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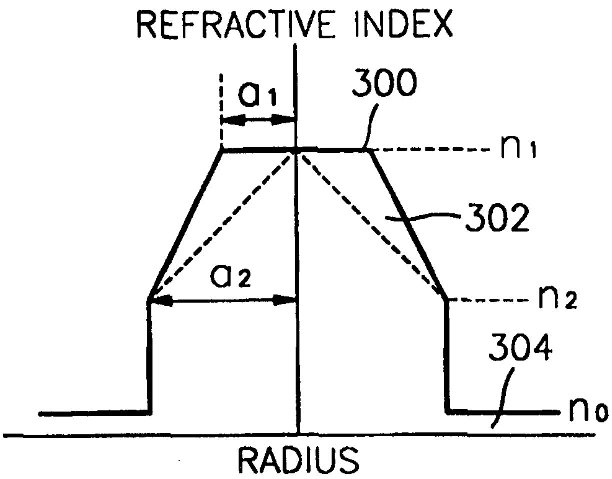
(54) Title: SINGLE MODE OPTICAL FIBER

(57) Abstract

A single mode optical fiber including a first core (300) having a constant refractive index (n1) within a predetermined radius (a1) from the center of an optical fiber, a second core (302) which covers the first core (300) and has a refractive index (n2) which decreases form the refractive index (u1) of the first core (300) with an increase in its radius, and a cladding (304) which covers the second core (302) and has a refractive index (u0) smaller than the minimum refractive index of the second core (302). Accordingly, the core structure of an optical fiber is controlled, and the optical fiber has a refractive index distribution being a complex of a staircase type having low dispersion and a triangular type having low loss, thus manufacturing an optical fiber having low dispersion and low loss.



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SINGLE MODE OPTICAL FIBER

Technical Field

The present invention relates to a single mode optical fiber, and more particularly, to a single mode optical fiber whose refractive index varies with the radius of a core.

Background Art

In general, an optical fiber for long-distance, superhigh-speed, and wide-band communications must have the characteristics of low loss, low dispersion, and low dispersion slope at wavelengths in use. An optical fiber having such characteristics is usually a dispersion shifted fiber or a non-zero dispersion shifted fiber. The distribution forms of the refractive indices of these fibers are changed into various structures to satisfy the aforementioned optical characteristics.

Such a change in the refractive index can be obtained by providing an annular region to a core whose refractive index varies in the shape of a triangle or allowing the core to have a double core structure corresponding to a convex type refractive index.

FIG. 1 shows relative refractive index differences according to the radius of a conventional core which are disclosed in U.S. Patent No. 5,553,185. Here, when n_{co} is a maximum refractive index of a core, and n_{cl} the refractive index of a cladding, the relative refractive index difference is expressed as $(n_{co}^2 - n_{cl}^2)/2n_{co}^2$. In this method, the difference in refractive index between the cladding and the core is made larger by depressing the refractive index of an annular region adjacent to the core, thereby obtaining a low dispersion slope.

In order to widen the difference in refractive index between the core and the cladding, the refractive index of the core is increased, or that of the cladding is depressed. However, in the first method, optical loss is increased by a dopant which is used to increase the refractive index, making it impossible to have a refractive index over a predetermined level. In the second method, loss is suddenly increased in a long-wavelength region by a depressed region. In order to solve this problem, the ratio of the radius of a cladding to that of a core must be large. FIG. 2 shows leakage loss depending on each wavelength of an optical fiber when the ratios between the radius of a cladding to that of a core are 6 and 7, which is disclosed in U.S. Patent No. 4,447,127. The solid line represents the case when a cladding-to-core diameter ratio is 6, and the dotted line represents the case when the cladding-to-core diameter ratio is 7. Here, a and a′ each have a relative refractive index difference of 0, indicating that the refractive index of a cladding is the same as that of a core. b and b′ each have a relative refractive index difference of 0.2, c and c′ each have a relative refractive index difference of 0.23, d and d′ each have a relative refractive index difference of 0.25, and e and e′ each have a relative refractive index difference of 0.27.

However, when modified chemical vapor deposition (MCVD) is applied to the optical fiber manufacturing method as described above, this conventional method still has problems in that it is difficult to manufacture an optical fiber preform having a large aperture, and it takes much time to manufacture the optical fiber.

Disclosure of the Invention

To solve the above problems, it is an object of the present invention to provide a single-mode optical fiber whose refractive index varies to obtain low dispersion and low dispersion slope.

Accordingly, to achieve the above objective, there is provided a single mode optical fiber comprising: a first core having a constant refractive index within a predetermined radius from the center of an optical fiber; a second core which covers the first core and has a refractive index which decreases from the refractive index of the first core with an increase in its radius; and a cladding which covers the second core and has a refractive index smaller than the minimum refractive index of the second core.

Brief Description of the Drawings

FIG. 1 is a graph showing a variation in the refractive index having a low dispersion slope according to the prior art;

FIG. 2 is a graph showing leakage loss with respect to each wavelength of an optical fiber when the ratios of a cladding radius to a core radius are 6 and 7;

FIG. 3 is a cross-sectional view of a single mode optical fiber according to an embodiment of the present invention;

FIG. 4 shows the distribution of the refractive index of the optical fiber shown in FIG. 3;

FIGS. 5A and 5B show the distribution of the refractive index of an optical fiber according to another embodiment of the present invention;

FIG. 6 shows the distribution of the refractive index of an optical fiber according to still another embodiment of the present invention;

FIG. 7 is a graph showing a variation in dispersion slope with respect to a variation in a_1/a_2 of FIG. 4;

FIG. 8 shows a dispersion slope obtained by varying a_1 with n_1, n_2, and a_2 of FIG. 4 fixed;

FIG. 9 shows a dispersion slope obtained by varying a_2 when a_1/a_2 of FIG. 4 is constant; and

FIG. 10 shows loss in a wavelength of 1.55μm depending on a_1/a_2 of FIG. 4.

Best mode for carrying out the Invention

Referring to FIG. 3, an optical fiber includes first and second cores 300 and 302, and a cladding 304. The distribution of the first and second cores 300 and 302 and the cladding 304 is shown in FIG. 4. That is, the refractive index of the first core 300 having a radius of a_1 from the center is constant as n_1. The refractive index of the second core 302 having a radius a_2 and covering the first core 300 linearly decreases from the refractive index n_1 of the first core to n_2. The refractive index of the cladding 304 is n_0 which is smaller than n_2. This distribution of refractive indices is a complex of a stepped refractive index distribution having low dispersion and a triangular refractive index distribution having low loss.

FIGS. 5A and 5B show the distributions of the refractive indices of optical fibers according to another embodiment of the present invention. The optical fiber of FIG. 5A further includes a third core in addition to the first and second core, and the optical fiber of FIG. 5B further includes a fourth core outside the third core of FIG. 5A. Here, the refractive index n_3 of the third core is smaller than a minimum refractive index n_2 of the second core, and the refractive index n_4 of the fourth core is smaller than the refractive index n_3 of the third core. Here, n_3 and n_4 are larger than n_0.

FIG. 6 shows the distribution of the refractive index of an optical fiber according to still another embodiment of the present invention. The optical fiber of FIG. 6 further comprises third and fourth cores in addition to the first and second cores of FIG. 4. Here, the refractive index of the third core is n_2 which is equal to the minimum refractive index of the second core, and the refractive index of the fourth core is n_3 which is smaller than the refractive index n_2 of the third core and larger than the refractive index n_0 of a cladding.

FIGS. 7 through 10 show the correlation between the refractive index distribution and the structure for satisfying the optical characteristics of low dispersion, low dispersion slope, and low loss of the optical fiber having the above-described complex distribution of refractive indices.

FIG. 7 is a graph showing a variation in dispersion slope with respect to a variation in a_1/a_2 of FIG. 4. Here, N is the result of (relative refractive index difference of first core − relative refractive index difference of second core)/(relative refractive index difference of first core). The refractive index profile of cores approaches the shape of a triangle as N increases, or approaches the shape of a step as N decreases. According to what is shown in FIG. 7, when the refractive index n_2 is small, i.e., when N is large, if a_1/a_2 is small, i.e., the refractive index profile is triangular, the dispersion slope has a high value. On the other hand, when a_1/a_2 increases and reaches a predetermined value, the dispersion slope has the lowest value.

Also, when the refractive index n_2 increases and becomes stepped, i.e., when N becomes smaller, the dispersion slope varies in a narrow range even when a_1/a_2 varies, and the dispersion slope becomes almost constant regardless of a_1/a_2. Thus, a small dispersion slope can be obtained in the N range of 0.2 to 0.85 and in the a_1/a_2 range of 0.7 or less. Also, an optimal small dispersion slope can be obtained by properly combining n_1, n_2, and a_1/a_2 with one another.

FIGS. 8 through 10 show dispersion slopes obtained from embodiments of an optical fiber manufactured based on values given in FIG. 7.

FIG. 8 shows a dispersion slope obtained by varying a_1 with n_1, n_2, and a_2 of FIG. 4 fixed. FIG. 9 shows a dispersion slope obtained by varying a_2 when a_1/a_2 of FIG. 4 is constant.

FIG. 10 shows loss in a wavelength of 1.55μm depending on a_1/a_2 of FIG. 4. Referring to FIG. 10, as a_1/a_2 becomes smaller, i.e., the refractive index profile becomes triangular shaped, the loss becomes small. As a_1/a_2 becomes larger, i.e., the refractive index profile becomes stepped, the loss becomes large. That is, the triangular-shaped refractive index distribution is preferable to obtain the optical characteristics of low loss. When a_1/a_2 is between 0 and 0.7, a loss of about 0.22dB/km can be obtained.

Consequently, it is preferable that an optical fiber has the refractive index distribution being a complex of the staircase type and the triangular type to obtain low dispersion and low loss.

<u>Industrial Applicability</u>

According to the present invention, the core structure of an optical fiber is controlled, and the optical fiber has the refractive index distribution being a complex of a staircase type having low dispersion and a triangle type having low loss, thus manufacturing an optical fiber having low dispersion and low loss. Also, the triangular refractive index of a large-radius core sensitive to an increase in loss according to micro or macro bending due to center dip is combined with the stepped refractive index of a small-radius core having small bending loss. Thus, bending loss can be reduced.

What is claimed is:

1. A single mode optical fiber comprising:

a first core having a constant refractive index within a predetermined radius from the center of an optical fiber;

a second core which covers the first core and has a refractive index which decreases from the refractive index of the first core with an increase in its radius; and

a cladding which covers the second core and has a refractive index smaller than the minimum refractive index of the second core.

2. The single mode optical fiber as claimed in claim 1, wherein the ratio of the first core radius to the second core radius is between 0 and 0.7.

3. The single mode optical fiber as claimed in claim 1, wherein the result of the equation (relative refractive index difference of first core − relative refractive index difference of second core)/(relative refractive index of first core) is between 0.2 and 0.85.

4. The single mode optical fiber as claimed in claim 1, further comprising a plurality of cores which cover the second core and have a refractive index which decreases in a staircase shape with an increase in radius and is smaller than the minimum refractive index of the second core and greater than the refractive index of the cladding.

5. The single mode optical fiber as claimed in claim 4, wherein a core directly covering the second core, among the plurality of cores, has the same refractive index as the minimum refractive index of the second core.

FIG. 1

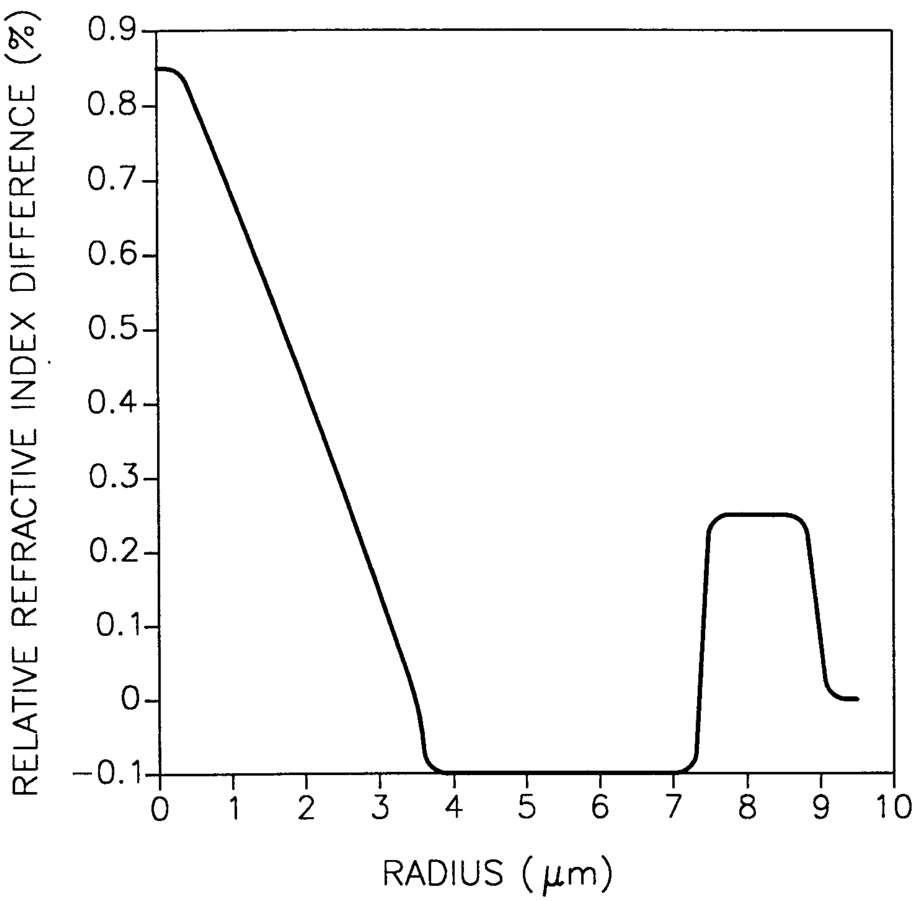

RELATIVE REFRACTIVE INDEX DIFFERENCE (%)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
0
1
2
3
4
5
6
7
8
9
10
RADIUS (μm)

FIG. 2

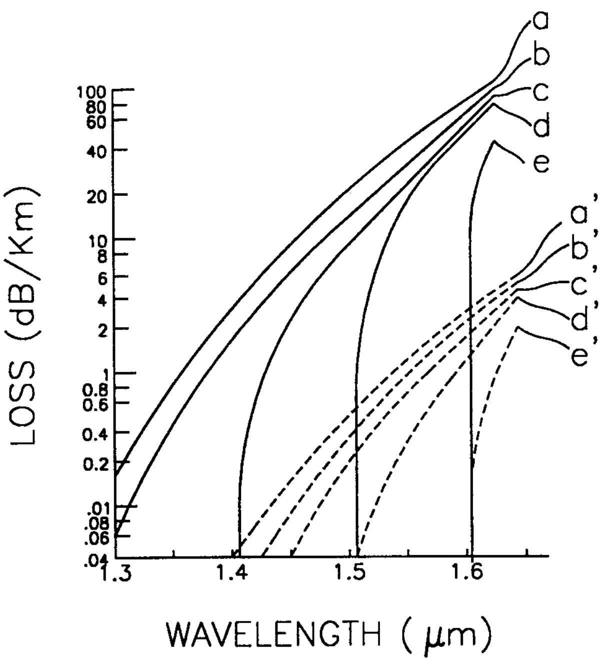

a
b
c
d
e
a'
b'
c'
d'
e'
LOSS (dB/Km)
100
80
60
40
20
10
8
6
4
2
1
0.8
0.6
0.4
0.2
.01
.08
.06
.04
1.3
1.4
1.5
1.6
WAVELENGTH (μm)

FIG. 3

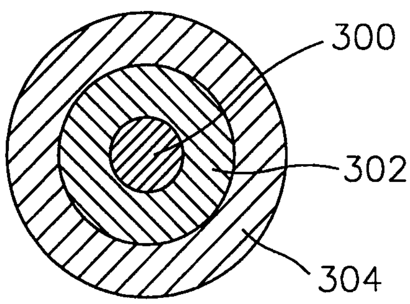

300
302
304

FIG. 4

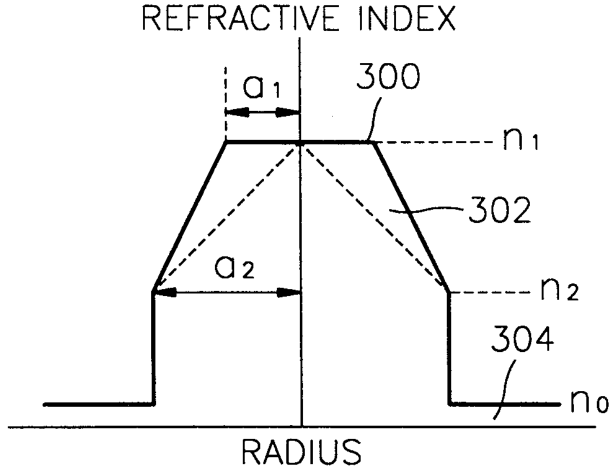


FIG. 5A

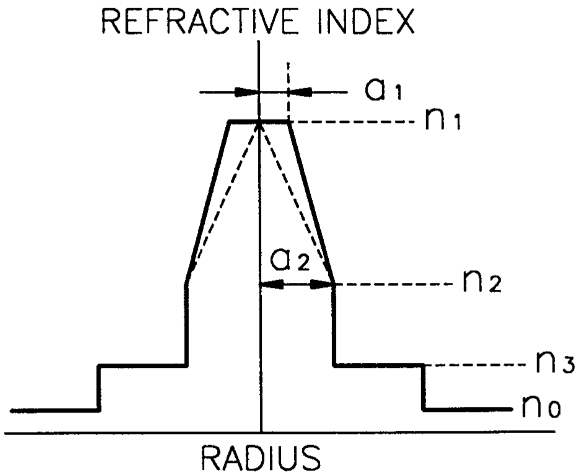


FIG. 5B

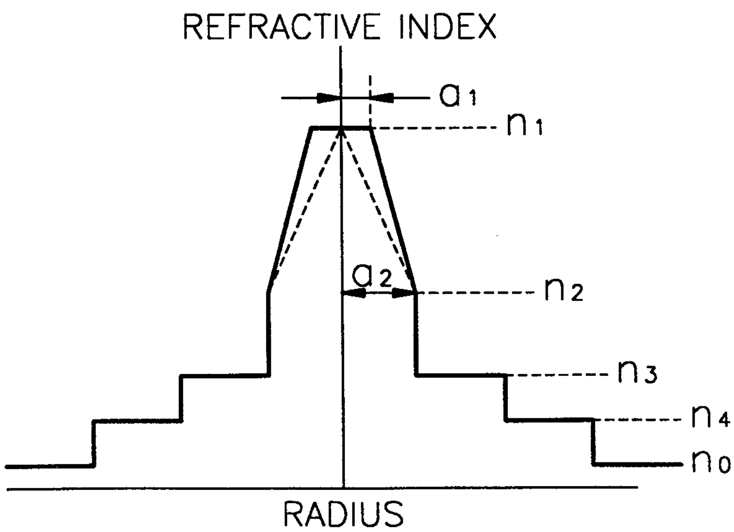


FIG. 6

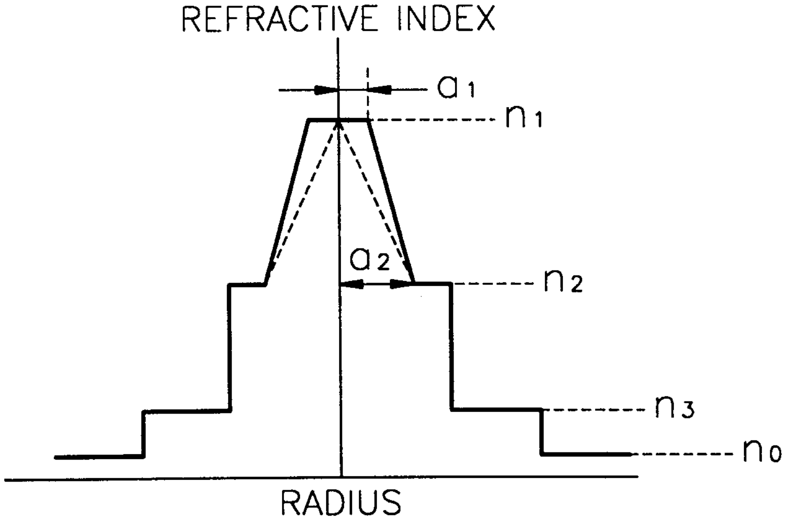

REFRACTIVE INDEX
a1
n1
a2
n2
n3
n0
RADIUS

FIG. 7

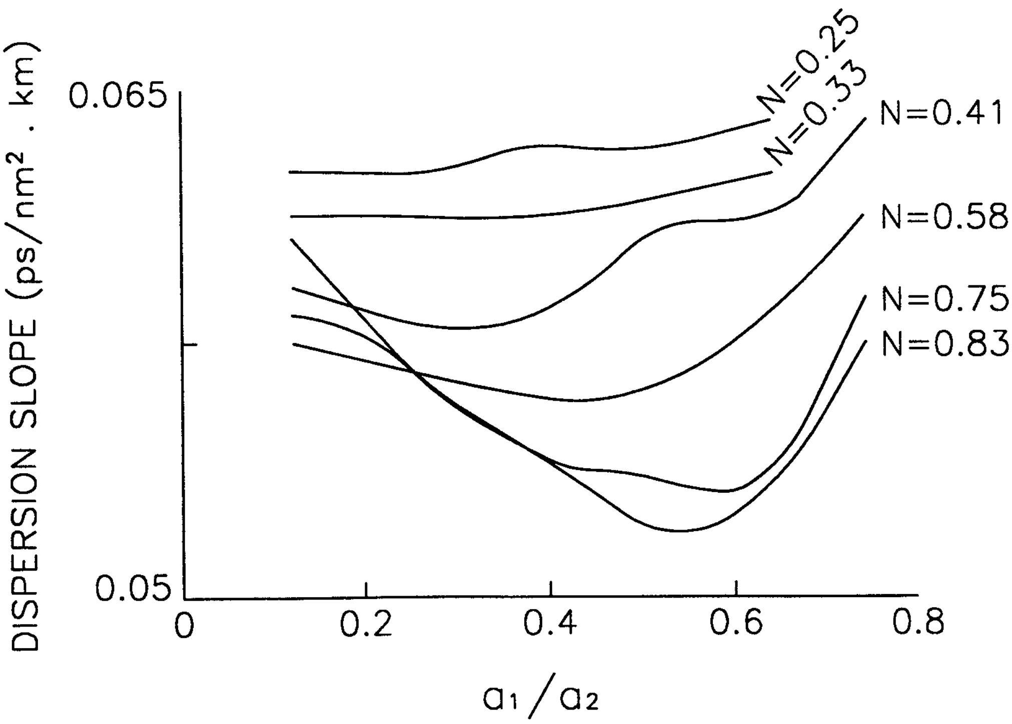

DISPERSION SLOPE (ps/nm² . km)
0.065
0.05
0
0.2
0.4
0.6
0.8
a1/a2
N=0.25
N=0.33
N=0.41
N=0.58
N=0.75
N=0.83

FIG. 8

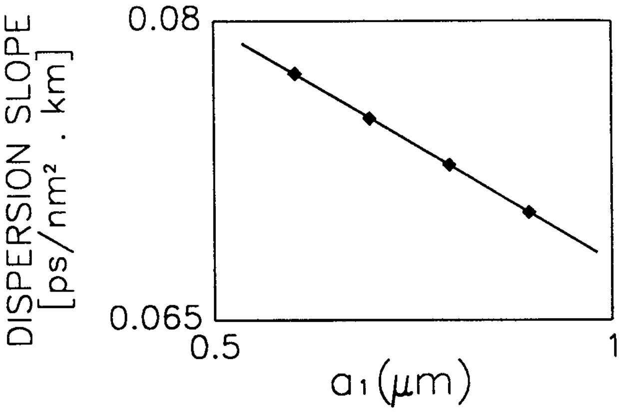


FIG. 9

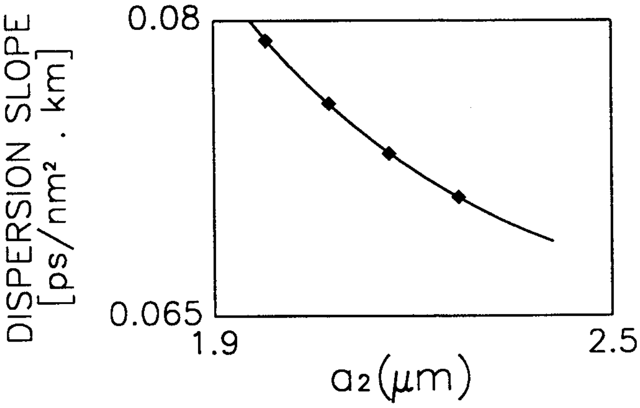
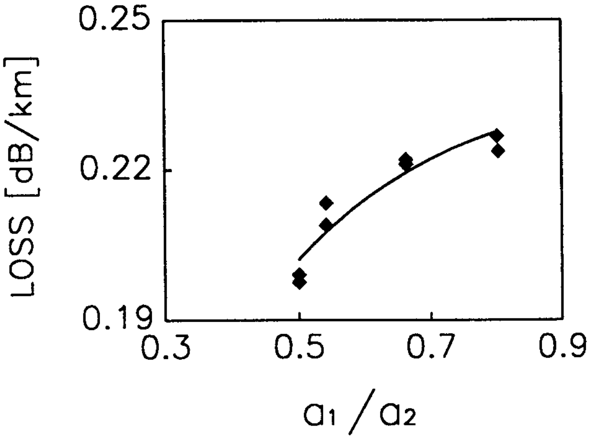


FIG. 10



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR 98/00481

A. CLASSIFICATION OF SUBJECT MATTER

IPC[6]: G 02 B 6/22, 6/18

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Minimum documentation searched (classification system followed by classification symbols)

IPC[6]: G 02 B 6/16, 6/18, 6/22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 755 022 A (OHASHI et al.) 05 July 1988 (05.07.88), column 3, lines 3-59; column 4, line 53 - column 6, line 55; column 8, lines 23-62.	1,4
A	EP 0 689 068 A1 (SUMITOMO) 27 December 1995 (27.12.95), column 3, line 40 - column 4, line 18; column 5, line 9 - column 8, line 58; column 10, line 7 - column 12, line 46.	1,2
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A	US 4 852 968 A (REED) 01 August 1989 (01.08.89), column 5, line 51 - column 7, line 51; column 8, line 56 - column 9, line 53.	1

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
16 March 1999 (16.03.99)	29 March 1999 (29.03.99)

Name and mailing adress of the ISA/AT	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR 98/00481

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		EP B1 260795	03-03-93
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