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(71) Applicant(s)
Corning Incorporated

(72) Inventor(s)
William R. Christoff; Paul D. Doud; John W. Gilliland

(74) Agent/Attorney
PHILLIPS ORMONDE and FITZPATRICK,367 Collins Street,MELBOURNE VIC 3000

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(71) Applicant *(for all designated States except US)*: CORNING INCORPORATED [US/US]; 1 Riverfront Plaza, Corning, NY 14831 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: CHRISTOFF, William, R. [US/US]; 212 Connelly Avenue, Elmira, NY 14903 (US). DOUD, Paul, D. [US/US]; Rural Delivery #1, Box 112, Lawrenceville, PA 16969 (US). GILLILAND, John, W. [US/US]; 486 Pine Circle Extension, Horseheads, NY 14845 (US).

(74) Agent: HERZFELD, Alexander, R.; Patent Dept., SP FR 02-12, Corning Incorporated, Corning, NY 14831 (US).

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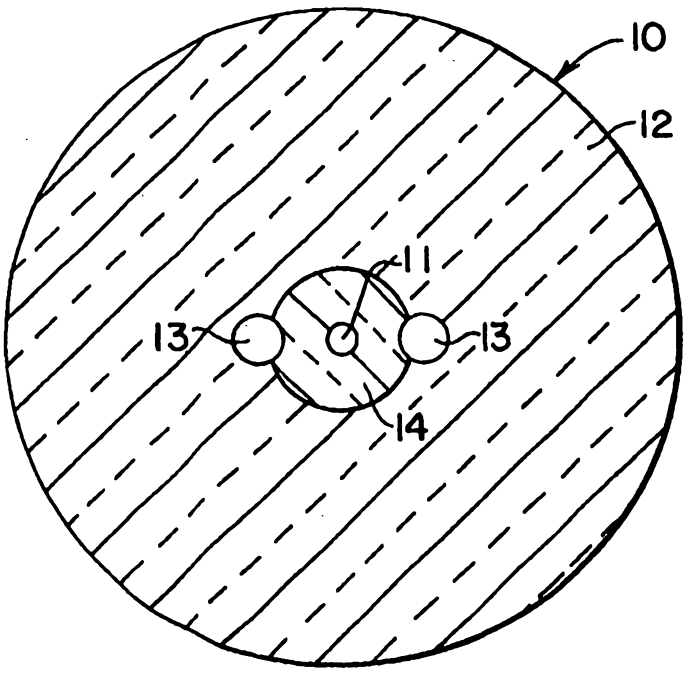
(54) Title: METHOD OF MAKING POLARIZATION RETAINING FIBER

(57) Abstract

A glass preform (10) is drawn into a fiber. Holes (13), running the length of the preform (10), collapse during the drawing, this causes the core (11) to have an elliptical cross section.



METHOD OF MAKING POLARIZATION RETAINING FIBER

Background of the Invention

This invention relates to the fabrication of polarization retaining single-mode (PRSM) optical fibers and more particularly to the fabrication of preforms from which fibers having elliptically-shaped cores can be drawn.

The discussion of the background to the invention herein is included to explain the context of the invention. This is not to be taken as an admission that any of the material referred to was published, known or part of the common general knowledge in Australia as at the priority date of any of the claims.

In many applications of single-mode optical fibers, eg. gyroscopes, sensors and the like, it is important that the propagating optical signal retain the polarization characteristics of the input light in the presence of external depolarizing perturbations. This requires the waveguide to have an azimuthal asymmetry of the refractive index profile.

One of the first techniques employed for improving the polarization performance of single-mode fibers was to distort the symmetry of the core. A method of making this kind of PRSM fiber is disclosed in U.S. patent 5,149,349, which is incorporated herein by reference. A PRSM optical fiber is formed by drawing a fiber from a draw blank having a glass core surrounded by cladding glass containing apertures that are diametrically opposed with respect to the core. The fiber is drawn at such a rate and temperature that the apertures close and the core becomes elliptically-shaped. In a preferred method

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of making the draw blank, longitudinal grooves are formed on diametrically opposed sides of a cylindrically-shaped core preform in which the glass core is surrounded by the cladding glass. Glass particles are deposited on the outer surface of a glass tube, and the core preform is inserted into the tube. The resultant assembly is heated to sinter or consolidate the particles, whereby the tube is collapsed and fused to the grooved core preform to form an assembly having longitudinal apertures on opposite sides of the core.

When the aperture-containing blank is drawn to form the PRSM fiber, the apertures close due to surface tension and the flow of molten glass into the apertures. This flow causes the round core of the blank to become elongated in the direction of the apertures. The core aspect ratio of the elliptically-shaped core is primarily determined by the spacing between the core and the apertures. As the spacing between the core and the apertures in the draw blank decreases, the core of the resultant fiber becomes more elongated in cross-section, but the core cross-section tends to have long thin ends. If the spacing is too small, the core may break through the cladding region between core and apertures, resulting in the formation of a core the cross-section of which is flattened with undesirable flared ends. By "ends" is meant the tips of the elongated core along the major axis of the core as observed in a plane perpendicular to the fiber longitudinal axis.

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Summary of the Invention

An object of the present invention is to provide an optical fibre, and method for making same, which overcome, or at least alleviate, one or more disadvantages of the prior art.

According to the present invention there is provided a method of making an optical fiber including:

forming an optical fiber draw blank having a glass core of refractive index n_1 surrounded by a cladding glass layer of refractive index n_2, said blank having apertures diametrically opposed with respect to said core and spaced from said core, said apertures extending longitudinally through said blank and parallel to said core, said core glass having a viscosity and said cladding glass having a viscosity higher than the viscosity of said core glass, and said draw blank having low viscosity glass layer between said core and said apertures, said low viscosity glass having a viscosity not greater than the viscosity of said core glass and said low viscosity glass having a refractive index n_3, and

drawing an optical fiber from said draw blank at such a rate that said core glass and said low viscosity glass flow toward said apertures and said apertures close to form a core having an elliptical cross-section in which said low viscosity glass layer has a major axis radius b_2, a minor axis radius a_2, and an aspect ratio b_2/a_2 and the core glass has a major axis radius b_1, a minor axis radius a_1 and an aspect ratio b_1/a_1, wherein the aspect ratio b_1/a_1 is greater than the aspect ratio b_2/a_2.

The present invention also provides a method of making an optical fiber including the steps of:

forming a cylindrical assembly including

a central core glass having a viscosity,

a first layer of cladding glass surrounding said core, said first layer of cladding glass having a viscosity not greater than the viscosity of the core glass,

a second layer of cladding glass surrounding said first layer, said second layer of cladding glass having a viscosity being greater than that of said first cladding glass layer,

a pair of longitudinal grooves extending along diametrically opposed sides of said second layer,

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a glass tube surrounding said second layer, and

a layer of glass particles surrounding said tube;

heating said assembly to consolidate said particles, thereby exerting on said tube a radially inwardly directed force that causes said heated tube to shrink onto and fuse to said second layer, thereby forming a draw blank having longitudinal apertures that are parallel to said core; and

drawing the draw blank to form an optical fiber having a solid cross-section.

The present invention further provides an optical fiber including:

a core having a viscosity, refractive index n_1 and an elliptically-shaped cross-section having a major axis radius b_1, a minor axis radius a_1 and an aspect ratio ρ_1, wherein ρ_1 equals b_1/a_1;

a low viscosity glass layer having a viscosity not greater than the viscosity of said core, an elliptically-shaped cross-section surrounding said core, said low viscosity layer having a major axis radius b_2 and a minor axis radius a_2, and an aspect ratio ρ_2,

wherein ρ_2 equals b_2/a_2, wherein the aspect ratio ρ_1 is greater than the aspect ratio ρ_2; and

a cladding glass layer having a viscosity and a refractive index n_2 surrounding said low viscosity layer, the viscosity of said low viscosity layer being lower than the viscosity of said cladding glass region.

An advantage of the invention is the provision of a method of making PRSM optical fibers which can overcome the disadvantages of the prior art. A further advantage is the provision of a PRSM fiber producing method which is relatively simple to practice. Yet another advantage is the provision of a method for making elliptical core PRSM fibers having improved core cross-sectional shape.

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In accordance with the present method, a polarization maintaining single-mode optical fiber is formed by initially forming an optical fiber draw blank having a glass core region of refractive index n_1 surrounded by a cladding glass region of refractive index n_2. The cladding region includes apertures that are diametrically opposed with respect to the core region and that are spaced from the core region. The draw blank has a region of low viscosity glass between the core region and the apertures, the low viscosity glass region having a refractive index n_3 and a viscosity lower than that of the cladding glass region. An optical fiber is drawn from the draw blank at such a rate that the apertures close and the core becomes elliptical in cross-section.

Another aspect of the invention pertains to an optical fiber having an elliptically-shaped core of aspect ratio ρ_1, where ρ_1 equals b_1/a_1, b_1 being the major axis radius and a_1 being the minor axis radius of the core. Surrounding the core is a low viscosity glass region of elliptically-shaped cross-sectional configuration having an aspect ratio ρ_2 that is equal to b_2/a_2, b_2 being the major axis radius and a_2 being the minor axis radius of the low viscosity region. The aspect ratio ρ_2 of the low viscosity region is less than ρ_1. A cladding glass region surrounds the low viscosity region. The viscosity of low viscosity region is lower than that of the cladding glass region.

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Brief Description of the Drawings

Fig. 1 is a cross-sectional view of a preform from which an elliptical core PRSM fiber can be drawn.

Fig. 2 is a schematic diagram illustrating the drawing of a PRSM fiber from the preform of Fig. 1.

Fig. 3 is a cross-sectional view of a PRSM fiber produced by the present method.

Figs. 4 and 5 are diagrams showing the major axis radius and the minor axis radius of the elliptical core and its surrounding low viscosity region, respectively.

Fig. 6 illustrates the application of a coating of glass particles to a mandrel.

Fig. 7 is a graph showing the core refracative index profile.

Fig. 8 is a schematic diagram illustrating the drawing of a rod from a consolidated core glass tube.

Fig. 9 is a schematic diagram illustrating the various dimensions of a grooved -blank.

Fig. 10 is a cross-sectional view of an assembly wherein a grooved core cane is disposed in a soot-coated cladding glass tube.

Description of the Preferred Embodiment

It is to be noted that the drawings are illustrative and symbolic of the invention, and there is no intention to indicate scale or relative proportions of the elements shown therein.

Draw blank 10 of Fig. 1, from which a PRSM fiber can be drawn, has core and cladding regions 11 and 12, respectively. The core and cladding regions may be formed of conventional materials employed in the formation of optical waveguides. The salient characteristics of these materials are that the refractive index n_1 of the core material must be greater than the refractive index n_2 of the cladding material and that both materials must exhibit low losses at the

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wavelength at which the waveguide is intended to be operated. By way of example only, core region 11 may consist of pure silica or silica containing one or more dopants which increase the refractive index thereof. Region 12 may consist of pure silica, silica containing a lesser amount of refractive index increasing dopant than core region 11, or silica containing one or more dopants, at least one of which is a refractive index lowering dopant such as B_2O_3 or fluorine. Although silica is a preferred base glass because it exhibits low loss at useful wavelengths, base glass materials other than silica may be employed.

In accordance with the invention a region 14 of low viscosity relative to that of cladding 12 is disposed between core 11 and apertures 13. The viscosity of low viscosity region 14 is preferably close to or slightly lower than that of core 11. This can be accomplished, for example, by forming region 14 of silica doped with appropriate amounts of one or more viscosity lowering dopants such as B_2O_3, fluorine, P_2O_5, GeO_2 and the like.

The refractive index n_3 of region 14 is typically equal to or less than n_2. The refractive index of region 14 can be made to be equal to that of cladding 12 by, for example, forming region 14 of silica doped with appropriate amounts of one or more refractive index decreasing dopants such as B_2O_3 and fluorine and one or more refractive index increasing dopants such as P_2O_5, GeO_2 and the like.

The refractive index of region 14 can be made to be lower than that of cladding 12 by, for example, employing a silica cladding 12 and forming region 14 of silica doped with B_2O_3 or fluorine or by doping silica with a refractive index increasing dopant such as P_2O_5, GeO_2 and the like as well as a sufficient amount of B_2O_3 and/or fluorine to reduce the refractive index of the composite material to a value less than that of silica. Examples

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of elliptical core fibers having this type of refractive index profile are disclosed in U.S. patent 5,482,525.

Apertures 13 extend longitudinally through blank 10 parallel to core region 11. While apertures 13 are illustrated as being D-shaped in cross-section, the cross-sectional configuration could be crescent shaped, circular, or the like. Any shape that results in the desired cross-sectional elongation of the core during fiber draw is considered to be suitable.

Referring to Fig. 2, draw blank 10 is placed in a conventional draw furnace where tractors 17 pull fiber 15 from the bottom portion of blank 10 which is heated to draw temperature by heating elements 16. The tendency for apertures 13 to close is a function of draw rate and glass viscosity. The viscosity of the draw blank root from which the fiber is drawn depends upon furnace temperature and glass composition. If the viscosity of the heated portion of the blank is sufficiently low and the draw rate is sufficiently low, apertures 13 will naturally close during the draw process. Since the apertures more readily close if they are evacuated, draw speed can be increased by affixing a vacuum attachment 18 to the upper end of the blank.

As apertures 13 close, they are replaced by the surrounding glass. When glass at smaller radii than the apertures flows radially outwardly into the apertures, core region 11 becomes elongated in cross-section. The resultant PRSM fiber 15, the cross-section of which includes cladding 22, oblong core 21 and low viscosity region 23, is shown in Fig. 3. The ellipticity or aspect ratio of the elliptical core is the ratio of its major dimension to its minor dimension in a plane perpendicular to the fiber axis (see Fig. 4). Cores of varying degrees of ellipticity can be made depending, inter alia, on the size of apertures 13 and the spacing between those apertures and the core.

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In accordance with the method of this invention, the shape of elliptical core 21 is also a function of the viscosity of region 23. When the glass of draw blank 10 starts to flow, the flow of core glass toward the apertures will be less restricted by the intervening glass between core region 11 and apertures 13 than was the case when that intervening glass was silica. Thus, core region 11 can flow farther toward the apertures before they close. Since the outer cladding 12 has a relatively high viscosity, e.g. that of pure silica, the flow of that glass into the apertures is very small; thus the core glass and the low viscosity region 14 can flow more.

Consequently, the cross-sectional shape of core 21 is more bar-shaped (Fig. 4) as opposed to the usual shape with relatively pointed ends and a bulging middle. In the fiber resulting from the present process, the low viscosity region 14 assumes a cross-sectional shape 23 (Fig. 3) having ends that are more pointed than the ends of core 21 and a middle section that bulges more than the middle of the core. A comparison of Figs. 4 and 5, which are relatively accurate representations of the cross-sections of core 21 and region 23, reveals that the aspect ratio b_1/a_1 of elliptical core 21 is greater than the aspect ratio b_2/a_2 of low viscosity region 23.

Apertures 13 must be parallel to the core and uniform in cross-sectional area throughout the longitudinal axis of draw blank 10 if fiber 15 is to have uniform properties throughout its length. Any conventional technique that meets these requirements can be used for forming the apertures. UK Patent Application GB 2,192,289 teaches two techniques for forming longitudinal holes in a preform on opposite sides of the core:

(1) The holes can be drilled with a diamond drill.

(2) A core preform having opposed flattened sides is placed in the center of a glass tube, and two glass rods

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are placed on opposite sides of of the core preform, leaving two opposed unfilled regions between the core preform and the tube. The resultant assembly is drawn to reduce the diameter thereof and to cause the glass members to fuse together to form an article that has a solid cross-section except for two opposed axe-head shaped holes that correspond to the unfilled regions.

An elliptical core PRSM fiber was made in accordance with the method illustrated in Figs. 6-10. A cylindrical mandrel 25 (Fig. 6) was rotated and translated with respect to a flame hydrolysis burner 26 such that a stream 27 of glass particles or soot formed a porous coating 28 on the mandrel. The composition of the soot stream 27 was initially SiO_2 doped with 37 wt. % GeO_2, the concentration of GeO_2 decreasing with increasing radius as shown in Fig. 7. The coated mandrel was removed from the lathe, and the mandrel was removed from the porous preform, thereby leaving a longitudinal aperture in the porous preform. The porous preform was then dried and consolidated in accordance with the teachings of U.S. Patent No. 4,125,388. The resultant consolidated preform or core blank 30 was inserted into the draw apparatus of Fig. 8 where its tip was heated to drawing temperature by heating means 32, and vacuum connection 34 was affixed to its upper end. After the end of the preform was stretched so that its aperture 35 was either very narrow or completely closed, the aperture was evacuated through fixture 34. As the lower end of the preform was pulled downwardly, and its diameter decreased, the evacuated aperture 35 collapsed. The radius r of the resultant α-cane 31 was 6 mm. Its germania concentration profile is shown in Fig. 7.

A plurality of 90 cm sections were severed from the α-cane, and one of the sections was inserted into a lathe and coated with SiO_2 soot as described in conjunction with Fig. 6. The resultant composite preform was consolidated at 1450° C while a mixture of 94.3 volume percent helium,

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1.0 volume percent chlorine and 4.7 volume percent SiF_4 flowed upwardly through the muffle. In the resultant consolidated preform the diameter of the fluorine-doped silica layer was 13.4 mm, and the core diameter was about 6.2 mm.

The consolidated preform was inserted into a lathe and coated with SiO_2 soot which was consolidated in an atmosphere of chlorine and helium to form a pure silica layer over the fluorine-doped silica layer.

Longitudinally-extending grooves were ground through the outer silica cladding layer on opposite sides of the core such that they extended into the fluorine-doped low viscosity region. After the grinding operation, the grooved β-blank (Fig. 9) was cleaned and rinsed.

The grooved β-blank was then inserted into a conventional draw furnace of the type illustrated in Fig. 8 where it was stretched to reduce its diameter to about 7.3 mm. The resultant β-cane 40 (Fig. 10) includes core region 41, silica cladding layer 42 and low viscosity region 43. Slots 44 extend longitudinally along β-cane 40 on opposite sides of core region 41.

Silica cladding tube 47 had inside and outside diameters of 7.5 mm and 9.5 mm, respectively. An end of tube 47 was tapered inwardly and fused to a handle suitable for supporting assembly 52 in a consolidation furnace. Grooved β-cane 40 was inserted into the end of tube 47 opposite the tapered end until it contacted the tapered end. The end of tube 47 into which preform 40 was inserted was tapered inwardly and fused to a glass rod. Tube 47 was then mounted in a lathe where it was rotated and translated with respect to a soot deposition burner where particles of silica soot were deposited thereon to build up porous coating 48, thereby forming assembly 52.

Assembly 52 was lowered into a consolidation furnace where it was subjected to a drying gas mixture of chlorine and helium and then sintered to form optical

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fiber draw blank 10 of Fig. 1. As coating 48 consolidated, it exerted a force radially inwardly on tube 47, thereby forcing that tube inwardly against preform 40. The original cladding region 42 and tube 47 are completely fused together, and porous coating 48 has become completely sintered and fused to tube 47, these layers forming cladding 12.

The resultant draw blank was inserted into a draw furnace, where an optical fiber was then drawn from the preform.

A grooved β-blank made by the above-described process can be characterized by the dimensions C, D, E and R of Fig. 10. Five different grooved β-blanks, which were made by the above-described method, were employed to form draw blanks that were drawn into optical fibers 1 through 5, which are characterized in Table 1. In each of the grooved β-blanks the radius R of the core region was about 3.5 mm.

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Table 1

Fiber No.	Soot Weight	wt. % fluorine	Dimension E (mm)	Dimension C (mm)	Aspect Ratio
C1	N/A	None	1.73	N/A	5.3
C2	N/A	None	1.80	N/A	5.1
C3	N/A	None	1.98	N/A	5.8
1	160 g	1.6	1.53	11.99	6.2
2	160 g	1.6	1.53	11.99	6.3
3	126 g	1.0	1.25	10.42	7.6
4	66 g	1.0	0.70	6.14	8.3
5	62 g	1.0	1.40	6.40	6.0

The dimension D of Fig. 9 was not measured but is related to the "soot weight" listed in Table 1. The soot weight is the weight of the silica glass particles that are deposited to form low viscosity region 43. The coating made up of those particles is then doped with fluorine and consolidated. A greater soot weight will result in a greater thickness D.

The relatively high aspect ratio of fibers 3 and 4 indicates that a relatively small dimension E is preferred.

The three comparison fibers C1, C2 and C3 of Table 1 were made by a process similar to that by which fibers 1 through 5 were made, but no low viscosity, fluorine-doped silica region 43 was employed. That is, the entire cladding from the core to the outer surface of the fiber was formed of SiO_2. The aspect ratios of fibers C1, C2 and C3 are lower than the aspect ratios of fibers 1 through 5.

In the embodiment of Fig. 1 the low viscosity region 14 extends from the core 11 and into the apertures 13. It is thought that some improvement in aspect ratio would be achieved if region 14 did not quite extend to apertures 13, but the effect on improved aspect ratio

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would not be as great as the improved effect achieved by the embodiment of Fig. 1.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of making an optical fiber including:

forming an optical fiber draw blank having a glass core of refractive index n_1 surrounded by a cladding glass layer of refractive index n_2, said blank having apertures diametrically opposed with respect to said core and spaced from said core, said apertures extending longitudinally through said blank and parallel to said core, said core glass having a viscosity and said cladding glass having a viscosity higher than the viscosity of said core glass, and said draw blank having low viscosity glass layer between said core and said apertures, said low viscosity glass having a viscosity not greater than the viscosity of said core glass and said low viscosity glass having a refractive index n_3, and

drawing an optical fiber from said draw blank at such a rate that said core glass and said low viscosity glass flow toward said apertures and said apertures close to form a core having an elliptical cross-section in which said low viscosity glass layer has a major axis radius b_2, a minor axis radius a_2, and an aspect ratio b_2/a_2 and the core glass has a major axis radius b_1, a minor axis radius a_1 and an aspect ratio b_1/a_1, wherein the aspect ratio b_1/a_1 is greater than the aspect ratio b_2/a_2.

2. A method according to claim 1, wherein the step of forming said draw blank further includes:

grinding longitudinally extending grooves through said cladding glass layer, said grooves extending into the low viscosity glass layer;

inserting said draw blank into a glass tube to form an assembly; and fusing said tube to said cladding glass layer to provide an interface between said tube and said cladding layer and to provide said longitudinally extending apertures.

3. A method according to claim 1 or 2, wherein said low viscosity glass layer completely surrounds said glass core.

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4. A method according to any preceding claim, wherein said low viscosity glass layer is formed of SiO_2 containing dopants selected from the group consisting of B_2O_3, fluorine, P_2O_5 and GeO_2,

5. A method according to any preceding claim, wherein said cladding glass region consists of SiO_2.

6. A method of making an optical fiber including the steps of:

forming a cylindrical assembly including

a central core glass having a viscosity,

a first layer of cladding glass surrounding said core, said first layer of cladding glass having a viscosity not greater than the viscosity of the core glass,

a second layer of cladding glass surrounding said first layer, said second layer of cladding glass having a viscosity being greater than that of said first cladding glass layer,

a pair of longitudinal grooves extending along diametrically opposed sides of said second layer,

a glass tube surrounding said second layer, and

a layer of glass particles surrounding said tube;

heating said assembly to consolidate said particles, thereby exerting on said tube a radially inwardly directed force that causes said heated tube to shrink onto and fuse to said second layer, thereby forming a draw blank having longitudinal apertures that are parallel to said core; and

drawing the draw blank to form an optical fiber having a solid cross-section.

7. An optical fiber including:

a core having a viscosity, refractive index n_1 and an elliptically-shaped cross-section having a major axis radius b_1, a minor axis radius a_1 and an aspect ratio ρ_1, wherein ρ_1 equals b_1/a_1;

a low viscosity glass layer having a viscosity not greater than the viscosity of said core, an elliptically-shaped cross-section surrounding said core,

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said low viscosity layer having a major axis radius b_2 and a minor axis radius a_2, and an aspect ratio ρ_2,

wherein ρ_2 equals b_2/a_2, wherein the aspect ratio ρ_1 is greater than the aspect ratio ρ_2; and

a cladding glass layer having a viscosity and a refractive index n_2 surrounding said low viscosity layer, the viscosity of said low viscosity layer being lower than the viscosity of said cladding glass region.

8. An optical fiber according to claim 7, wherein said low viscosity layer is formed of SiO_2 containing dopants selected from the group consisting of B_2O_3, fluorine, P_2O_5 and GeO_2.

9. An optical fiber according to claim 7 or 8, wherein said cladding glass layer consists of pure SiO_2.

10. A method of making an optical fiber, substantially as herein described with reference to the accompanying drawings.

11. An optical fiber, substantially as herein described with reference to the accompanying drawings.

DATED: 24 November 2000

PHILLIPS ORMONDE & FITZPATRICK
Patent Attorneys for:
CORNING INCORPORATED

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FIG. 1

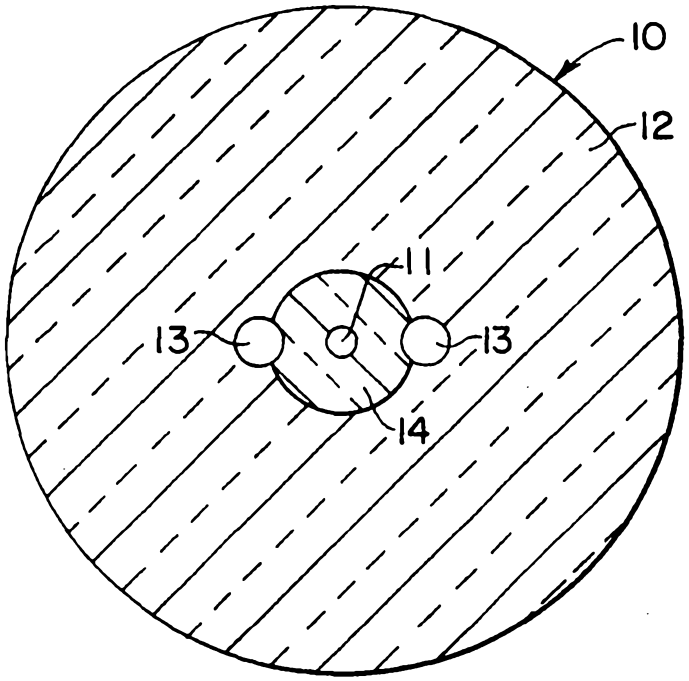

FIG. 2

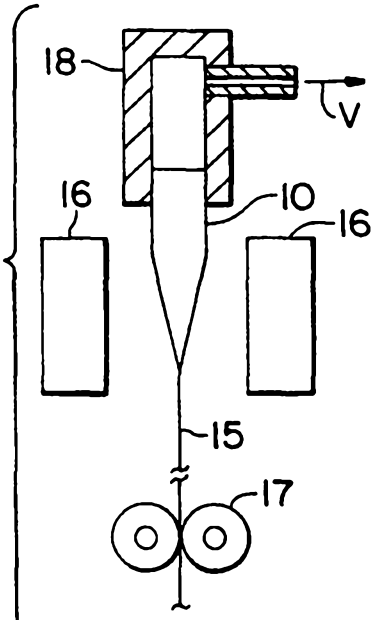

FIG. 3

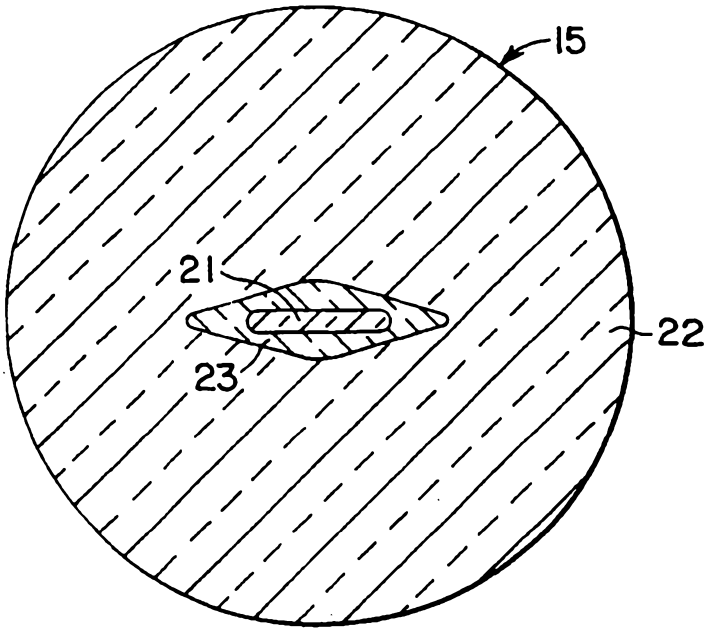

FIG. 4

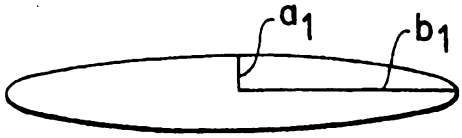

FIG. 5

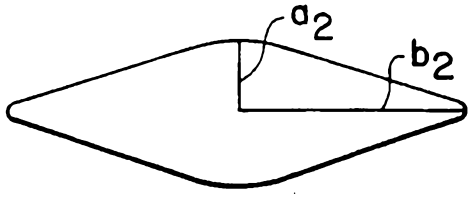

FIG. 6

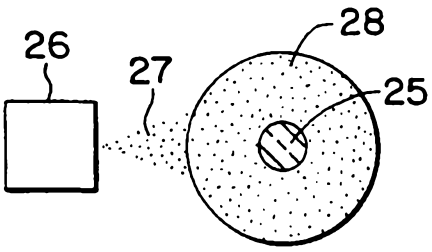

FIG. 7

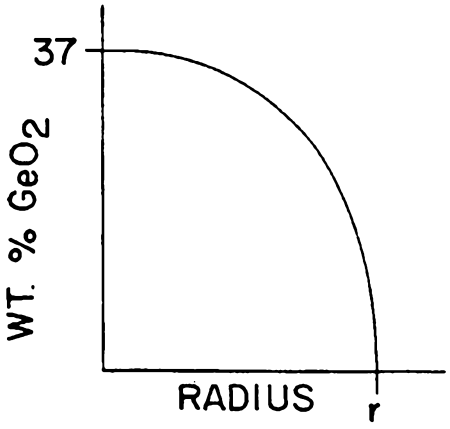

FIG. 8

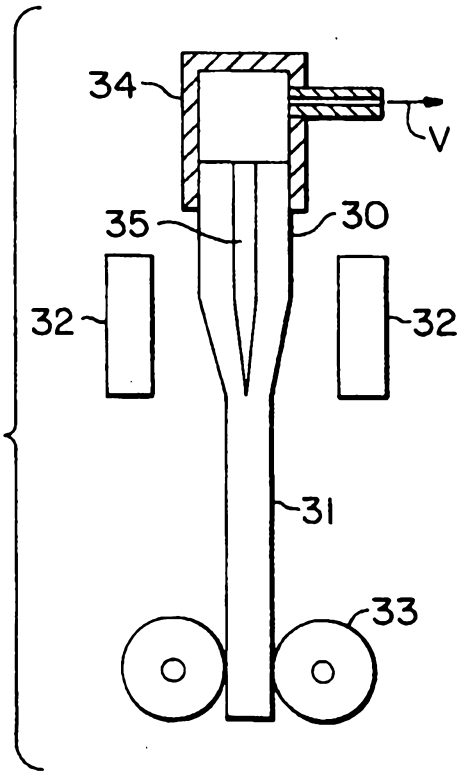

FIG. 10

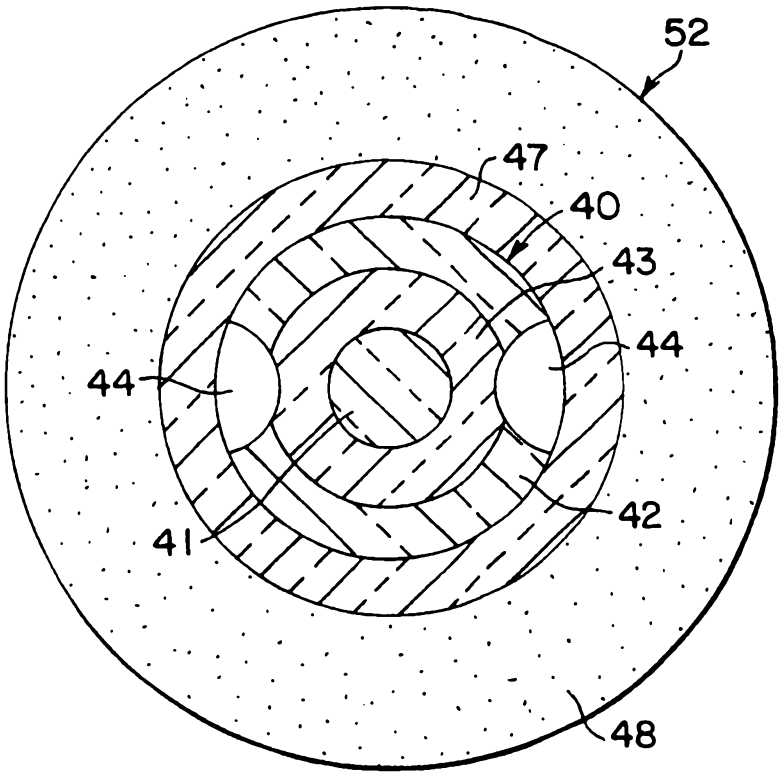
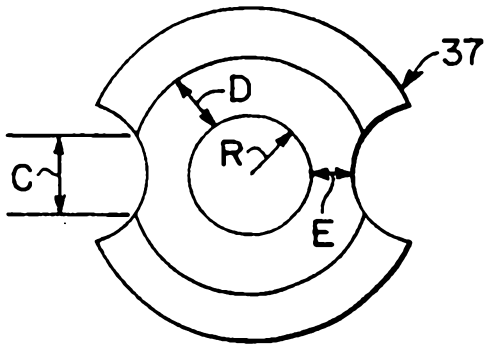
FIG. 9