MANUFACTURING OF AEFF ENLARGED PURE SILICA CORE FIBER WITH ULTRA-LOW LOSS OF 0.154 DB/KM

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Abstract: For digital coherent technology in ultrahigh-speed long-haul data transmission, lowering optical attenuation and enlargement of Aeff are the most important for an optical fiber to improve system performance. Recently, an analytical calculation has shown the lowest possible attenuation is the most effective to improve system OSNR but that optimal Aeff exists depending on system reach. Based on the calculation, two types of PSCF are designed to have Aeff of 112 μm^2 and 130 μm^2 to cover a wide range of system reach from 4,000 km to 10,000 km, and are manufactured with ultra-low optical attenuation of 0.154 dB/km at 1550 nm in average of about 10,000 km on a mass-production basis successfully.

1. Introduction

To keep pace with the rapid increase of data traffic, digital coherent technology has progressed rapidly and is introduced widely in the submarine field with greatly changing the demands on optical fiber performance. Digital signal processors at a receiver can equalize linear impairments caused by chromatic dispersion and PMD, and optical signal-to-noise ratio, OSNR, becomes the most important parameter in transmission. As a result, complicated refractive index design of an optical fiber to control chromatic dispersion is no longer necessary, and low optical attenuation and large effective core area, Aeff, are more strongly desired than ever before, in order to improve the system OSNR.

In a long history of low optical attenuation and large Aeff fiber development, many studies utilizing pure silica core fiber, PSCF, have been reported. For example, 0.148 dB/km at 1570 nm [1] and Aeff of 211 μm^2 at 1550 nm [2] have been demonstrated based on PSCF, however, the best performance of PSCFs actually installed in the field is an optical attenuation of 0.162 dB/km and Aeff of 112 μm^2 at 1550 nm [3], which are far from the demonstrated records. The major reason for this discrepancy is thought to be the difficulty in mass-production for the optical attenuation and insufficient bending performance for the Aeff.

On the other hand, contribution of optical attenuation and Aeff to system performance has been revealed by an analytical OSNR formulation [4, 5], and it has been reported that the lowest possible attenuation is the most effective to improve system OSNR, however, the optimal Aeff exists as a function of system reach.

In this paper, two types of PSCF with different Aeff each for middle and long system reach are designed, and their productivity is demonstrated with ultra-low attenuation of 0.154 dB/km at 1550 nm in average of about 10,000 km on a mass-production basis.

2. Aeff target and refractive index profile design

It has been reported that the optimal Aeff varies widely as a function of system reach, 106 μm^2 for 4,000 km to 138 μm^2 for 10,000 km for example [5], and two PSCFs were designed targeting Aeff at 112 μm^2 and 130 μm^2, hereinafter "PSCF-112" and "PSCF-130" respectively, based on the report in order to cover all of the rage.

One design each for PSCF-112 and PSCF-130 were simulated based on a Ring-Core profile as shown in Figure 1 which gives better dissimilar-splice performance to an optical repeater than that of a Step-Core profile at same Aeff [6]. A slightly fluorine-doped center-core is surrounded by a pure silica ring-core, and fluorine-doped W-cladding structure is applied in order to improve macro-bending performance. A ratio of the inner core to the outer core was set at 2.5.

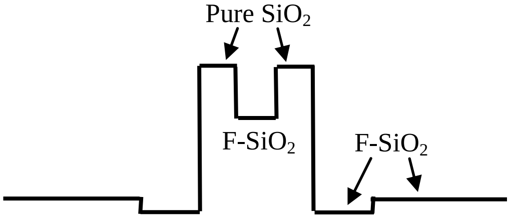

Figure 1: "Ring-Core" refractive index profile

3. Fabrication of ultra-low attenuation PSCF

In order to improve optical attenuation, it is essential to reduce Rayleigh scattering which dominates about 80 % of the optical attenuation at 1550 nm. Rayleigh scattering is caused by fluctuation in concentration of dopant and density of glass composition. This is why PSCF intrinsically is a good candidate to achieve low optical attenuation, which has no germanium in its core portion [7].

A Low-Loss Technology to reduce the density fluctuation and a PSCF with 0.162 dB/km on mass-production basis has been reported [3]. The Low-Loss Technology was successfully improved and it was applied to PSCF-112 and PSCF-130 in order to reduce Rayleigh scattering further.

Table 1 summarizes typical characteristics and Figure 2 shows typical spectral attenuation of the two PSCFs. There is no difference in attenuation between the two PSCFs, and ultra-low attenuation of 0.154 dB/km at 1550 nm is achieved for both of them as a result of further improvement of Rayleigh scattering coefficient from 0.80 dB/km/μm^{-4} to 0.74 dB/km/ μm^{-4}.

Table 1. Typical characteristics at 1550 nm

	PSCF-112	PSCF-130
ITU-T category	G.654.B	G.654.B
Cladding Diameter μm	125	125
Coating Diameter μm	245	245
Optical Attenuation, dB/km	0.154	0.154
Aeff, μm^2	112	130
Chromatic Dispersion, ps/nm/km	20.5	20.5
Dispersion Slope, $ps/nm^2/km$	0.061	0.061

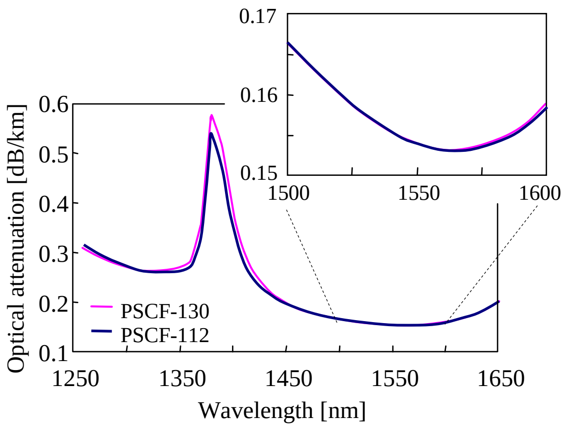

Figure 2: Attenuation spectra

4. Validation of the ultra-low attenuation on mass-production

In order to understand productivity of PSCF-112 and PSCF-130 in a large manufacturing quantity over an extended period of mass-production, about 5,000 km each of the two PSCFs were manufactured over 6 months and their attenuation distribution, bending performance and environmental and mechanical characteristics were verified.

4-1. Stability of fiber performance

Figure 3 shows distribution of optical attenuation at 1550 nm of PSC-112 and PSCF-130. The distribution of each PSCF seems to be Gaussian in shape, and standard deviation is calculated as less than 0.002 dB/km. Other properties such as Aeff, chromatic dispersion and dispersion slope also showed good stability as well as the optical attenuation.

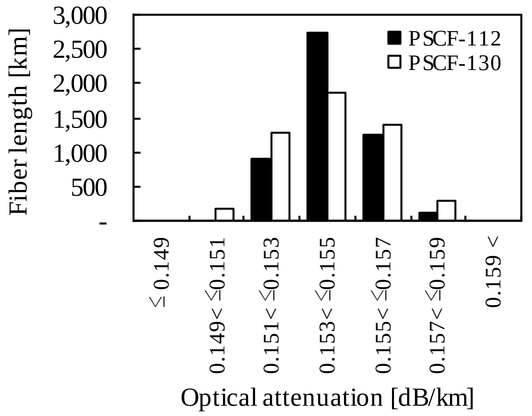

Figure 3: Distribution of optical attenuation at 1550 nm

4-2. Bending performance

PSCF-130 has larger Aeff than that of the existing PSCF with Aeff of 112 μm^2 [3], and its bending performance has to be investigated carefully because large Aeff affects micro-bending sensitivity which is an important parameter in view of cabling capability. A resin coating with lower Young's modulus than that of a conventional coating was applied as a primary layer on the fiber [6] at manufacture stage in order to keep a good micro-bending performance as well as that of the existing PSCF.

Figure 4 shows micro-bending loss characterized by a wire mesh bobbin method at winding tension of 80 gram-force [8] as a function of Aeff. In comparison with the conventional coating, the performance of PSCF-130 was improved by about 20 μm^2 in Aeff and resulted in the same performance as that of the existing PSCF with Aeff of 112 μm^2 with a conventional coating. PSCF-112 with the soft coating naturally has better micro-bending performance as expected.

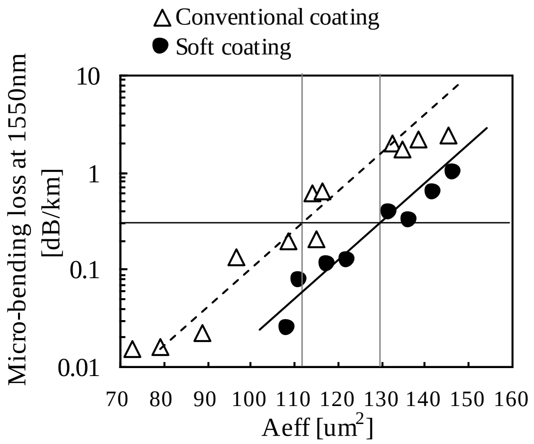

Figure 4: Micro-bending performance

4-3. Environmental and mechanical characteristics

Environmental and mechanical tests were performed on PSCF-112 and PSCF-130 according to IEC60793-2-50. The PSCFs showed good results in all of the damp heat, dry heat, change of temperature, water immersion, tensile strength, stress corrosion susceptibility, fiber curl and proof test.

Figure 5 shows damp heat test results of the two PSCFs at 85 degree C and 85% RH for example.

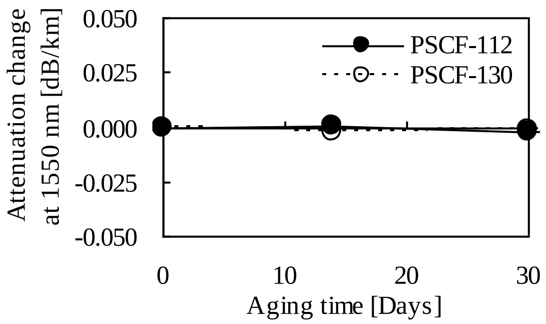

Figure 5: Damp heat test results

5. Conclusion

Two types of Ring-Core shaped PSCF with Aeff of 112 μm^2 and 130 μm^2 were designed to cover system reach of 4,000 km to 10,000 km, and ultra-low attenuation of 0.154 dB/km at 1550 nm in average was demonstrated successfully for the PSCFs with good stability in a large quantity of 10,000 km over an extended period of 6 months on a mass-production basis. Bending performance, environmental and mechanical characteristics also were confirmed to be normal. The two types of PSCFs are thought to be able to contribute to the dramatic capacity growth in submarine systems.

6. References

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