to 150 μm^2, Z+150 employed an improved coating that protects the silica glass fiber. Since deployed optical fibers usually suffer microbends due to various disturbances present in operating environments, a larger Aeff often suffers higher microbend losses as a result of weaker confinement of light. Consequently, improved coating that can prevent microbends is essential for large Aeff. As illustrated in Fig. 3, the fiber coating consists of two layers, where the inner layer has a lower modulus of elasticity than the outer layer. By reducing the modulus of

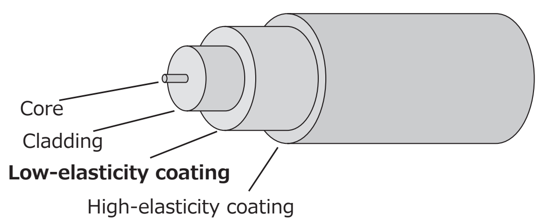

Fig. 3. Optical fiber structure

elasticity of the inner layer, it was made possible to protect the glass fiber from disturbances better and consequently to reduce microbend losses compared to the previous coating.

The improved fiber coating successfully reduced microbend losses, as shown in Fig. 4 that illustrates the relationship between Aeff and microbend losses measured by the wire mesh drum method.[(2),(5),(6)] This method uses a 405 mm-diameter drum whose face is covered with a mesh of metal wires 50 µm in thickness woven at 100 µm intervals. A 500-m optical fiber under test was wound around the drum with a tension of 80 gf. The increase in loss caused by winding the fiber on this drum was measured as microbend loss. In Fig. 4, the plots belonging to each coating show microbend losses that monotonically increase as a function of Aeff. This is because a larger Aeff led to weaker confinement of light, and hence higher microbend losses. Figure 4 also shows that the improved coating, which was used in Z+150, reduced microbend losses to approximately one-tenth compared with the previous coating used in Z+130. Because of this improved coating, it became possible to enlarge Aeff from 130 μm^2 to 150 μm^2.

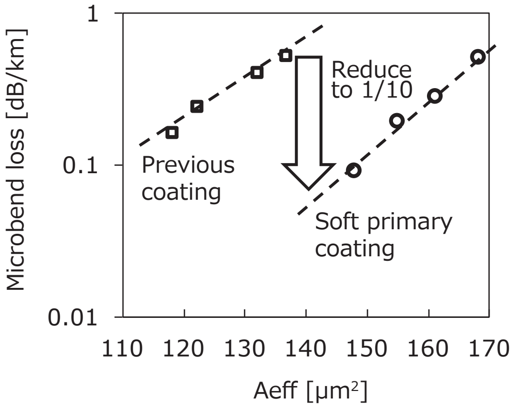

Fig.4. Microbend loss measurement result (λ=1550 nm)

3. Stable Mass Production of Z+150

We also succeeded in the stable mass production of Z+150 and verified the feasibility of stable supply. Figure 5 shows the distribution of transmission losses measured on approximately 4,000 km of Z+150 manufactured in a trial mass production. The average transmission loss was as low as 0.152 dB/km at a wavelength of 1550 nm and stable as shown by a standard deviation of 0.003 dB/km. It was also confirmed that the mass production of Z+150 was stable in terms of optical properties other than transmission loss. We also tested Z+150 for its environmental stability and mechanical strength required in submarine communication cables, according to the international standard IEC 60793-2-50. As a result, Z+150 passed all the tests, showing sufficient reliability and stability. In view of these good results of trial mass production, we believe Z+150 is suited for upcoming transoceanic cable projects.

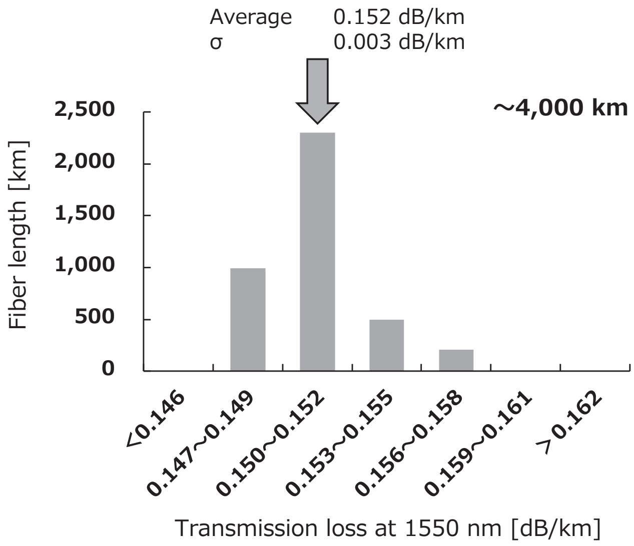

Fig.5. Transmission loss results for Z+150 manufactured through trial mass production

4. Benefits of Z+150 for Optical Communication Systems

Because of the low transmission loss and low nonlinearity, Z+150 can improve the optical signal-to-noise ratio (OSNR) of transmitted signals. This benefit is expressed quantitatively by the fiber figure of merit (FOM), which was developed by Sumitomo Electric and others as a formula that gives improvement in OSNR as a function of transmission loss, Aeff, dispersion, and splicing loss.[(3)] A greater FOM of fiber implies a higher OSNR and therefore an increase in theoretical maximum possible capacity. Take a system for example that has a 70 km span length between repeaters and a repeater output power of −1 dBm/ch or less. Figure 6 shows the results of calculating the FOM of this system as a function of transmission loss and Aeff. Furthermore, as a comparison with Z+150 in terms of FOM, Fig. 6 also shows the FOM values of other products[(7)-(9)] at the time of writing (July 2017). As revealed in the figure, the FOM is higher with decreasing transmission loss and increasing Aeff, and Z+150 exhibits the highest

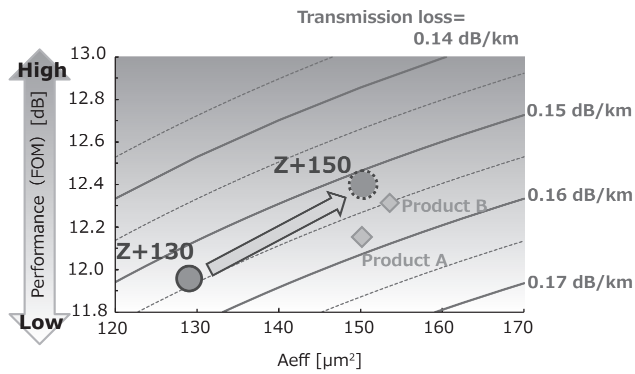

Fig.6. Comparison of optical fiber transmission performance

FOM, which suggests the highest transmission performance, among the commercially available optical fibers.

5. Conclusion

Sumitomo Electric has developed the optical fiber Z-PLUS Fiber 150 (Z+150). It exhibits the highest transmission performance among commercial products, due to its enlarged effective area (Aeff) of 150 μm^2 and reduced transmission loss of 0.152 dB/km. The reduced modulus of elasticity of the inner layer of the coating contributes to the enlarged Aeff. The transmission loss was reduced by suppressing the fluctuations in density of the silica glass.

The demand for higher-capacity submarine communication cables is expected to continue. To meet this demand, Sumitomo Electric is developing optical fibers with even lower transmission losses. In March 2017, Sumitomo Electric achieved a world-record transmission loss of 0.1419 dB/km (at 1560 nm).[10] We intend to continue to provide products that meet the needs of the society, by working on research and development regarding low-loss manufacturing technology.

• Z-PLUS Fiber is a trademark or registered trademark of Sumitomo Electric Industries, Ltd.

Technical Terms

∗1 Pure silica core fiber (PSCF): A generic term for fibers free of core dopants for adjusting the refractive index. The cores of standard fibers are made of silica glass (SiO_2) that contains GeO_2 as a dopant to confine light with an elevated refractive index.

∗2 Effective core area (Aeff): A parameter expressing how wide the optical power confined in the core is distributed. With a larger Aeff, the power density of light decreases and the occurrence of nonlinear optical phenomena is suppressed.

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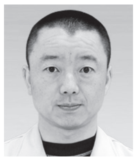

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