ULTRA-LOW LOSS AND LARGE AEFF PURE-SILICA CORE FIBER ADVANCES

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Abstract: Fiber loss of 0.152 dB/km at 1550 nm on a mass production basis is realized, which will be the lowest among commercially available optical fibers, by decreasing Rayleigh scattering on a pure-silica-core fiber having enlarged Aeff of 130 μm^2. By virtue of the ultralow loss, this pure-silica-core fiber will have the highest fiber figure-of-merit and be the most suitable for ultra-high capacity transoceanic communication systems.

1. INTRODUCTION

Long haul transmission systems based on digital coherent technologies have been actively deployed in transoceanic links in order to keep up with exponential growth of global data traffics. A major challenge for realizing high capacity long haul transmission is to improve a system optical signal to noise ratio (OSNR) [1]. Therefore, transmission fibers having low loss and low nonlinearity are strongly desired, and actually various fibers have been proposed [2-7]. Especially, decreasing in the fiber loss is the most important, since it can increase the OSNR in any of transmission system configurations.

In this paper, we set the new world record mass production-basis loss of 0.152 dB/km at 1550 nm on average over a total of 10,000 km of pure-silica-core fiber (PSCF). In addition, we quantitatively discuss the impact of this loss decrease on OSNR improvement according to the fiber figure-of-merit (FOM) calculation [4, 8, 9].

2. LOSS IMPROVEMENT HISTORY

Figure 1 shows a historical chart of loss improvement at 1550 nm for commercially available products and R&D based fibers. PSCFs are known to have the lower loss compared to GeO_2-doped core fibers. In R&D basis, a loss of 0.154 dB/km was reported in 1986 [10], and the latest record is 0.1467 dB/km at 1550 nm [5].

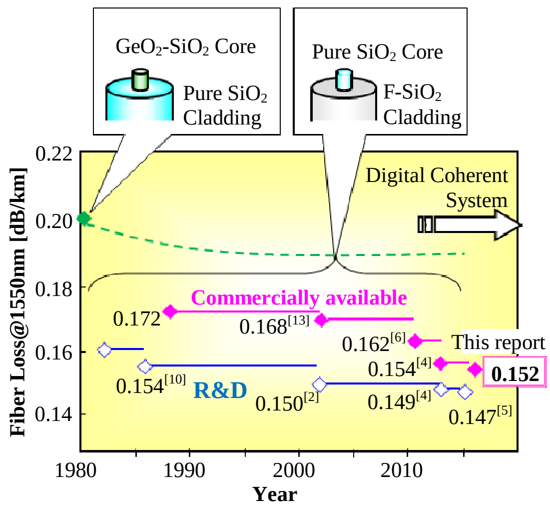

Figure 1: Historical chart of loss improvement.

Hence, the loss improvement of R&D based fibers during the last 30 years is only 0.007 dB/km. On the other hand, a loss of commercially available products has been dramatically improved by 0.014 dB/km since 2010. Until 2010, the available loss remained around 0.17 dB/km for more than

20 years, but since then, the loss has been decreased almost every two years, and in 2013, 0.154 dB/km was achieved [4]. Furthermore, we successfully realized the averaged loss of 0.152 dB/km as discussed hereinafter in this paper. This significant loss improvement in commercially available fibers can be attributed to strong demands from the market along with the rapid spread of digital coherent systems.

3. LOSS IMPROVEMENT OF OPTICAL FIBER

The loss of optical fibers consists of Rayleigh scattering proportional to the minus forth power of the wavelength (λ), structural imperfection loss and absorptions (infared, ultraviolet, impurities, and point defects) as shown in equation (1),

$$\alpha(\lambda) = A/\lambda^4 + B + C(\lambda), \quad (1)$$

where A is Rayleigh scattering coefficient, B is structural imperfection loss, C(λ) is absorptions. In these factors, Rayleigh scattering loss dominates about 80 % of a fiber loss at the λ of 1550 nm. Rayleigh scattering results from microscopic fluctuations of glass refractive indices caused by a dopant concentration fluctuation and a density fluctuation of glass network structure. In this regard, the use of pure silica glass core with no dopant is intrinsic way to eliminate the dopant concentration fluctuation. In addition, we reduced the density fluctuation by improving manufacturing conditions and achieved loss of 0.154 dB/km at 1550nm.

Figure 2 shows a typical loss spectra of improved pure-silica-core fiber with Aeff of 130 μm^2 (PSCF-130). The loss of 0.152 dB/km at 1550 nm was realized by successful reduction in the Rayleigh scattering coefficient from 0.76 dB/km/μm^{-4} to 0.74 dB/km/μm^{-4} by means of the improvement of manufacturing process conditions.

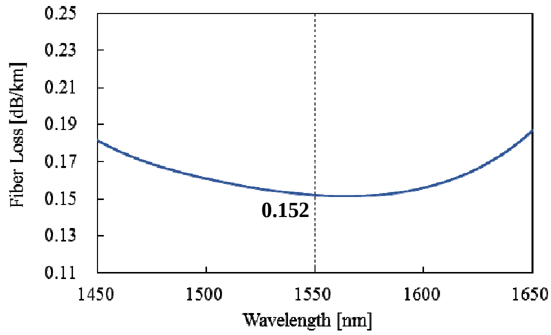

Figure 2: Typical loss spectra of improved PSCF-130 manufactured by mass production-basis processes.

4. FABRICATION OF ULTRA LOW LOSS PSCF

4-1. Refractive index profile

Figure 3 schematically shows a refractive index profile of the loss improved PSCF-130, which is the same design as the current PSCF-130 of 0.154 dB/km [4, 11]. We employed a ring core refractive index profile having a center core slightly doped with fluorine, surrounded by a pure silica ring core. We confirmed that the ring core profile gives better dissimilar splice loss to a standard single mode fiber (SSMF) composing an optical repeater than a splice loss between SSMF and a step core PSCF having the same Aeff as that of ring-core profile [12].

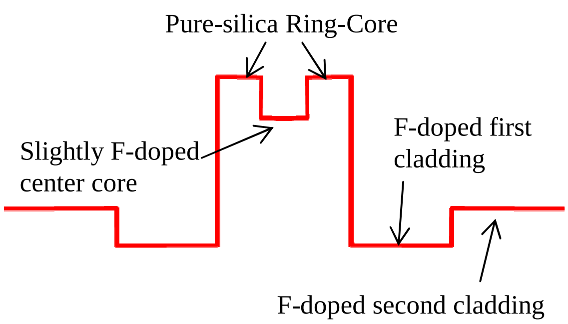

Figure 3: Schematic of Refractive index profile of improved PSCF-130.

4-2. Optical loss

We manufactured ultra low loss PSCF-130 with accumulated quantity about 10,000 km based on mass production processes. Figure 4 shows fiber-loss distributions of improved PSCF-130 and current PSCF-130. In the improved PSCF-130, averaged loss of 0.152 dB/km at 1550 nm was successfully achieved, which exhibits the lowest loss among commercially available optical fibers today. The loss distribution seems to be Gaussian in shape having small standard deviation of 0.001 dB/km.

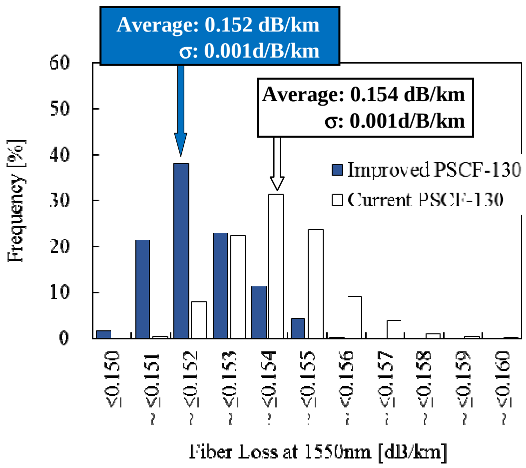

Figure 4: Manufactured fiber loss distribution of improved and current PSCF-130.

Table 1: Typical characteristics of improved PSCF-130 at 1550nm.

	Improved PSCF-130	Current PSCF- 130 [11]
Fiber Loss [dB/km]	0.152	0.154
Chromatic Dispersion [ps/nm/km]	20.4	20.4
Dispersion Slope [ps/nm^2/km]	0.060	0.060
Aeff [μm^2]	130	130

Table 1 summarizes typical characteristics of improved and current PSCF-130. As described above, the refractive index profiles of the improved and the current PSCF-130 are same to each other, hence all characteristics are also same to each other including chromatic dispersion, Aeff, mode field diameter, macro- and micro- bending sensitivities, environmental / mechanical reliabilities and durabilities, other than the fiber loss.

5. Sysem OSNR improvement prediction with fiber figure-of-merit (FOM)

In order to quantitatively evaluate the transmission performance, we calculated fiber FOM described as [4, 8, 9],

$$FOM[dB]=10/3\log(Aeff^2\cdot\alpha\cdot|D|)-2/3\cdot\alpha L+10\log(L)-2/3\alpha_{sp}, \quad (2)$$

where α [dB/km], D [ps/nm/km], L [km] and α_{sp} [dB] are the fiber loss, chromatic dispersion, span length and splice loss to a repeater respectively. In practical submarine systems, launched signal power is limited because of a limitation of electric power supply to wet repeaters. Therefore, signal launched power P_{ch} will be lower than optimal launched power P_{opt} due to the limitation. FOM at arbitrary launched signal power ($P_{ch} = r\cdot P_{opt}$) of FOM_R can be written as [9]

$$FOM_R[dB]=FOM+10\log[3r/r^3+2]]. \quad (3)$$

Using equation (3), Figure 5 shows calculated iso- FOM_R lines as a function of fiber loss and Aeff at L = 80 km with solid lines along with performance of some of commercially available fibers. In this calculation, D=+21 ps/nm/km and n_2=2.2 x 10^{-20} m^2/W were assumed. The splice loss of a fiber to a repeater was calculated as dissimilar splice loss caused by MFD-mismatching between the fibers and SSMF [3, 14].

The improved PSCF-130 shows the highest FOM_R among the commercially available fibers to our knowledge. From these results, the PSCF with 0.152 dB/km is the best commercial product to long haul submarine cable systems.

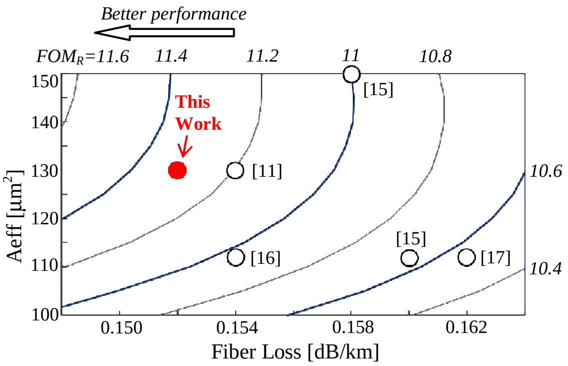

Figure 5: Iso-FOM_R as a function of Loss and Aeff at Span Length of 80km.

6. CONCLUSION

We presented the ultra low loss PSCF-130 with a loss of 0.152 dB/km at 1550 nm over accumulated length of 10,000 km owing to the reduction of Rayleigh scattering by improvement of manufacturing conditions. We have also confirmed that the realized PSCF-130 has the highest fiber FOM for digital coherent transmission systems. This PSCF-130 will be able to contribute to constructions of ultra high capacity global optical networks.

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