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Description

[0001] The present invention relates to the field of optical fibre transmissions, and more specifically, a line fibre having an enlarged effective area.

[0002] For optical fibres, the index profile is generally classified according to the appearance of the graph of the function which associates the refractive index with the radius of the fibre. In standard fashion, the distance r to the centre of the fibre is shown on the x-axis. On the y-axis the difference between the refractive index (at radius r) and the refractive index of the fibre cladding is shown. Thus the terms "step", "trapezium", "alpha" or "triangle" index profile are used to describe graphs having curves with the shapes of a step, trapezium, alpha or triangle. These curves are generally representative of the theoretical or set profile of the fibre, whilst the manufacturing constraints of the fibre may result in a slightly different profile.

[0003] In standard fashion, an optical fibre is composed of an optical core the function of which is to transmit and optionally, amplify an optical signal, and an optical cladding the function of which is to confine the optical signal within the core. To this end, the refractive indices of the core n_c and the cladding ng are such that $n_c>n_g$. As is well known, the propagation of an optical signal in a single-mode optical fibre can be broken down into a fundamental mode which is guided in the core, and into secondary modes which are guided over a certain distance in the core-cladding assembly, called cladding modes.

[0004] In standard fashion, step-index fibres, also called SMF ("Single Mode Fibres") are used as line fibres for optical fibre transmission systems. These fibres have a chromatic dispersion and a chromatic dispersion slope complying with specific telecommunications standards as well as standardized cut-off wavelength and effective area values.

[0005] In response to the need for compatibility between optical systems from different manufacturers, the International Telecommunication Union (ITU) has defined a standard, reference ITU-T G.652, with which a standard optical transmission fibre, called SSMF (Standard Single Mode Fibre), must comply.

[0006] Among others, the G.652 standard recommends for a transmission fibre the range of 8.6-9.5 µm [8.6; 9.5 µm] for the Mode Field Diameter (MFD) at a wavelength of 1310 nm; a maximum of 1260 nm for the value of the cable cut-off wavelength; the range of 1300-1324 nm [1300; 1324 nm] for the value of the zero dispersion wavelength (denoted $\lambda_{0)}$; a maximum of 0.092 ps/nm^2-km for the value of the chromatic dispersion slope. In standard fashion, the cable cut-off wavelength is measured as the wavelength at which the optical signal is no longer single mode after propagation over twenty-two metres of fibre, as defined by subcommittee 86A of the International Electrotechnical Commission in the IEC 60793-1-44 standard.

[0007] In a manner known *per se,* an increase in the effective area of a transmission fibre contributes to a reduction in the nonlinear effects in the fibre. A transmission fibre having an enlarged effective area allows a transmission over a longer distance and/or an increase in the operating margins of the transmission system. Typically, an SSMF has an effective area A_{eff} of the order of 80 µm^2.

[0008] In order to increase the effective area of a transmission fibre, it was proposed to produce fibre profiles having an enlarged and flattened core compared with an SSMF. However, such an alteration in the shape of the fibre's core leads to an increase in the microbending losses and to an increase in the effective and cable cut-off wavelengths over the fibre. In standard fashion, the effective cut-off wavelength is measured as the wavelength from which the optical signal is single mode after propagation over two metres of fibre, as defined by subcommittee 86A of the IEC in the IEC 60793-1-44 standard.

[0009] US-A-6 658 190 describes transmission fibres with an enlarged effective area greater than 110 µm^2. This fibre has a very broad core - 1.5 to 2 times that of an SSMF - and a configuration with a constant or shallowly depressed cladding. In order to compensate for the increase in microbending losses caused by an increase in the effective area, this document proposes increasing the diameter of the fibre (Figure 29). Such an increase in the diameter of the fibre, however, involves in increase in the cost and leads to cabling problems because of incompatibility with the other fibres. In addition, this document points out that the cut-off wavelength decreases with the length of the fibre under consideration (Figure 5) and in particular that the fibre achieves a single-mode character after 1 km of transmission. Such a measurement of the cut-off wavelength, however, does not comply with the standardized measurements cited above. The fibres described in this document have cable cut-off wavelengths greater than 1260 nm and zero chromatic dispersion wavelengths λ_0 less than 1300 nm. The fibres of this document therefore do not comply with the recommendations of the G.652 standard.

[0010] US-A-6 614 976 describes a transmission fibre having a high chromatic dispersion at the wavelength 1550 nm in order to compensate for the negative chromatic dispersion of a NZ-DSF fibre (Non Zero - Dispersion Shifted Fibre). The fibre of this document has an effective area greater than or equal to 90 µm^2. However, the desired high dispersion results in a cable cut-off wavelength greater than 1260 nm and a chromatic zero dispersion wavelength λ_0 of less than 1300 nm. These features mean that this fibre does not comply with the recommendations of the standard G.652.

[0011] US-B-7 187 833 describes a transmission fibre having an effective area greater than 80 µm^2. The fibre of this document has a central core, an intermediate cladding and a depressed cladding. Such a profile can result in the appearance of leaky modes in the fibre which make it difficult to control the cut-off wavelength.

[0012] None of the documents of the prior art identified describe an optical fibre having an enlarged effective area compared with an SSMF, while remaining fully compatible with the G.652 standard.

[0013] There is therefore a need for a transmission fibre having an enlarged effective area, exceeding 90 µm^2, without departing from the recommendations of the G.652 standard.

[0014] To this end, the invention proposes a fibre profile comprising a central core, an intermediate cladding and a ring; the central core, intermediate cladding and ring being optimized simultaneously to enlarge the effective area of the fibre without adversely affecting the other transmission parameters imposed by the G.652 standard.

[0015] More particularly, the invention proposes a single-mode optical fibre according to claim 1.

[0016] According to the embodiments, the fibre of the invention can also comprise one or more of the following characteristics:

- the fibre optionally has a depressed cladding outside the ring;
- the depressed cladding has a radius comprised between 14 µm and 17 µm and an index difference comprised between -10×10^{-3} and -1×10^{-3};
- the fibre has a standardized ratio between the effective area and the mode field diameter greater than or equal to 1.270;
- the fibre has an effective area strictly greater than 90 µm^2.
- the fibre has an effective area less than 100 µm^2;
- for a wavelength of 1625 nm the fibre has bending losses less than or equal to 0.05 dB/100m$_{turns}$ for a radius of curvature of 30 mm.
- for a wavelength of 1550 nm the fibre has microbending losses such that the ratio of the microbending losses of the fibre to the microbending losses of a standard single-mode fibre subjected to identical constraints is less than or equal to 1.5.

[0017] Other characteristics and advantages of the invention will become apparent on reading the description which follows of embodiments of the invention, given by way of example and with reference to the attached figures which show:

- Figure 1, a diagrammatic representation of the set profile of a fibre according to a first embodiment of the invention;
- Figure 2, a diagrammatic representation of the set profile of a fibre according to a second embodiment of the invention;

[0018] The fibre of the invention will be described with reference to Figures 1 and 2 which represent set profiles, i.e. representative of the theoretical profile of the fibre, the fibre actually obtained after fibre drawing of a preform being able to have a slightly different profile.

[0019] According to a first embodiment (Figure 1), the transmission fibre according to the invention comprises a central core having an index difference Δn_1 with an outer cladding (serving as the optical cladding); an intermediate inner cladding having an index difference Δn_2 with the outer cladding; and a ring having a positive index difference Δn_3 with the outer cladding. The refractive indices in the central core, in the intermediate cladding and in the depressed cladding are substantially constant throughout their widths. The width of the core is defined by its radius r_1; the width of the intermediate cladding is defined by r_2-r_1 (r_2 minus r_1); the width of the ring is defined by r_3-r_2 (r_3 minus r_2). The intermediate cladding (r_2, Δn_2) directly surrounds the central core (r_1, Δn_1) and the ring (r_3, Δn_3) directly surrounds the intermediate cladding (r_2, Δn_2). Typically, the central core, the intermediate cladding and the ring are obtained by CVD type deposition in a silica tube and the outer cladding is constituted by refilling the tube generally using natural or doped silica, but can also be obtained by any other deposition technique (VAD or OVD).

[0020] According to a second embodiment (Figure 2) as recited in claim 6 the transmission fibre according to the invention also comprises a depressed cladding directly outside the ring (r_3, Δn_3) having a negative index difference Δn_4 with the outer cladding and has an outer radius r_4. The width of the depressed cladding is defined by r_4-r_3 (r_4 minus r_3).

[0021] In the fibre according to the invention, the central core has a radius r_1 comprised between 4.5 µm and 6 µm, and an index difference Δn_1 comprised between 4.2×10^{-3} and 5.2×10^{-3} compared with the outer optical cladding (made of silica for example). The core of the fibre according to the invention is therefore slightly larger and more flattened than in an SSMF. These characteristics make it possible to increase the value of the effective area beyond 90 µm^2 for a wavelength of 1550 nm. The intermediate cladding of the fibre according to the invention has a width r_2 comprised between 6.5 µm and 9.5 µm. This cladding also has an index difference Δn_2 with the outer cladding comprised between -3×10^{-3} and 1.0×10^{-3}. The fibre according to the invention also comprises a ring of radius r_3 comprised between 9.5 µm and 12.5 µm. This ring has an index difference Δn_3 with the outer cladding comprised between 1.0×10^{-3} and 5.0×10^{-3}. The dimensions of the ring, optimized with those of the core and the intermediate cladding, make it possible to control the optical characteristics of the fibre and in particular to retain a mode field diameter value for a wavelength of 1310 nm comprised between 8.6 µm and 9.5 µm, while ensuring an effective area greater than 90 µm^2 at 1550nm, and retaining the dispersion and cut-off characteristics within the intervals imposed by the G652 standard.

[0022] The fibre according to the invention can moreover have a depressed cladding with a radius r_4 comprised between 14 µm and 17 µm, and an index difference Δn_4 comprised between -10×10^{-3} and -1×10^{-3}. The presence of a depressed cladding makes it possible to confine the signal to a greater extent within the core of the fibre. An outer radius r_4 limited to 17 µm is chosen in order to limit the cost of production of the fibre.

[0023] Table I below gives six examples of possible index profiles for a transmission fibre according to the invention in comparison with a standard SSMF fibre having a "step" index profile. The first column gives a reference to each profile. The following columns give the radius values of each section (r_1 to r_4), and the next columns show the values of the refractive index differences of each section with the outer cladding (Δn_1 to Δn_4). The refractive index values are measured at the wavelength of 633 nm. The fibres of the examples from Table I have an outer diameter of 125 µm. The values in Table I correspond to set profiles of fibres.

TABLE I

Example	r_1 (µm)	r_2 (µm)	r_3 (µm)	r_4 (µm)	Δn_1 (@633 nmx10^{-3})	Δn_2 (@633 nmx10^{-3})	Δn_3 (@633 nmx10^{-3})	Δn_4 (@633 nmx10^{-3})
SSMF	4.35				5.2			
1	4.80	7.59	9.86		5.0	-0.6	2.0	
2	4.73	7.90	9.79		5.0	-0.4	2.3	
3	5.10	7.00	9.67		4.9	-2.5	2.2	
4	5.00	8.47	11.16	15.68	4.7	-1.7	4.0	-3.0
5	4.85	8.82	12.00	15.58	4.8	-1.0	3.0	-3.4
6	4.97	8.19	11.82	15.49	4.7	-1.4	2.6	-3.0
7	4.51	9.52	11.00		5.1	0.2	2.4	

[0024] Table II below shows optical characteristics simulated for the transmission fibres corresponding to the index profiles of Table I. In Table II, the first column repeats the references of Table I. The following columns provide, for each fibre profile, the values of cable cut-off wavelength (λ_{cc}), mode field diameter ($2W0_2$) for the wavelength of 1310 nm, effective area (A_{eff}) at the wavelength of 1550 nm, the normalized relationship between the effective area at 1550 nm and the mode field diameter at 1310 nm, chromatic dispersion (D) at the wavelength of 1550 nm, and slope (P) of the chromatic dispersion at the wavelength of 1550 nm. The following columns provide, for each fibre profile, the values of the zero chromatic dispersion wavelength (ZDW), chromatic dispersion slope (P_{ZDW}) at this wavelength, and bending losses (PC) at the wavelength of 1625 nm for a radius of curvature of 30 nm.

TABLE II

Example	λ_{CC} (nm)	$2W_{02}$ @ 1310nm (µm)	A_{eff} @ 1550nm (µm^2)	A_{eff}[1550nm]/ $\pi(W_{02}[1310nm])^2$	D @ 1550 nm (ps/nm-km)	P @ 1550 nm (ps/nm^2-km)	ZDW (nm)	P_{ZDW} @ ZDW (ps/nm^2-km)	PC R=30 nm @1625 nm (dB/100$_{turns}$)
SSMF	1240	9.2	82	1.21	16.8	0.058	1315	0.086	<0.05
1	<1260	9.5	92	1.28	16.2	0.058	1315	0.085	<0.05
2	<1260	9.5	91	1.27	16.2	0.058	1315	0.084	<0.05
3	<1260	9.5	93	1.29	16.0	0.057	1310	0.084	<0.05
4	<1260	9.5	92	1.30	16.1	0.057	1310	0.083	<0.05
5	<1260	9.5	91	1.29	16.1	0.057	1310	0.083	<0.05

Example	λ_{CC} (nm)	$2W_{02}$ @ 1310nm (µm)	A_{eff} @ 1550nm (µm^2)	A_{eff}[1550nm]/ $\pi(W_{02}[1310nm])^2$	D @ 1550 nm (ps/nm-km)	P @ 1550 nm (ps/nm^2-km)	ZDW (nm)	P_{ZDW} @ ZDW (ps/nm^2-km)	PC R=30 nm @1625 nm (dB/100$_{turns}$)
6	<1260	9.5	92	1.29	16.1	0.057	1310	0.083	<0.05
7	<1260	9.5	91	1.27	16.0	0.058	1315	0.085	<0.05

[0025] For the six examples according to the invention, it is noted from Table II that the normalized ratio between the effective area A_{eff} and the mode field diameter $2W_{02}$ (see formula I) is greater than or equal to 1.270.

$$Formula\,1 \qquad ratio = \frac{A_{eff}[1550nm]}{\pi(W_{02}[1310nm])^2}$$

[0026] This makes it possible to obtain an effective area greater than 90 µm^2 while retaining a mode field diameter comprised between 8.6 µm and 9.5 µm. It is noted from Table II that Examples 1 to 7 comply with the G.652 standard. The cable cut-off wavelength λ_{cc} is less than 1260 nm; the zero chromatic dispersion wavelength ZDW is comprised between 1300 nm and 1324 nm, and the chromatic dispersion slope is less than 0.092 ps/nm^2-km. On the other hand, bending losses are noted as less than or equal to 0.05 dB/100$_{tums}$. These bending loss values are equivalent to those of a standard step-index profile G.652 fibre. Therefore the transmission fibre according to the invention has a high effective area while complying with the recommendations of the G.652 standard.

[0027] Moreover, the fibre according to the invention has microbending losses such that the ratio of the microbending losses of a fibre according to the invention to the microbending losses in an SSMF subjected to identical constraints is less than or equal to 1.5. The microbending losses can be measured, for example, by a method termed the fixed diameter drum method. This method is described in the technical recommendation of the IEC subcommittee 86A under the reference IEC TR-62221.

[0028] The fibre according to the invention has an effective area value that is increased compared to an SSMF. The effective area however remains less than 100 µm^2. This limit ensures compliance with the set of criteria of the G.652 standard.

[0029] The profile of the fibre according to the invention is optimized to comply with these constraints of a high effective area and optical parameters in compliance with the G.652 standard. Tables I and II illustrate the radius and index limit values mentioned above in order to ensure a high effective area and compliance with the constraints of the G.652 standard. In particular, if the radius of the core r_1 falls below 4.5 µm and if Δn_1 rises above 5.5, the effective area will be less than 90 µm^2. If r_1 rises above 6 µm, then the mode field diameter $2W_{02}$, the cable cut-off wavelength λ_{cc} and the zero chromatic dispersion wavelength ZDW have values outside the G.652 standard. Similarly if r_2 is too small, the mode field diameter $2W_{02}$ will be greater than the maximum value 9.5 µm imposed by the G.652 standard; and if r_2 becomes too large, the effective area will be less than 90 μm^2. Moreover, if r_3 becomes too small, the effective area will be less than 90 μm^2; and if r_3 becomes too large, the mode field diameter $2W_{02}$ becomes greater than the maximum value 9.5 µm imposed by the G.652 standard, as well as the value of the cable cut-off wavelength λ_{cc}.

[0030] The transmission fibre according to the invention is particularly suited to C-band long-distance transmission systems. The increase in the effective area, without significant degradation of the other optical parameters of the fibre, allows an increase in the power of the optical signals transmitted without increasing the nonlinear effects; the signal-to-noise ratio of the transmission line is thus improved, which is particularly sought after in land-based or underwater long-distance optical transmission systems.

[0031] Moreover, the fibre according to the invention complies with the recommendation of standard ITU G.652. The fibre according to the invention can thus be installed in a number of transmission systems with good compatibility with the other fibres of the system.

PATENTKRAV

1. Optisk singlemode fiber, omfattende:

- en central kerne med en radius r_1 på mellem 4,5 µm og 6 µm og en positiv indeksforskel Δn_1 på mellem $4{,}2x10^{-3}$ og $5{,}2x10^{-3}$ til en ydre optisk kappe;

- en mellemliggende kappe med en radius r_2 på mellem 6,5 µm og 9,5 µm og en indeksforskel Δn_2 til den ydre optiske kappe på mellem $-3{,}0x10^{-3}$ og $1{,}0x10^{-3}$;

- en ring med en radius r_3 på mellem 9,5 µm og 12,5 µm og en positiv indeksforskel Δn_3 til den ydre optiske kappe på mellem $1x10^{-3}$ og $5{,}0x10^{-3}$;

hvor den optiske fiber ved en bølgelængde på 1550 nm har et effektivt areal, der er større end eller lig med 90 μm^2, med

- en kabelafskæringsbølgelængde λ_{cc} på mindre end 1260 nm;

- en modefeltdiameter MDF ved bølgelængden på 1310 nm på mellem 8,6 µm og 9,5 µm;

- en kromatisk nuldispersionsbølgelængde X_O på mellem 1300 nm og 1324 nm;

- en kromatisk dispersionshældning, der er mindre end 0,092 ps/nm^2-km ved den kromatiske nuldispersionsbølgelængde X_O.

2. Optisk singlemode fiber, omfattende:

- en central kerne med en radius r_1 på mellem 4,5 µm og 6 µm og en positiv indeksforskel Δn_1 på mellem $4{,}2x10^{-3}$ og $5{,}2x10^{-3}$ til en ydre optisk kappe;

- en mellemliggende kappe med en radius r_2 på mellem 6,5 µm og 9,5 µm og en indeksforskel Δn_2 til den ydre optiske kappe på mellem $-3{,}0x10^{-3}$ og $1{,}0x10^{-3}$;

- en ring med en radius r_3 på mellem 9,5 µm og 12,5 µm og en positiv indeksforskel Δn_3 til den ydre optiske kappe på mellem $1x10^{-3}$ og $5{,}0x10^{-3}$;

- en forsænket kappe med en radius r_4 og en negativ indeksforskel Δn_4 til den ydre optiske kappe;

hvor den optiske fiber ved en bølgelængde på 1550 nm har et effektivt areal, der er større end eller lig med 90 μm^2, med

- en kabelafskæringsbølgelængde λ_{CC} på mindre end 1260 nm;

- en modefeltdiameter MDF ved bølgelængden på 1310 nm på mellem 8,6 µm og 9,5 µm;

- en kromatisk nuldispersionsbølgelængde X_O på mellem 1300 nm og 1324 nm;

- en kromatisk dispersionshældning, der er mindre end 0,092 ps/nm^2-km ved den kromatiske nuldispersionsbølgelængde X_O.

3. Optisk fiber ifølge krav 2, hvor den forsænkede kappe har en radius r_4 på mellem 14 µm og 17 µm.

4. Optisk fiber ifølge et hvilket som helst af krav 2 til 3, hvor den forsænkede kappe har en indeksforskel Δn_4 til den ydre optiske kappe på mellem $10x10^{-3}$ og $-1x10^{-3}$.

5. Optisk fiber ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** den har et normaliseret forhold mellem det effektive areal og modefeltdi-

ameteren MFD, der er større end eller lig med 1,270.

6. Optisk fiber ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** den har et effektivt areal, der er mindre end 100 μm^2.

7. Optisk fiber ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** den for en bølgelængde på 1625 nm har bøjningstab, der er mindre end eller lig med 0,05 $db/100_{viklinger}$ for en krumningsradius på 30 mm.

8. Optisk fiber ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** den for en bølgelængde på 1550 nm har sådanne mikrobøjningstab, at forholdet mellem fiberens mikrobøjningstab og mikrobøjningstabene af en standard singlemode fiber SSMF udsat for de samme begrænsninger er mindre end eller lig med 1,5.

Figure 1.

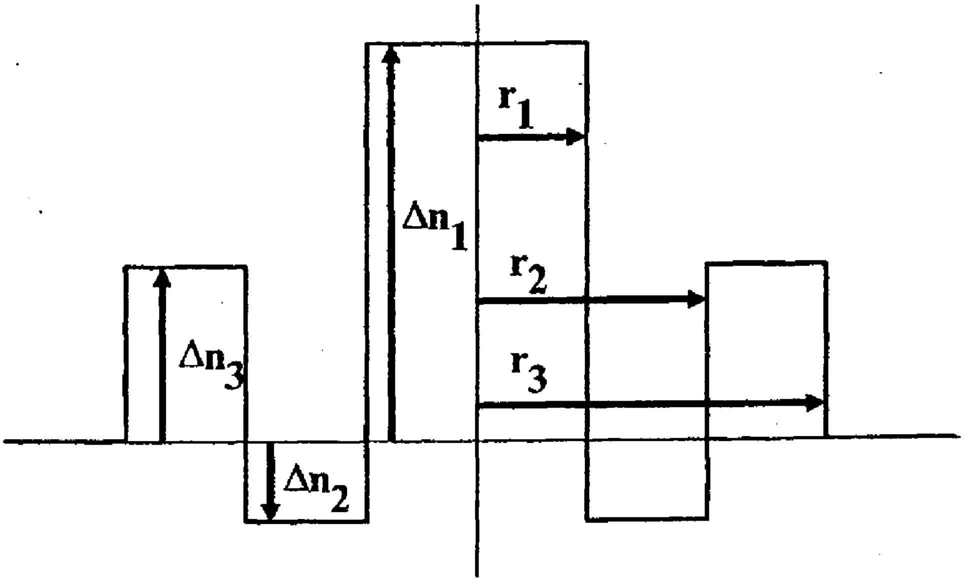

Figure 2.