Uncoupled 4-core Fibre with Ultra-low Loss and Low Inter Core Crosstalk

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Abstract *An uncoupled 125-*µm*-cladding 4-core multicore fibre (MCF) with record low-loss of 0.155dB/km among uncoupled MCFs was realized. Span loss of 60.2km MCF was reduced to less than 10dB including fan-in and fan-out. Inter core crosstalk of the MCF is less than -60dB/100km.*

Introduction

The improvement of the transmission capacity of optical communication systems using conventional single-mode fibre (SMF) is approaching a theoretical limit, and space division multiplexing (SDM) technology is drawing attention as a technology to overcome this limit [1]. Among optical fibres for SDM transmission, development of multicore fibre (MCF) has been actively carried out, and many research results have been reported. Among them, the MCF with cladding diameter of 125 µm, which is the standard cladding diameter of SMF, has attracted attention from the viewpoint of practical applications [2-3]. The use of the MCF with standard cladding diameter has a major advantage in that existing techniques can be used for cutting and connecting fibres, as well as for splicing techniques and cable structures.

Optical submarine systems are one of the desirable applications for the MCFs with standard cladding diameter. Optical submarine systems are required to have large capacity, low power consumption, and low cost. The amount of information that can be transmitted in one core is theoretically limited by the nonlinear Shannon limit, and the upper limit of the transmission capacity is increased in proportion to optical signal-to-noise ratio (OSNR) [4]. Since the OSNR deteriorates due to noise generated in an optical amplifier and nonlinear optical phenomenon in an optical fibre, it is required to reduce loss and nonlinearity in the optical fibre. When applying the SDM transmission technique using the MCF, the MCF is also required to have low loss. To reduce nonlinearity, it is effective to increase effective area (A_{eff}) in the case of conventional single core fibre (SCF). On the other hand, in the case of MCF, which scales the transmission capacity by the number of cores, the intensity of the signal light launched into one core should be smaller than that of the SCF, especially for the systems in which the transmission capacity is restricted by the supplied power, such as submarine systems. Since the nonlinear phenomenon in the optical fibre is proportional to the optical power, it should be sufficient to design the A_{eff} as large as the conventional SMF when the MCF is used.

There are two types of MCF, coupled MCF in which the signal transmits in each core interferes each other, and uncoupled MCF in which each core independently propagates the signal. In the coupled MCF, the signals propagating in each core are coupled to each other, and it requires multiple-input-multiple-output (MIMO) digital signal processing in the transmission system. On the other hand, MIMO processing is not required in uncoupled MCF because the signal propagates independently in each core. Since the economical efficiency of the MIMO processing at the practical operation is still under consideration, it is desirable to use the uncoupled MCF that does not require the MIMO processing in terms of cost reduction. When the uncoupled MCF is used for long-distance transmission, it is necessary to reduce inter core crosstalk (XT), since interference between the signals propagating through the cores causes degradation of the OSNR.

In order to apply the MCF to practical transmission systems, fan-in and fan-out (FIFO) devices are required to connect each core of the MCF to SMF. A fibre bundle type FIFO has been reported for the MCF with standard cladding diameter [5]. The fibre bundle FIFO using four thin cladding fibres can connect SMF to each core of the 4-core fibre with low loss.

In this report, low propagation loss and low XT of the uncoupled 4-core fibre with standard cladding diameter are realized, simultaneously. In order to realize low propagation loss and low XT, we designed and fabricated an MCF with pure silica cores having optimized refractive index profile. As a result, a propagation loss of 0.155 dB/km, which is the lowest loss in ever reported uncoupled MCFs, is realized. In addition, low XT of less than –60 dB/100km is realized. Minimum span loss of 60.2 km MCF is reduced to less than 10 dB including the fibre bundle type FIFO connected to the both end of the MCF.

Design of uncoupled 4-core Fibre

An uncoupled 4-core fibre with standard cladding diameter is designed. Uncoupled MCFs need low XT. To realize low XT, it is effective to increase the core pitch. On the other hand, when the cladding diameter is fixed, if the core pitch is increased, distance between centre of the core and the interface between cladding and coating (cladding thickness) is decreased. When the cladding thickness is decreased, excess loss caused by light leakage outside the cladding is increased. Therefore, in the design of the MCF with standard cladding diameter, there is a trade-off between suppression of XT and reduction of excess loss. In the case of the 4-core fibre with standard cladding diameter, low XT cannot be achieved using a core with a step index profile used in conventional SMF at the wavelength of 1550 nm [6]. Low XT can be realized even at a wavelength of 1550 nm by adding a trench layer on the outer periphery of the core [6]. Therefore, in this design, trench-assisted refractive index profile is applied for a pure silica core. Fig. 1 shows a schematic diagram of the designed core. A pure silica core similar to that used in the low-loss TeraWave ® SCUBA Ocean Optical Fiber [7] is used as the centre core. Effective area (A_{eff}) is set to 87 μm^2, which is comparable to SMF at a wavelength of 1550 nm, in consideration of the connectivity with SMF. A trench layer and a clad layer made of F-doled silica glass are used on the outside of the core. As a result of relaxing the trade-off between core pitch and XT by using trench-assisted profile, low XT and low excess loss are realized at a clad diameter of 125 μm and a core pitch of 43 μm.

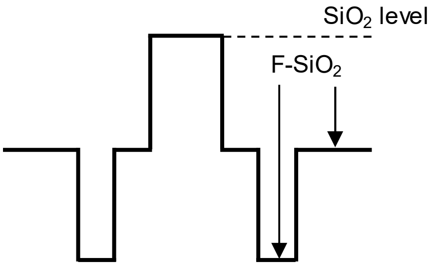

Fig. 1: Schematic diagram of the core design for uncoupled 4-core fibre

Characterisitcs of fabricated MCF

Based on the design, uncoupled 4-core fibre is fabricated. A picture of the cross section of the fabricated MCF is shown in fig. 2, and the characteristics of the MCF are shown in Table 1. Cladding diameter of the fabricated MCF is 125 μm, and the core pitch is 43.0 μm on average, as designed. Cut-off wavelength is 1539 nm. When the fibre length is increased to about 0.8 km, single-mode operation is confirmed at a wavelength of 1500nm or more. Attenuation loss at the wavelength of 1550 nm is 0.155 dB/km to 0.157dB/km. Fig. 3 shows the loss spectrum of the core 1. Attenuation loss is less than 0.158 dB/km in C-band, and lowest loss is 0.152 dB/km at 1560 nm. XT is less than –60 dB/100km in all cores. Table 2 shows the reported characteristics of the MCF with standard cladding diameter and

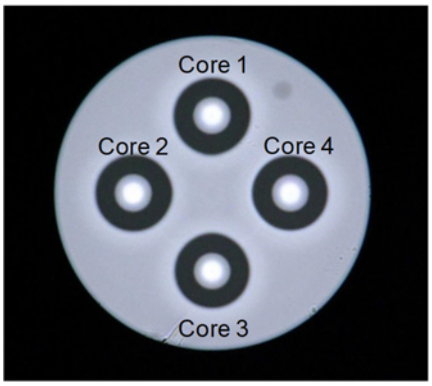

Fig. 2: Cross section of fabricated uncoupled 4-core fibre

Tab. 1: Characteristics of fabricated MCF at 1550 nm

Characteristics	Unit	Value
Cladding diameter	μm	125
Coating diameter	μm	245
Core pitch	μm	43.0
Effective area	μm^2	87.1
Cut-off wavelength (22m)	nm	1539
Dispersion	ps/nm/km	22.6
Dispersion slope	ps/nm^2/km	0.06
Attenuation loss	-	-
Core 1	dB/km	0.155
Core 2	dB/km	0.156
Core 3	dB/km	0.157
Core 4	dB/km	0.155
Inter core crosstalk	-	-
Core 1 – Core 2	dB/100km	-63.8
Core 2 – Core 3	dB/100km	-60.7
Core 3 – Core 4	dB/100km	-62.7
Core 4 – Core 1	dB/100km	-61.8

Tab. 2: Characteristics of MCFs with 125 μm cladding

Characteristics	Unit	MCF [8]	MCF [9]	MCF [10]	This work
Core design	-	Coupled	Uncoupled	Uncoupled	Uncoupled
Core number	-	4	4	2	4
Attenuation loss	dB/km	0.155	0.169	0.162	0.155
XT	dB/100km	-	-46	-56	-64

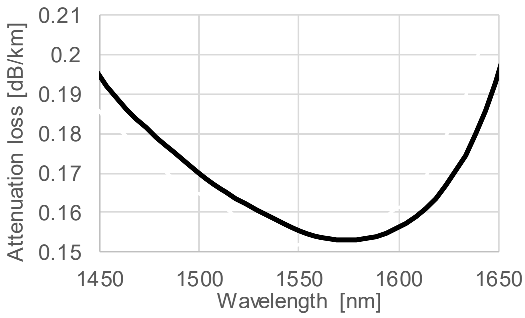

Fig. 3: Attenuation spectra of core 1

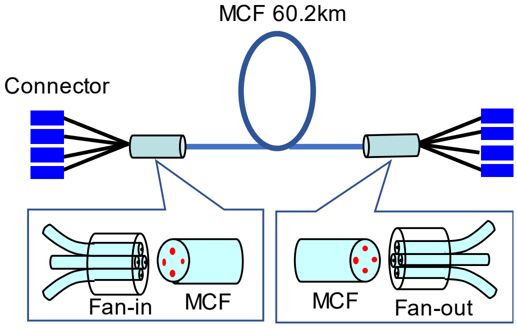

Fig. 4: Schematic diagram of fabricated MCF with FIFO

result of this work. In the reported MCFs, coupled MCF is considered to be advantageous for low propagation loss and the lowest loss of 0.155 dB/km among SDM fibres is realized at the wavelength of 1550 nm by the reported coupled 4-core fibre [8]. On the other hand, attenuation loss of the uncoupled 4-core fibre [9] is 0.169 dB/km, which is larger than that of the coupled MCF. In the uncoupled 2-core fibre [10], attenuation loss is reduced to 0.162dB/km, but the number of cores is 2, which is half of the 4-core fibre. Attenuation loss of the fabricated uncoupled 4-core fibre is 0.155 dB/km, which is the lowest loss for the uncoupled MCF, and the same loss as the lowest loss of all SDM fibres including the coupled MCF is realized. The fabricated MCF also realized the lowest XT compared with the reported uncoupled low-loss MCF. When the MCF is used in actual transmission systems, a device for connecting each core of the MCF to the SMF is required. A fibre bundle FIFO device have been reported [5]. The bundle of the thin cladding fibres and the MCF are inserted into capillaries, and bonded and fixed using a UV curing adhesive. Fig. 4 shows a span structure in which the FIFOs are connected to both ends of the fabricated MCF. In this configuration, length of the MCF is set to 60.2 km. Span characteristics is measured with both FIFOs. Table 3 shows the measured span characteristics. These results include the characteristics of the FIFOs and connectors attached to both ends of the MCF. The span loss is 9.9 dB to 10.4 dB. From this result, loss of the fan-out is less than 0.5 dB including the coupling loss to the MCF. Span XT is less than -62 dB, and no major XT degradation caused by the FIFO is found. Polarization mode dispersion (PMD) is

Tab. 3: Span characteristics of fabricated MCF with FIFO

Characteristics	Unit	Value
Fibre length	km	60.2
Span loss (core 1)	dB	9.9
Span loss (core 2)	dB	10.4
Span loss (core 3)	dB	10.1
Span loss (core 4)	dB	10.0
XT	dB	< -62
PMD	$ps/km^{1/2}$	< 0.1
PDL	dB	< 0.1

less than 0.1 $ps/km^{1/2}$, and polarization dependent loss (PDL) is less than 0.1 dB. From these results, it is confirmed that the polarization dependence is small for both MCF and FIFO.

Conclusions

Uncoupled 4-core fibre with lowest loss of 0.155 dB/km among uncoupled MCFs, is realized. This attenuation loss is the same loss as the lowest loss of coupled MCF. In addition, low XT of less than -60 dB/100km is achieved. Span loss of 60.2 km MCF is 9.9 dB to 10.4 dB including FIFO connected to both ends of the MCF, and the span XT is less than -62 dB. Since low attenuation loss and low XT is desirable for long distance transmission, it is considered that the fabricated MCF has attractive characteristics as a next generation fibre for the optical submarine transmission systems.

Acknowledgements

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