Ultra-low-loss (0.1484 dB/km) pure silica core fibre and extension of transmission distance

K. Nagayama, M. Kakui, M. Matsui, T. Saitoh and Y. Chigusa

A pure silica core fibre with unprecedented low-loss of 0.1484 dB/km has been successfully fabricated. With a large effective area of 118 μm^2, this ultra-low-loss fibre extends transmission distance by 33% compared to conventional Ge-SMF, and over 400 km distance transmission is possible with Raman amplification.

Introduction: Low-loss optical fibres are now indispensable transmission media for long transmission systems. The lowest attenuation of 0.154 dB/km was realised in 1986 [1]. While optical amplification techniques such as EDFAs and Raman amplifiers [2] have made dramatic advances, fibre attenuation remains critical to extend the transmission distance and to increase the bit rate. In this Letter, we introduce a fibre with the record-breaking low-loss of 0.1484 dB/km. We further examined its possible impact on transmission systems. Using this ultra-low-loss fibre, the advantages of designing EDFA systems and the extension of repeaterless systems with Raman amplifier by 33% are also described.

Fibre design and characteristics: Ultra-low-loss pure silica core fibre (PSCF) has been fabricated. This PSCF has a large effective area (A_{eff}) to reduce nonlinearity. Fig. 1 shows the refractive index profile of the PSCF with depressed cladding. Depressed cladding is introduced to improve the bending characteristics of the large A_{eff} fibre by confining the optical power into the core [3]. The structural parameters used are $\Delta^+ = 0.26\%$, $\Delta^- = -0.06\%$. The fibre characteristics at 1550 nm are dispersion +20.3 ps/km/nm, dispersion slope 0.060 ps/km/nm^2, MFD 12.2 μm, A_{eff} 118 μm^2, PMD 0.0025 ps/rkm and cutoff wavelength 1.41 μm. Spectral attenuation of the PSCF in Fig. 2 shows 0.265 dB/km at 1310 nm and 0.1484 dB/km at 1570 nm, which are the lowest values reported so far. Accuracy of measurements by a cutback method was evaluated in detail. An instrument used is the model of AQ2140 by ANDO Corporation. Low-loss PSCF was measured four times and those values were scattered within +/−0.0005 dB/km from the mean value at each wavelength. The fibre length of 11.28 km is accurate within +/−0.05% which is less than +/−0.0001 dB/km in attenuation, thus total accuracy is within +/−0.0006 dB/km. Detailed spectral attenuation is shown in Fig. 3 where averaged values of four measurements with 2 nm pitch are plotted by symbols with a fitting curve. The attenuation at wavelengths of 1566, 1568, 1570 and 1572 nm are 0.1483, 0.1485, 0.1485 and 0.1483 dB/km, respectively. Thus the minimum loss of about 0.1484 dB/km occurs at around 1570 nm. The PSCF is measured with a loose coil condition to avoid bending loss in the spool condition. The loose coil or bundle condition is close to the loose tube cable condition where lateral force is relieved. Loss components are analysed at 1570 nm where the fibre achieves minimum loss. Rayleigh scattering coefficient of PSCF (0.745 dB/km/μm^{-4} which is 0.123 dB/km in scattering loss at 1570 nm) is considerably smaller than that of GE-SMF (typically 0.94 dB/km/μm^{-4}), which shows the advantage of making a core of pure silica. The contribution of an OH absorption tail on minimum loss is estimated as 0.0024 dB/km. This means there is the possibility of achieving the minimum loss of 0.146 dB/km by eliminating OH from this fibre. Other components are the imperfection loss that is a low value of 0.004 dB/km and infrared absorption loss of 0.019 dB/km.

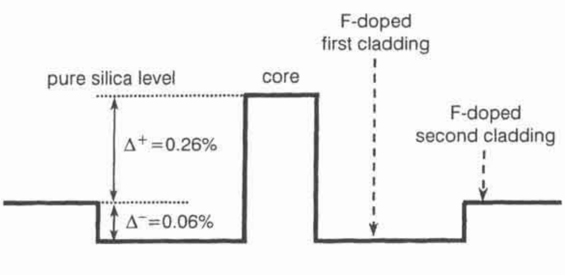

Fig. 1 *Schematic refractive index profile of PSCF*

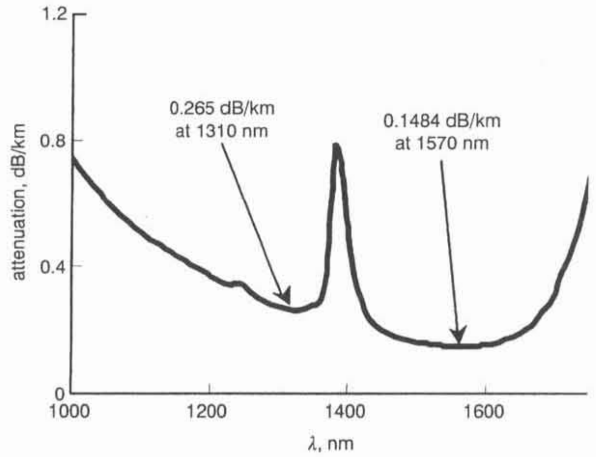

Fig. 2 *Spectral attenuation of PSCF*

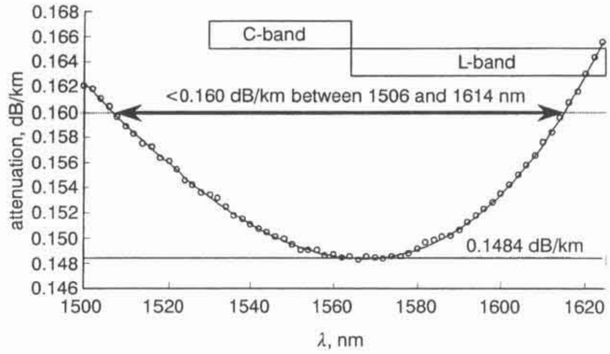

Fig. 3 *Detailed spectral attenuation of PSCF (1500–1625 nm)*

Possible impact on repeaterless transmission system: The impact on transmission systems employing EDFAs and/or Raman amplifiers has been examined. The transmission loss is less than 0.160 dB/km within the wavelength range from 1506 to 1614 nm, which covers most of the EDF amplification range. This demonstrates that the ultra-low-loss characteristics are fully utilised by the existing EDFAs. Low-loss fibre is profitable especially for the extension of the repeaterless transmission distance. The advantage of the newly developed low-loss PSCF has been examined in the model with and without the backward pumped distributed Raman amplifier (DRA). Table 1 summarises the system conditions adapted to the low-loss PSCF and conventional Ge-SMF as a reference. The transmitted signal power has been controlled to set the nonlinear weight [3] to 1 rad. The large A_{eff} of the PSCF allows the higher transmitted power by 0.5 dB. The wavelength of signal and pump light is set to 1570 and 1470 nm, respectively. The pump power has been optimised so that Raman gain is maximised within the range where the DRA does not oscillate.

Table 1: Simulation conditions for Raman amplification

	PSCF	Ge-SMF
Loss at 1570 nm [dB/km]	0.1484	0.189
A_{eff} [μm^2]	118	83
Transmitted signal power [dBm]	15.5	15.0
Pump power [mW]	1126.0	966.1
On/off gain [dB]	29.8	29.2

Fig. 4 shows the simulation results. Using DRA, the low-loss PSCF increases the maximum transmission distance by 33% compared to conventional Ge-SMF. When the DRA is employed, PSCF requires higher pumping power because of the lower nonlinearity, while slightly larger Raman gain is available since the Rayleigh backscattering coefficient is lower. According to this examination, a longer distance is achieved with the PSCF than that with Ge-SMF by 33% whether the DRA is employed or not, and the longest distance is calculated to be 404 km. It is also interesting to note that the transmission distance of the PSCF without Raman is 341 km, which is longer than that of conventional Ge-SMF with Raman systems. Thus the fabricated PSCF is very attractive to extend the transmission distance.

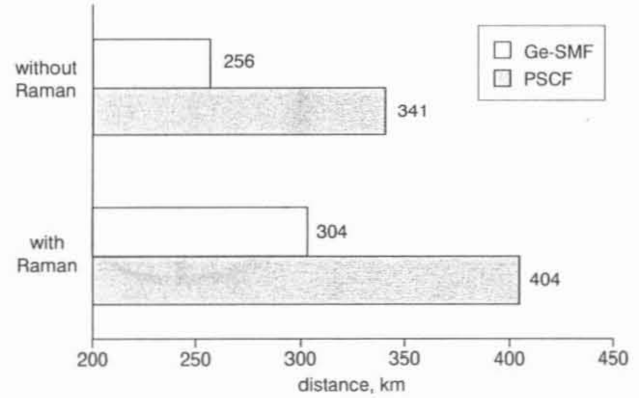

Fig. 4 *Maximum transmission distance*

Conclusions: Ultra-low-loss pure silica core fibre with minimum attenuation of 0.1484 dB/km has been successfully fabricated. The minimum attenuation is the lowest attenuation achieved so far. Its impact on transmission systems has also been examined. The attenuation in the C- and L-band is below 0.160 dB/km and wide, which is attractive for EDFAs systems. In repeater-less systems, low-loss fibre will extend transmission distance by 33% compared to conventional Ge-SMF, and the maximum distance is about 400 km if it is combined with Raman amplification. We believe that low-loss fibres will contribute to the evolution of future transmission systems.

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