**OTuI2.pdf**

# OSNR-Enhancing Pure-Silica-Core Fiber with Large Effective Area and Low Attenuation

**Yoshinori Yamamoto, Masaaki Hirano, Kazuya Kuwahara and Takashi Sasaki**
*Optical Communications R&D Laboratories, Sumitomo Electric Industries, Ltd., 1, Taya-cho, Sakae-ku, Yokohama, 244-8588 Japan*
*yamamoto-yoshinori@sei.co.jp*

**Abstract:** Pure-silica-core fiber with large Aeff of 134μm$^2$ is designed to enhance OSNR considering splice loss to SSMF, and realized by appropriate depressed cladding profile and soft primary coating. It also exhibits low attenuation of 0.169dB/km.

**OCIS codes:** (060.2280) Fiber design and fabrication; (060.2330) Fiber optics communications

## 1. Introduction

Along with enhancement of channel bit-rate, the higher OSNR is required for optical transmission systems. Although rapid progress has been achieved in transmission systems including multi-level modulation formats and digital coherent detection techniques to reduce the OSNR requirement [1], the most straightforward means to improve the OSNR would be enhancement of linearity in optical fibers, i.e., reduction of the attenuation and enlargement of the effective area (Aeff). We have proposed pure-silica-core fiber (PSCF) that has depressed cladding index profile with Aeff of 115μm$^2$ and attenuation of 0.171dB/km in 1999 [2], and it has been deployed in actual operating transmission systems. For further enlargement of Aeff while suppressing microbending loss, fibers with thicker cladding diameter of 170μm have been proposed [3]. However, they have not been practical because mismatch of the cladding diameter to that of standard fibers of 125μm is too large to be installed as a telecom fiber. For improving the microbending loss, use of primary coating with low Young's modulus has also been proposed [4]. However, 125μm-diameter fiber with Aeff larger than 120μm$^2$ has not been reported yet.

On the other hand, Aeff should be smaller than 150μm$^2$ in a transmission system with distributed Raman amplification (DRA) that is often employed to improve the OSNR in long-haul systems, because a fiber with larger Aeff requires seriously high pump power [5]. In addition, the larger Aeff fiber may degrade splice loss to existing standard fibers unacceptably because of large mismatch of mode-field diameter (MFD).

In this paper, we clarify that Aeff should be around 135μm$^2$, considering splice loss to a standard single mode fiber (SSMF). In order to enlarge Aeff, we design an index profile with depressed cladding so as to overcome macrobending loss and leakage loss due to fundamental mode cutoff. Applying the newly designed index profile and a primary coating with lower Young's modulus, we have successfully fabricated PSCF with Aeff of 134μm$^2$ and attenuation of 0.169dB/km. The novel PSCF is expected to have the highest OSNR improvement among practical fibers with the cladding diameter of 125μm by as much as 3.4dB compared to SSMF for a 80km-span transmission link to our best knowledge.

## 2. Fiber index profile design for appropriately enlarged Aeff

The OSNR for the linear transmission system is in proportion to the following equation;

$$\mathrm{OSNR} \propto 10\log\left(\mathrm{Aeff} \times \alpha[1/\mathrm{km}]\right) - \alpha_{\mathrm{sp}}[\mathrm{dB}] \times \mathrm{N} - \alpha[\mathrm{dB/km}] \times \text{span length}[\mathrm{km}], \quad (1)$$

where $\alpha_{sp}$, N and $\alpha$ are splice loss, number of splices per span and fiber attenuation, respectively. The first term corresponds to the allowable signal input power limited by fiber nonlinearity. The second and third terms represents splice loss and fiber attenuation. Firstly, the effect of enlarging Aeff has been evaluated considering improvement of allowable signal input power and degradation of the splice loss due to MFD mismatching to SSMF. Figure 1 shows the relative OSNR as a function of Aeff normalized to that for a SSMF (Aeff=80μm$^2$), considering at N to 0, 2 and 4. The splice loss was calculated from the degradation of coupling efficiency to SSMF due to the MFD mismatching. If there is no splice to SSMF in the transmission system, OSNR simply increases by enlarging Aeff. However, there would be several splices to SSMF in a single span, because fiber-based devices are made with SSMFs today. In the case for N=2, the OSNR improvement would be limited and almost saturated for the Aeff larger than 140μm$^2$. If we suppose the N=4, the OSNR becomes the maximum at Aeff around 135μm$^2$. Therefore, Aeff around 135μm$^2$ should be appropriate for linear transmission lines with less than 4 splices/span. It should also be noted that pump power of DRA required for a fiber with Aeff around 135μm$^2$ is below a realistic upper limit [5].

We have investigated a fiber with Aeff of 135μm$^2$ considering macro- and microbending performances. In order to suppress the macrobending loss, we have designed the index profile of fiber with a depressed cladding as depicted

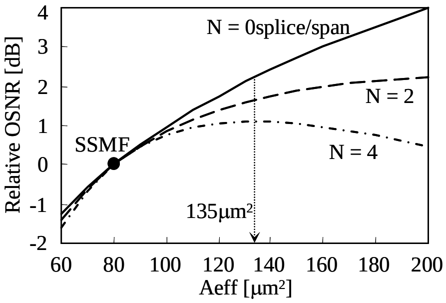

Fig. 1. Relative OSNR normalized to that for a SSMF with 0, 2 and 4 splices/span to SSMF.

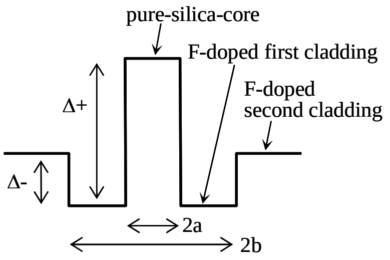

Fig. 2. Depressed cladding profile with pure-silica-core.

in Fig. 2, which has been utilized to realize an enlarged-Aeff fiber [2]. As for a fiber with the depressed cladding, the fundamental guided mode may become leaky at the longer wavelength, and eventually become cutoff at a wavelength, where the effective index of the fundamental mode becomes lower than the index of second cladding [6]. In order to clarify the shorter limit of the fundamental mode cutoff wavelength ($\lambda_{FC}$) to avoid the leakage loss in telecom wavelength bands up to 1625nm, we have calculated the $\lambda_{FC}$ for fibers with different depressed cladding profiles. Then, we have fabricated the fibers and measured a wavelength $\lambda_{LK}$, where the leakage loss of the fiber increases by 20% to the attenuation of a PSCF with step index profile wound on a 280mm-diameter bobbin. The relationship between $\lambda_{FC}$ and $\lambda_{LK}$ is shown in Fig. 3. We found that the $\lambda_{FC}$ should be longer than 2400nm to make the $\lambda_{LK}$ longer than 1625nm. After that, we have calculated the relationship between the $\lambda_{FC}$ and the macrobending loss in 20mm-diameter to examine the depressed cladding profile realizing both the low macrobending loss and the long $\lambda_{FC}$. The result is shown in Fig. 4. The considered parameters are the diameter ratio 2b/2a and the relative index difference Δ-, whereas Δ+ and 2a are adjusted so as to set the Aeff to be 135μm$^2$ and the fiber cutoff wavelength ($\lambda_C$) of LP11 mode to be 1350nm. From Fig. 4, the macrobending loss becomes minimum by adjusting 2b/2a to 3.0. We have also found that Δ- should be lower than 0.12% to set the $\lambda_{FC}$ longer than 2400nm for 2b/2a=3.0.

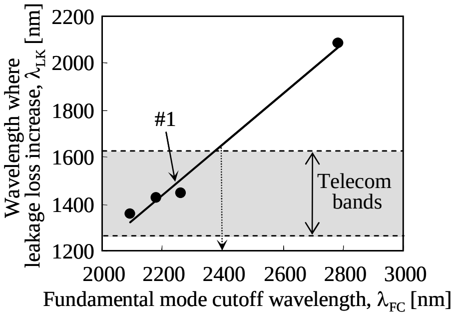

Fig. 3. Wavelength where leakage loss increases ($\lambda_{LK}$) versus fundamental mode cutoff wavelength ($\lambda_{FC}$).

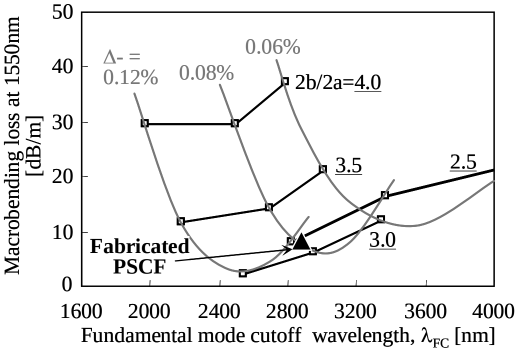

Fig. 4. Macrobending loss for diameter of 20mm versus fundamental mode cutoff wavelength.

It is also known that the Aeff-enlarged fiber would have poor microbending performance. In order to improve the microbending loss to a practical level, we have newly developed a primary coating which has lower Young's modulus than conventional coating. Figure 5 shows the microbending losses for 125μm-diameter fibers as a function of Aeff with new and conventional coatings. The microbending loss was characterized by a wire mesh bobbin test with wound tension of 80g [7]. For a fiber with the same Aeff, the new coating can reduce the microbending loss by half to that with the conventional coating. By applying the new coating, a fiber with Aeff of 135μm$^2$ would have the equivalent microbending performance to the 115μm$^2$-Aeff fiber with the conventional coating that has been actually deployed in operating systems.

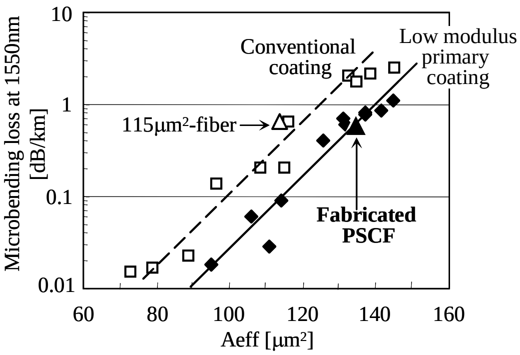

Fig. 5. Microbending loss for 125μm-diameter fiber with low modulus primary and conventional coating.

## 3. Fabrication of the Aeff-enlarged PSCF with low attenuation

From the third term in Eq.(1), the lower attenuation directly improves OSNR. Therefore, we have employed the pure-silica-core that has inherently low attenuation. According to above discussion, a PSCF with Aeff of 134μm$^2$ has been successfully fabricated by applying the depressed cladding profile of 2b/2a=3.0 and $\Delta$-=0.08% with the low modulus primary coating. The macro- and microbending losses of the fabricated PSCF are also plotted in Fig. 4 and 5, respectively. The measured macrobending loss agrees well with the calculation in Fig. 4, which is equivalent to that of a SSMF. It is also verified that the microbending loss is well suppressed to be equivalent with the commercial 115μm$^2$-Aeff fiber with the conventional coating, as shown in Fig. 5. Figure 6 shows the attenuation spectrum of the fabricated PSCF. The attenuation is as low as 0.169dB/km at 1550nm without the leakage loss up to 2100nm. Figure 6 also shows the attenuation spectrum of fiber #1 in Fig. 3, which has the shorter $\lambda_{LK}$ of 1440nm despite the almost same $\lambda_C$ (LP11) of 1361nm as the fabricated PSCF. Table 1 summarizes the characteristics of the fabricated PSCF. The splice loss to SSMF should be below 0.3dB/splice regarding the MFD of the fabricated PSCF.

Finally we have evaluated the OSNR improvement by using the fabricated PSCF in a 80km-span transmission link. Figure 7 shows a contour map of the relative OSNR normalized to that for a SSMF (Aeff=80μm$^2$, $\alpha$=0.19dB/km) as a function of Aeff and attenuation, $\alpha$, where the splice loss is not considered. In Fig. 7, relative OSNR for several reported fibers with large Aeff and low attenuation [2,8-12] are also plotted. As can be seen, the newly fabricated PSCF is expected to have the highest OSNR among these fibers, which is 3.4dB-improvement compared to SSMF. Even if we take 4 splices/span to SSMF into consideration, the fabricated PSCF would keep its superiority in OSNR improvement, as seen in Fig. 1.

Table 1. Fiber characteristics at 1550nm.

| Attenuation [dB/km] | Cladding diameter [μm] | MFD [μm] | Aeff [μm$^2$] | λc (LP11) [nm] | Disp. [ps/nm/km] | Disp. slope [ps/nm$^2$/km] | Macrobend. loss(20mmϕ) [dB/m] | Microbend. loss [dB/km] | PMD [ps/rt-km] |
|---|---|---|---|---|---|---|---|---|---|
| 0.169 | 125 | 12.7 | 134 | 1341 | 20.9 | 0.060 | 8.0 | 0.58 | 0.02 |

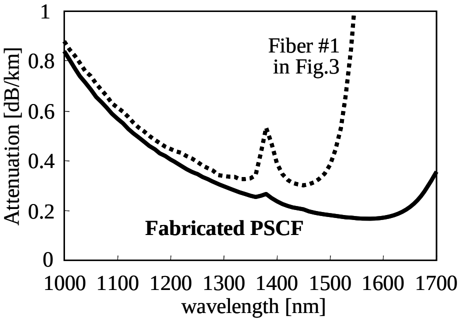

Fig. 6. Attenuation spectrum of fabricated PSCF.

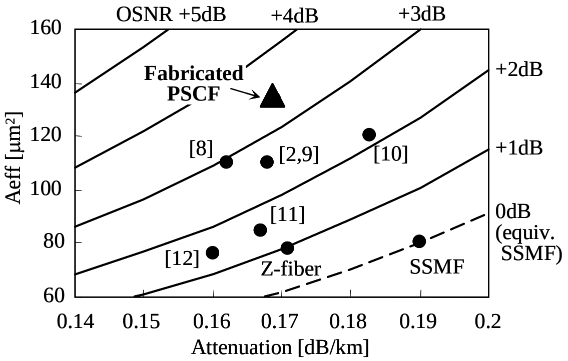

Fig. 7. Relative OSNR normalized to that for a SSMF for a 80km-span transmission.

## 4. Summary

We have reported that the PSCF with Aeff around 135μm$^2$ should be the appropriate candidate for a linear transmission fiber, considering splice loss to SSMF and limitation of pump power for DRA. A novel PSCF with large Aeff of 134μm$^2$ and low attenuation of 0.169dB/km has been successfully fabricated with cladding diameter of 125μm. Newly designed depressed cladding profile has efficiently suppressed both macrobending loss and leakage loss due to fundamental mode cutoff. In addition, good microbending performance has been realized with low Young's modulus primary coating. The fiber can improve the OSNR by as much as 3.4dB in 80km-span transmission systems compared to SSMF. We strongly believe that the new PSCF is best suited for the high-speed and long-haul transmission systems by virtue of the linearity of the fiber.

## References

[1] D. van den Borne et al., ECOC2009, Paper 3.4.1
[2] T. Kato et al., Electron. Lett. 35, pp.1615-1617 (1999)
[3] M. Tsukitani et al., ECOC2002, 3.2.2
[4] B. Overton et al., IWCS2008, pp.279-282
[5] H. Bissessur, in OFC2009, Panel Discussion NTuD
[6] L. G. Cohen et al., IEEE J. of Quantum Electron. QE-18, pp.1467-1472 (1982)
[7] JF. Libert et al., IWCS1998, pp.375-384
[8] H Masuda et al., OFC2009, PDPB5
[9] M. Salsi et al., ECOC2009, PD2.5
[10] M. Bigot-Astruc et al., ECOC2008, Mo.4.B.1
[11] E. Pincemin et al., OFC2009, OThC2
[12] J. D. Downie et al., ECOC2006, Mo3.3.3