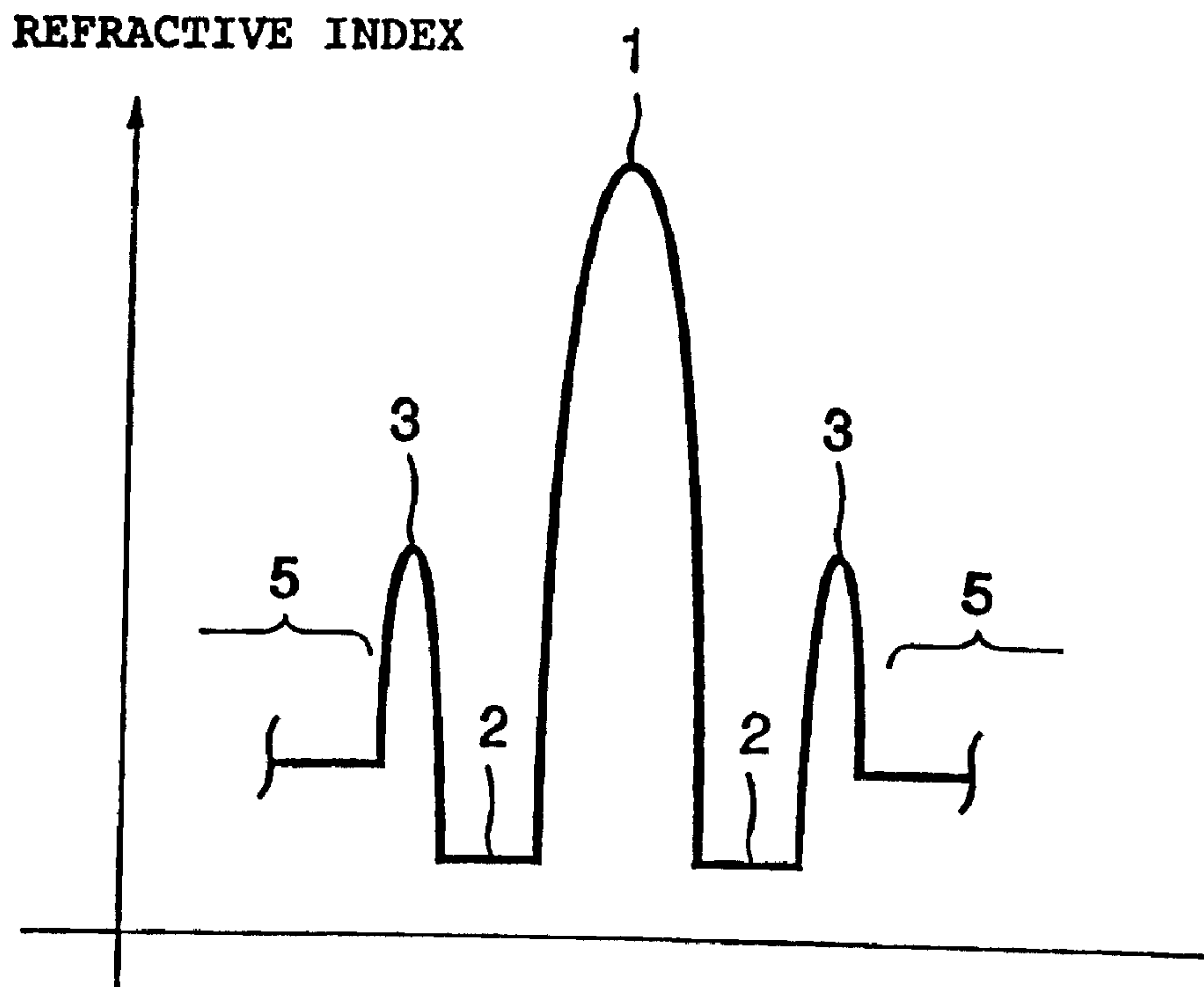




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(54) Titre : FIBRE OPTIQUE A AFFAIBLISSEMENT REDUIT
(54) Title: LOW ATTENUATION OPTICAL FIBER



(57) Abrégé/Abstract:

A low attenuation optical fibre which falls within 2-14 ps/nm/km in absolute value of dispersion over the full wavelength range of 1530-1565 nm and no more than 0.25dB/km of transmission loss at 1550 nm of wavelength at ordinary temperature and relative humidity, and still remains no more than 0.25 dB/km of transmission loss at 1550nm or 1520 nm after its being long-enough exposed to an atmosphere consisting substantially of hydrogen under ordinary pressure; and which further comprises a polarization mode dispersion (PMD) of no more than 0.5 ps/(km)^{1/2} at a wavelength of 1550 nm and a loss increase of no more than 40 dB/m in a bending diameter of 20 mm.

Abstract of the Disclosure

A low attenuation optical fibre which falls within 2-14 ps/nm/km in absolute value of dispersion over the full wavelength range of 1530-1565 nm and no more than 0.25dB/km of transmission loss at 1550 nm of wavelength at ordinary temperature and relative humidity, and still remains no more than 0.25 dB/km of transmission loss at 1550nm or 1520 nm after its being long-enough exposed to an atmosphere consisting substantially of hydrogen under ordinary pressure; and which further comprises a polarization mode dispersion (PMD) of no more than $0.5 \text{ ps}/(\text{km})^{1/2}$ at a wavelength of 1550 nm and a loss increase of no more than 40 dB/m in a bending diameter of 20 mm.

Low Attenuation Optical Fibre

Field of the Invention

[001] The present invention relates to low-attenuation optical fibres suitable for wavelength-division-multiplexing (WDM) optical transmission systems.

Background of the Invention

[002] Extensive studies have been carried out on techniques to increase the capacity of optical-fibre transmission with optical fibres.

[003] It is believed that an increase of optical transmission capacity requires the optical fibres for the optical transmission to enable single-mode transmission at the operating wavelength, because the groupings of different speeds of optical signals in various modes inevitably induces mode dispersion in the propagation through an optical fibre. As a result, the signal waveforms can decay or warp.

[004] Consequently, use of a single-mode fibre (SMF), having a zero-dispersion wavelength around 1.3 μm began. At this zero-dispersion wavelength, the fibre was able to have a transmission distance of scores of kilometers, and a transmission capacity of hundreds of Mbps (megabits per second).

[005] The least transmission loss in an optical fibre occurs at a wavelength of 1.55 μm , and a dispersion-shifted fibre (DSF) with a zero-dispersion wavelength around 1.55 μm was developed. This optical fibre enabled optical transmission with a capacity of several Gbps (gigabits per second) at a wavelength of about 1.55 μm . The same single-mode fibres were laid in long-distance optical transmission routes, each with a capacity of several Gbps at a wavelength band around 1.55 μm .

Summary of the Invention

[006] A purpose of the present invention is to provide low-attenuation fibres, comprising:

- a dispersion D of 2.0 to 14.0 ps/nm/km in a wavelength range of 1530 to 1565 nm in absolute value;
- a transmission loss of 0.25 dB/km or less under the standard atmospheric conditions; wherein the transmission loss at a wavelength of 1550 nm and/or 1520 nm is adjusted not to exceed 0.25 dB, as a result of being exposed to an atmosphere composed substantially of

hydrogen under the ordinary atmospheric pressure at ordinary temperature for a certain period of time. The standard atmospheric conditions refer to the definitions in JISC0010, Section 5, and refer to an ordinary temperature (25 ± 10 °C), an ordinary relative humidity (25-75%) and an ordinary atmospheric pressure (86 – 106 kPa). In addition, the certain period of time is needed, which is at least the time required for hydrogen to penetrate the midmost/core of an optical fibre. In effect, the hydrogen penetration is represented by a loss increase of at least 0.03dB/km around 1.24 μm .

Brief Description of the Drawings

[007] Fig. 1 is a sample sketch of a refractive index (RI) profile for a low attenuation optical fibre as an embodiment in the present invention, in which 1 denotes a core region, 2 a 1st annular region, 3 a 2nd annular region, and 5 denotes a clad.

[008] Fig. 2 is a second sample sketch of a refractive index (RI) profile for a low attenuation optical fibre as an embodiment in the present invention, in which the numbers 1 to 3 and 5 are defined as in Fig. 1, and 4 denotes a 3rd annular region.

Detailed Description

[009] In the latter half of the 1980s, a transmission loss increase in optical fibre was discovered. In the optical fibre, hydrogen molecules, stemming from hydrogen gas (H_2) trapped in the fibre, had dissociated. On analysis, the increase in transmission-loss could be assigned to absorption peaks in the transmission-loss spectrum, induced by hydrogen in the optical fibre. Hydrogen-induced absorption peaks emerge around 1.24 μm , at 1.52 μm , and on the longer wavelength side. The absorption peaks at 1.52 μm and longer wavelengths will have an adverse impact on the optical transmission around 1.55 μm , in the first place as described, for instance, by Ogai et al. in ECOC '86, pp7-10.

[0010] At the same time, in terms of 1.31 μm transmission SMF and 1.55 μm transmission DSF, various efforts in research and development had been undertaken to prevent the hydrogen-induced loss increase, focusing on the aspect of fabrication technique or of fibre coating material. Yet, for example, optical-fibre cables for terrestrial application were usually filled with a filling compound, without a threat of seriously trapping gaseous hydrogen.

[0011] Accordingly, no argument over hydrogen-proof treatment (resistance to hydrogen) today takes place, as for example described in Bellcore-GR-20-Core issue 2, July 1998, Section 6. 6. 9, generic specification in the United States.

[0012] In recent years, during the search for increased capacity optical transmission systems, designs for wavelength division multiplexing (WDM) have been studied and developed in dead earnest, while a plethora of studies on the optical fibres optimal for WDM optical transmission have been undertaken.

[0013] Regarding the aspect of evading four-wave mixing, the optical fibres for WDM optical transmission systems are required not to have a zero-dispersion wavelength within their operating wavelength bands. In this context, a non-zero dispersion shifted fibre (NZDSF) has been developed, without any zero-dispersion in the operating wavelength band. In general, NZDSFs are required to have even more complicated refractive-index (RI) profiles than those of SMFs or DSFs, because they need to deal with additional requirements for a large effective core area (A_{eff}), a reduced dispersion slope, and so forth, to provide for high-density WDM (DWDM) optical transmission.

[0014] Complicated RI profile designs of NZDSFs are prone to induce minute glassmaking flaws in optical fibres, and are accompanied by irksome process control.

[0015] Although NZDSFs are in use, which cover a broad wavelength band including the wavelength of 1.55 μm , no hydrogen-proof treatment techniques are disclosed to the public.

[0016] In recent years, cables to shroud optical fibres have structurally been reviewed and improved. In fact, a great number of optical fibre cables are shifting from a compound-filled type to a dry-core type, which contains a water absorbent material instead of a filling compound. The filling-compound free cable fabrication is far less toilsome (it is not required to wipe clean the cables). Also, the filled cables could hardly be enhanced with respect to fire resistance, but filling-compound free (dry-type) cables can readily be enhanced with respect to fire resistance. A sample dry-core type of optical fibre cable is described in U.S. Pat. No. 5,422,973.

[0017] The dry-core type contains a water absorbing material in the cable to lengthwise block out water penetration. When the absorbent material comes into contact with water, it swells and dams off the water. However, the water absorbent material tends to induce a certain ambient humidity (moisture), even without any cable damage or opening, and poses a threat of allowing the trapped wet (absorbed ambient moisture) to react with component metals inside the cable, where hydrogen molecules emerge. Accordingly, even optical fibres for terrestrial cables need to be considered for hydrogen-proof treatment.

[0018] For instance, U.S. Pat. No. 6,131,415 describes an optical fibre with consideration of hydrogen-proof performance (hydrogen resistance), and a technique for suppressing the

hydroxyl-ion concentration in an optical fibre to reduce the transmission loss at 1385nm. In particular, the present patent owner, Lucent Technologies, discloses in "Catalog Allwave" certain information about a required design concept of hydrogen-proof performance (hydrogen resistance) of optical fibres for metropolitan use.

[0019] Moreover, U.S. Pat. Nos. 5,838,866 and 6,128,928 each describe an optical fibre, considering the issue of hydrogen resistance. Each fibre is designed to exhibit hydrogen resistance by making the (inner) clad contain germanium to a degree to raise its refractive index, not in substance.

[0020] However, USP No. 6,131,415 remarks on no more than a technique for suppressing the loss increase at 1385nm, arising from absorption peaks of hydroxyl ions, without any remarks on the loss increase at 1520nm, due to the absorption peaks of hydrogen ions.

[0021] Moreover, none of the techniques in U.S. Pat. Nos. 6,131,415, 5,838,866 and 6,128,928 involve any additives to bring on substantial shifts in the refractive-index profile in each clad region. Thus, these three patents are expected to aim for characteristic improvements in SMF or the equivalent, but not in NZDSF for WDM optical transmission systems.

[0022] The present invention is designed to provide hydrogen-proof optical fibres with moderate dispersions in a wavelength band between 1530 and 1565nm and transmission losses remaining almost constant over time.

[0023] The present invention recites a low attenuation optical fibre which falls within 2-14 ps/nm/km in absolute value of dispersion over the wavelength range of 1530-1565 nm and no more than 0.25dB/km of transmission loss at 1520nm of wavelength at ordinary temperature and relative humidity, and still remains no more than 0.25dB/km of transmission loss at 1520 nm of wavelength even after being exposed long enough under ordinary pressure in an atmosphere consisting substantially of hydrogen.

[0024] The present invention also recites a low attenuation optical fibre which falls within 2-14 ps/nm/km in absolute value of dispersion over the wavelength range of 1530-1565 nm and no more than 0.25 dB/km of transmission loss at 1550 nm of wavelength at ordinary temperature and relative humidity, and still remains no more than 0.25 dB/km of transmission loss at 1550 nm of wavelength even after being exposed long enough under ordinary pressure in an atmosphere consisting substantially of hydrogen.

[0025] The present invention further recites a low attenuation optical fibre based on the fibre as described above, which further comprises a dispersion slope of no more than $0.15 \text{ ps/nm}^2/\text{km}$ over the wavelength band of 1530-1565 nm, a PMD of no more than $0.5 \text{ ps}/(\text{km})^{1/2}$ at a wavelength of 1550 nm and a loss increase of no more than 40dB/m in a bending diameter of 20 mm.

[0026] In addition, the present invention recites a low attenuation optical fibre based on the above-mentioned optical fibre,, which further comprises A_{eff} of no more than $90 \mu\text{m}^2$.

[0027] Finally, the present invention recites a low attenuation optical fibre based on the above-mentioned optical fibre, which further comprises a dispersion slope of 0.04-0.08 $\text{ps/nm}^2/\text{km}$ over the wavelength band of 1530-1565 nm, an absolute value of dispersion of 6-10 ps/nm/km over the wavelength band of 1530-1565 nm and an A_{eff} of 40-70 μm^2 .

[0028] Building blocks of the present invention as described up to now allow fabrication of optical fibres suitable for the WDM optical transmission in a wavelength band of 1530-1565 nm.

[0029] The numerical limitations in the claims brought forward in the present invention are rounded in a method as authorized, for instance, by ASTM E29.

[0030] An embodiment of the present invention is now explained with reference to the drawings.

[0031] Fig. 1 is a sample sketch of an RI profile for a low-attenuation optical fibre of the present invention. Fig. 1 shows the midmost (core) region 1 and a clad 5, between which a first annular region 2, a second annular region 3 are located. The maximum refractive indices (RI) in the core and second regions 1 and 3 are larger than in the clad 5. The first annular region 2 is lower in refractive index than clad 5.

[0032] Fig. 2 shows a second sample of the RI profile, which an optical fibre of the embodiment may have. The profile in Fig.2 has the midmost (core) region 1 and a clad 5, between which a first annular region 2, a second annular region 3 and a third annular region 4 are located. The maximum RI in the core and second region 1 and 3 are larger than in the clad 5. Refractive indices in the first and third region 2 and 4 are lower than in the clad 5.

[0033] Notably, the RI profiles in Figs 1 and 2 are simple examples to which low-attenuation fibres of the present invention are not limited, in RI profile, provided that any RI profiles regarded as accordant with the present invention can be accepted.

[0034] In this embodiment, optical fibres are designed to have an absolute value of dispersion in the range of $2 \text{ ps/nm/km} \leq |D| \leq 14 \text{ ps/nm/km}$ over the wavelength (λ) range of $1530 \text{ nm} \leq \lambda \leq 1565 \text{ nm}$. It is because, in the wavelength (λ) range of $1530 \text{ nm} \leq \lambda \leq 1565 \text{ nm}$, a four-wave mixing impact is undesirably large at an absolute value of dispersion: $|D|$ less than 2 ps/nm/km ; and, cumulative dispersions might unfavorably be combined to make high-density WDM optical transmission impracticable in the designed transmission routes (systems), at an absolute value of dispersion: $|D|$ more than 14 ps/nm/km .

[0035] In contrast to similar conventional fibres, the embodiment is characterized in that an optical fibre as based on the present invention, when exposed long enough at ordinary temperature and under ordinary pressure to an atmosphere consisting substantially of hydrogen, does not exceed 0.25 dB/km in transmission loss at 1550 nm . The designed characteristic results from a fact of optical fibres with transmission losses in excess of 0.25 dB/km are regarded as undesirable at 1520 or 1550 nm for long-distance WDM transmission, even when having been exposed long enough to a hydrogen atmosphere. Here, the atmosphere at ordinary pressure consisting substantially of hydrogen refers to atmosphere for yielding an effect equivalent to an atmosphere consisting of 100% hydrogen; an atmosphere of at 90% hydrogen is desirable, if the remainder, 10% or less, is air. The expression exposed long enough indicates that the time elapsed is sufficient to allow hydrogen to reach the core of an optical fibre. Practically, this is the case when a loss increase of at least 0.03 dB/km is determined at $1.24 \mu\text{m}$.

[0036] Considering the requirements for fibre characteristics in a wavelength band of 1530 - 1565 nm , a range of dispersion of more than 15 ps/nm/km is undesirable, because this causes dispersions to vary greatly from wavelength to wavelength in WDM optical transmission; a polarization mode dispersion (PMD) of more than $0.5 \text{ ps/(km)}^{1/2}$ is undesirable, because this induces a mass of polarization dispersion to disable WDM optical transmission; a bending loss increase of more than 40 dB/m is undesirable, because this induces variations in transmission loss in optical fibre cables.

[0037] In addition, more than $90 \mu\text{m}^2$ of A_{eff} in a wavelength range of 1530 - 1565 nm is undesirable, because of it causes the bending loss to increase in volume, hardly allowing cabling the optical fibres. Less than $40 \mu\text{m}^2$ of A_{eff} is undesirable, because it is more likely to induce nonlinear phenomena. In particular, more than $40 \mu\text{m}^2$ of A_{eff} , which would be a factor in disagreement with other characteristic requirements, ought to be experimented with in detail, in comparison to discrete system specifications in practice.

[0038] Here, the effective area (A_{eff}) is defined with reference to Opt. Lett., Vol. 19, No. 4, pp 257-259 (Feb. 115, 1994).

[0039] A slope of dispersion of the fibre, which would preferably be minimized, could be a factor in disagreement with other characteristic requirements, if reduced to less than 0.04 ps/nm²/km, and should be tested, in comparison to discrete system specifications in practice, as to the choice of less than 0.04 ps/nm²/km. Conversely, more than 0.08 ps/nm²/km of dispersion slope, with a propensity of possible loss of application to high-density WDM optical transmission, would preferably be tested, in comparison to discrete system specifications in practice, as to the choice of more than 0.08 ps/nm²/km.

[0040] In terms of absolute values of dispersion, a four-wave mixing effect would arise below 6 ps/nm/km, and cumulative dispersions would risk the application to high-density WDM optical transmission above 10 ps/nm/km. Design values of dispersion should preferably be set up, in view of discrete virtual system specifications.

[0041] In conclusion, considering the above details, it is preferable to opt for 40-70 μm^2 of A_{eff} , 0.04 -0.08 ps/nm²/km of dispersion slope range, and 6-10 ps/nm/km of absolute value of dispersion, in a wavelength band of 1530-1565 nm.

[0042] Optical fibres were made having refractive index (RI) profiles as illustrated in Figs 1 and 2, which then underwent hydrogen-proof treatment and hydrogen-proof test, and served to demonstrate the present invention.

[0043] To name but a few, the hydrogen-proof treatments include a method of superficially etching in-process preforms, disclosed in U.S. Pat. No. 6,131,415, and method of treating optical fibres in a heated heavy-hydrogen atmosphere (deuterium, D₂), disclosed in European Patent Application No. 0673895A2. Introducing the hydrogen-proof treatment into the production line, more safety and less process change are the most important items to be considered. After studying the condition of the hydrogen-proof treatment, we found that the hydrogen-proof treatment under ordinary atmospheric pressure at ordinary temperature could provide sufficient hydrogen resistance for the NZDSFs.

[0044] In praxis, a 3 km-long coated optical fibre was led and held, for about 3 hours, in a treatment tank charged with D₂ (heavy hydrogen) at almost ordinary temperature. Notably, more than two hours of remaining in a D₂ atmosphere will produce a substantially constant effect, subject to a fibre length of 3 kilometers, where the hydrogen atmosphere does not need to be

heated, but can produce a sufficient effect even at ordinary temperature. The holding time in a hydrogen atmosphere may be required to be longer as the fibre under treatment becomes longer.

[0045] In the hydrogen-proof test, a 3 km long coated optical fibre was led and held, for six hours, in a test chamber charged with H₂ at a ordinary atmospheric pressure and ordinary temperature; the test chamber was recharged with nitrogen or air at ordinary temperature and the fibre was tested for transmission loss after dozens of hours. Here, more than four hours of holding time in a hydrogen atmosphere will produce an almost constant effect, subject to a fibre length of three kilometers. However, the holding time in a hydrogen atmosphere is required to be longer as the fibre under treatment becomes longer.

[0046] Pre/post hydrogen-proof treatment transmission losses (dB/km) are presented in Table 1, resulting from 20 sample pieces per embodiment, and consist of the discrete worst values. The Measures (units) are as follows: Dispersion: ps/nm/km; Dispersion slope: ps/nm²/km; PMD: ps/(km)^{1/2}; Loss increase, 20 mm in bend diameter: dB/m; A_{eff}: μm².

[0047] For the values of dispersion, dispersion slope are the maximums in a wavelength range of 1530 – 1565 nm; other values are taken at a wavelength of 1550 nm.

[0048] Table 1 reveals that hydrogen-proof optical fibres have been suppressed to be less than 0.25 dB/km in transmission loss, even after each hydrogen-proof test in a hydrogen (D₂) atmosphere. In contrast, References 1 and 2 without hydrogen-proof treatment, turn out to be more than 0.25 dB/km in transmission loss after hydrogen-proof test.

[0049] Moreover, it is verified that hydrogen-proof optical fibres with other RI profiles (e.g., single peaked, stepped or W pattern) than those in Figs 1 and 2, have incurred no increase in transmission loss in a hydrogen-proof test.

[0050] As unveiled in the above descriptions, the present invention has superior effects to facilitate the fabrication of optical fibres suited to the WDM optical transmission in a wavelength band of 1530-1565 nm.

Table 1

	RI profile	Dispersion (ps/nm/km)	Dispersion Slope (ps/nm ² /km)	PMD (ps/(km) ^{1/2})	Bend loss (dB/m)	A ^{eff} (μm ²)	1.55 μm loss (dB/km)		1.52 μm loss (dB/km)	
							pre-test	post-test	pre-test	post-test
Embodiment 1	Fig.1	11	0.05	0.03	1	53	0.213	0.224	0.220	0.228
Embodiment 2	Fig.1	9	0.06	0.08	5	56	0.201	0.215	0.209	0.218
Embodiment 3	Fig.1	7	0.06	0.09	6	56	0.205	0.217	0.213	0.224
Embodiment 4	Fig.2	5	0.07	0.12	15	57	0.209	0.221	0.218	0.227
Reference 1	Fig.1	9	0.06	0.08	5	56	0.201	0.268	0.209	0.396
Reference 2	Fig.2	5	0.07	0.12	15	57	0.209	0.277	0.218	0.420

Claims

What is claimed is:

1. A low attenuation optical fibre comprising:
a dispersion (D) of 2.0 to 14.0 ps/nm/km in absolute value over a wavelength band of 1530 to 1565 nm;
a transmission loss of no more than 0.25 dB/km at a wavelength of 1520nm under standard atmospheric conditions;
wherein said transmission loss at 1520 nm does not exceed 0.25 dB/km after being exposed, for a sufficient period, to an atmosphere consisting of at least approximately 80 % hydrogen at a pressure of approximately 96 ± 10 kPa and at a temperature of approximately 25 ± 10 °C.
2. The low attenuation optical fibre according to claim 1, wherein said atmosphere consisting of at least approximately 80 % hydrogen consists of approximately 90 % hydrogen.
3. The low attenuation optical fibre according to claim 1, further comprising:
a dispersion slope (S) of no more than 0.15 ps/nm²/km over a wavelength band of 1530 to 1565nm;
a polarization mode dispersion (PMD) of no more than 0.5 ps/(km)^{1/2}; and
a loss increase of no more than 40dB/m at a wavelength of 1550nm as bending in a diameter of 20 mm.
4. The low attenuation optical fibre according to claim 1, further comprising an effective area (A_{eff}) of no more than 90 μm^2 at a wavelength of 1550nm.
5. The low attenuation optical fibre according to claim 1, further comprising:
a dispersion slope of 0.04 ps/nm²/km to 0.08 ps/nm²/km over a wavelength band of 1530 to 1565 nm;
a dispersion of 6 ps/nm/km to 10ps/nm/km in absolute value; and
an effective area of 40 μm^2 to 70 μm^2 at a wavelength of 1550 nm.
6. The low attenuation optical fibre according to claim 2, further comprising an effective area of no more than 90 μm^2 at a wavelength of 1550 nm.

7. The low attenuation optical fibre according to claim 3, further comprising:
 - a dispersion slope of $0.04 \text{ ps/nm}^2/\text{km}$ to $0.08 \text{ ps/nm}^2/\text{km}$ over a wavelength band of 1530 to 1565 nm;
 - a dispersion of 6 ps/nm/km to 10 ps/nm/km in absolute value; and
 - an effective area of $40 \mu\text{m}^2$ to $70 \mu\text{m}^2$ at a wavelength of 1550 nm.
8. A low attenuation optical fibre comprising:
 - a dispersion (D) of 2.0 to 14.0 ps/nm/km in absolute value over a wavelength band of 1530 to 1565 nm;
 - a transmission loss of no more than 0.25 dB/km at a wavelength of 1550 nm under the standard atmospheric conditions;
 - wherein said transmission loss at 1550 nm does not exceed 0.25 dB/km after being exposed, for a sufficient period, to an atmosphere consisting of at least approximately 80 % hydrogen at a pressure of approximately $96 \pm 10 \text{ kPa}$ and at a temperature of approximately $25 \pm 10 \text{ }^\circ\text{C}$.
9. The low attenuation optical fibre according to claim 8, wherein said atmosphere consisting of at least approximately 80 % hydrogen consists of approximately 90 % hydrogen.
10. The low attenuation optical fibre according to claim 8, further comprising:
 - a dispersion slope (S) of no more than $0.15 \text{ ps/nm}^2/\text{km}$ over a wavelength band of 1530 to 1565 nm;
 - a polarization mode dispersion (PMD) of no more than $0.5 \text{ ps}/(\text{km})^{1/2}$; and
 - a loss increase of no more than 40 dB/m at a wavelength of 1550 nm as bending in a diameter of 20 mm.
11. The low attenuation optical fibre according to claim 8, further comprising an effective area (A_{eff}) of no more than $90 \mu\text{m}^2$ at a wavelength of 1550 nm,
12. The low attenuation optical fibre according to claim 8, further comprising:
 - a dispersion slope of $0.04 \text{ ps/nm}^2/\text{km}$ to $0.08 \text{ ps/nm}^2/\text{km}$ over a wavelength band of 1530 to 1565 nm;
 - a dispersion of 6 ps/nm/km to 10 ps/nm/km in absolute value; and
 - an effective area of $40 \mu\text{m}^2$ to $70 \mu\text{m}^2$ at a wavelength of 1550 nm.

13. The low attenuation optical fibre according to claim 10, further comprising an effective area of no more than $90 \mu\text{m}^2$ at a wavelength of 1550 nm.
14. The low attenuation optical fibre according to claim 10, further comprising:
a dispersion slope of $0.04 \text{ ps/nm}^2/\text{km}$ to $0.08 \text{ ps/nm}^2/\text{km}$ over a wavelength band of 1530 to 1565 nm;
a dispersion of 6 ps/nm/km to 10 ps/nm/km in absolute value, and
an effective area of $40 \mu\text{m}^2$ to $70 \mu\text{m}^2$ at a wavelength of 1550 nm.
15. A method of hydrogen-proof treatment for low-attenuation optical fibres, comprising the step of exposing the optical fibre to an atmosphere consisting substantially of deuterium at a temperature of approximately $25 \pm 10 \text{ }^\circ\text{C}$ after the fibre drawing process.
16. A method according to claim 15, in which an optical fibre is exposed to an atmosphere of approximately 90 % deuterium.
17. A method according to claim 15, in which an optical fibre is exposed to an atmosphere consisting substantially of deuterium at a pressure of approximately $96 \pm 10 \text{ kPa}$.
18. A method according to claim 15, in which the exposure time of an optical fibre is no less than the time required for deuterium to diffuse to the core section of said optical fibre.

Fig. 1

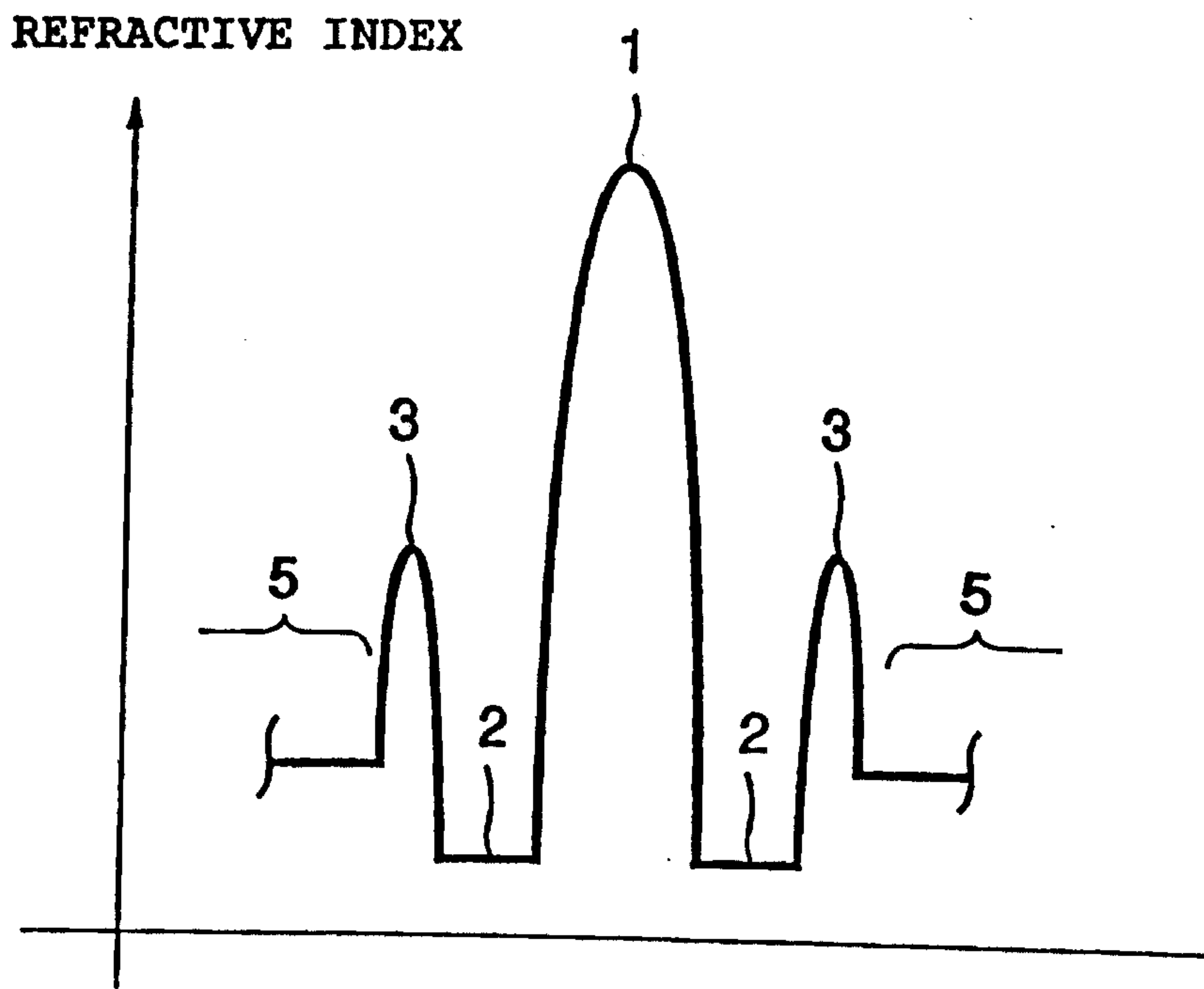
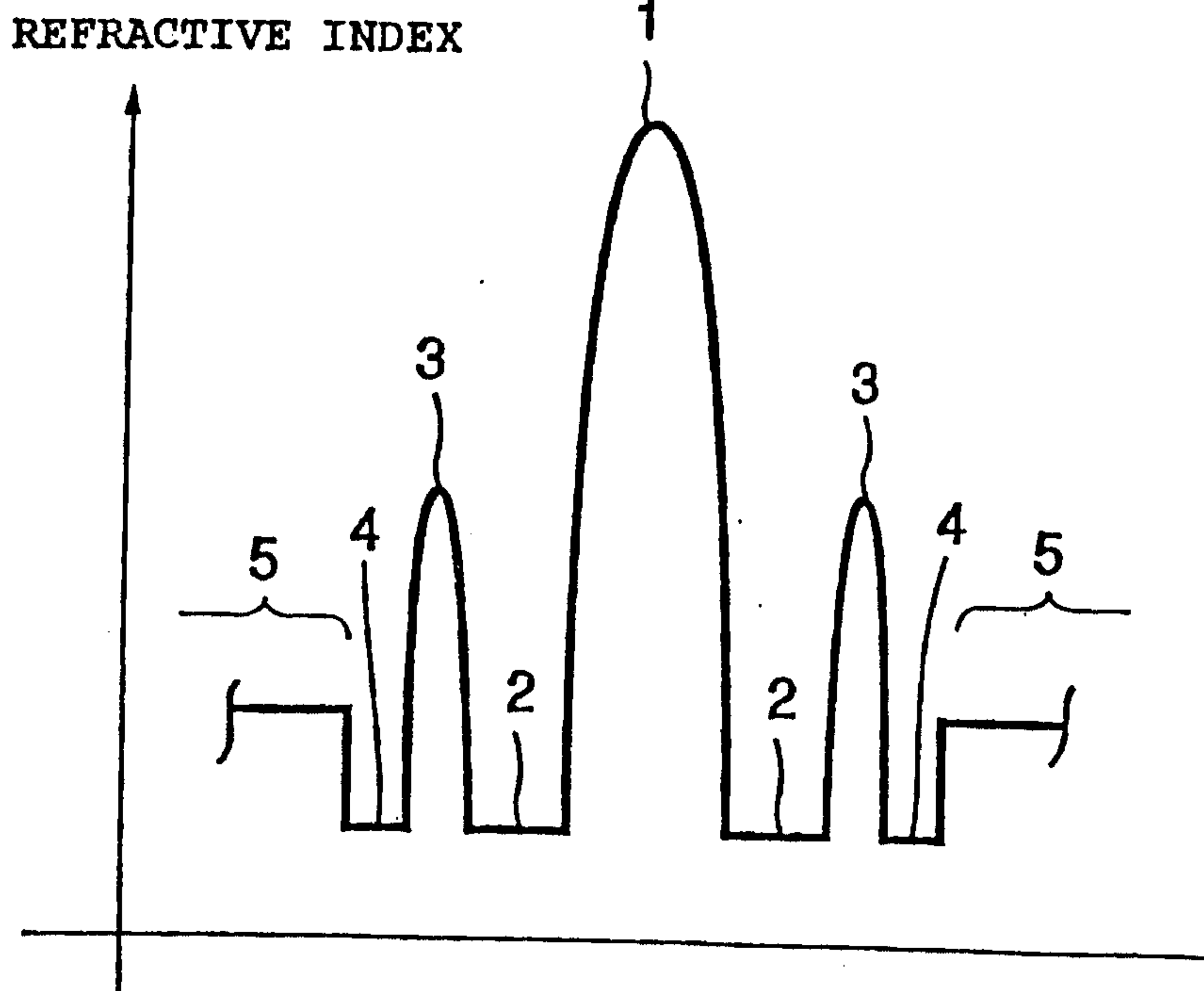


Fig. 2



REFRACTIVE INDEX

