(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 May 2006 (11.05.2006)

PCT

(10) International Publication Number
WO 2006/049266 A1

(51) International Patent Classification:
G02B 6/00 (2006.01) *G02B 6/44* (2006.01)

(21) International Application Number:
PCT/JP2005/020328

(22) International Filing Date: 31 October 2005 (31.10.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

2004-317770	1 November 2004 (01.11.2004)	JP
2004-354786	8 December 2004 (08.12.2004)	JP
2005-030160	7 February 2005 (07.02.2005)	JP

(71) Applicant *(for all designated States except US)*: **FUJI PHOTO FILM CO., LTD.** [JP/JP]; 210, Nakanuma, Minami-ashigara-shi, Kanagawa, 2500193 (JP).

(72) Inventors; and

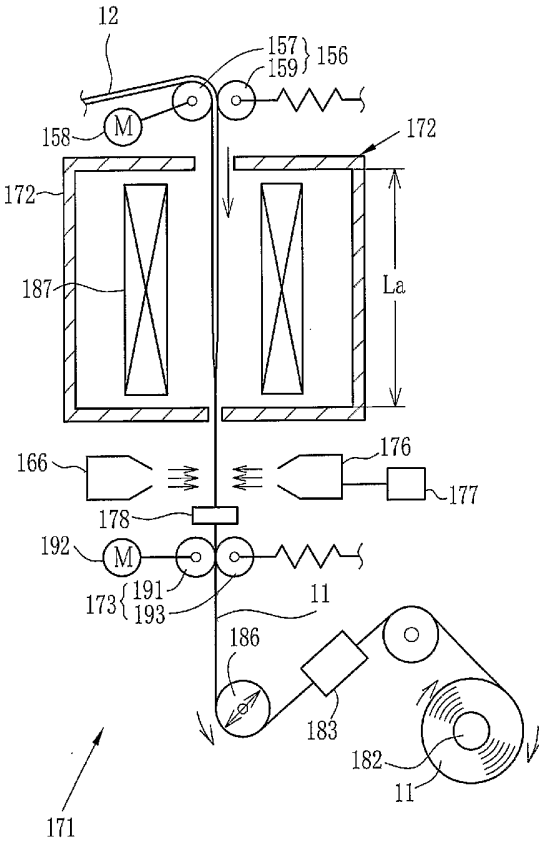
(75) Inventors/Applicants *(for US only)*: **KEGASAWA, Tadahiro** [JP/JP]; c/o Fuji Photo Film Co., Ltd., 200, Ohnakazato, Fujinomiya-shi, Shizuoka, 4188666 (JP). **NAKAMURA, Yoshisada** [JP/JP]; c/o Fuji Photo Film Co., Ltd., 200, Ohnakazato, Fujinomiya-shi, Shizuoka, 4188666 (JP). **SATO, Takanori** [JP/JP]; c/o Fuji Photo Film Co., Ltd., 200, Ohnakazato, Fujinomiya-shi, Shizuoka, 4188666 (JP). **MIYASAKA, Rei** [JP/JP]; c/o Fuji Photo Film Co., Ltd., 200, Ohnakazato, Fujinomiya-shi, Shizuoka, 4188666 (JP).

(74) Agents: **KOBAYASHI, Kazunori** et al.; Taiyo-seimei-otsuka Bldg., 3F, 25-1, Kita-otsuka 2-chome, Toshima-ku, Tokyo, 1700004 (JP).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK,

[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR PRODUCING PLASTIC OPTICAL FIBER, AND METHOD AND APPARATUS FOR COATING THE SAME



(57) Abstract: A raw POF is drawn by first and second roller pairs being as a drawing device while continuously advanced and heated by a heater. A heating length of the heater is set to a range of 0.1 to 1 m, and a magnification for drawing is set to 1.5 to 3.5 times in a longitudinal direction. Rollers of the first and second roller pairs are independently driven to individually control rotating speeds thereof. The obtained POF is excellent in mechanical strength and has a uniform outside diameter. Further, the obtained POF is excellent in optical transmission properties and workability. When a clad of the POF has an outside diameter D1 and a core thereof has an outside diameter D2, a relation of D1 ≥ D2 x 1.5 is satisfied. At a time of coating, a percentage of length change is set so as to be 1% or less.

WO 2006/049266 A1

SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

DESCRIPTION

METHOD AND APPARATUS FOR PRODUCING PLASTIC OPTICAL FIBER, AND METHOD AND APPARATUS FOR COATING THE SAME

Technical Field

The present invention relates to a method and an apparatus for producing a plastic optical fiber, and further relates to a method and an apparatus for coating the same.

Background Art

An optical fiber is an optical transmission material comprising a core part for transmitting the light, and a clad part for covering a circumference of the core part. The optical fibers are generally classified into a glass optical fiber and a plastic optical fiber (hereinafter called as POF) in accordance with a kind of its component. The POF has larger transmission loss in comparison with the glass optical fiber. Thus, the POF is not suitable for transmission of a middle distance and a long distance. However, the POF is made of a plastic material and is excellent in moldability, light weight, low cost, flexibility, impact resistance and so forth. Moreover, in virtue of these properties, there are advantages in that it is possible to enlarge a diameter of the core part of the optical fiber and it is possible to avoid the danger of stabbing human body. For this reason, it is considered to use the POF for a home and an automobile. Meanwhile, regarding a plastic optical cable in which the circumference of the optical fiber is coated with a coating material to form a protective layer, it is considered to utilize the plastic optical cable as a short-distance, high-capacity cable such as inner

wirings for high-speed data processing device and a digital video interface (DVI) link.

As to the optical fiber being capable of obtaining high-speed transmission and small transmission loss, attention is directed to a gradient index POF in which refractive index is distributed toward the center of the POF at the core part thereof. The gradient index POFs are generally classified into an SI (Step Index) type and a GI (Graded Index) type on the basis of difference of refractive-index distribution. The refractive index of the former increases stepwise toward the center of the core part, and the refractive index of the latter increases continuously toward the center of the core part. In both of the SI type and the GI type, the refractive index increases toward the center of the core part. However, the refractive index of the GI type continuously increases toward the center, although that of the SI type changes stepwise. Thus, the GI type has a feature that a transmission waveform hardly transforms. In comparison with the SI type, the GI type is likely to be expensive due to difficulty of manufacture, but it is possible to obtain the high-speed transmission and small transmission loss. In the present invention, the POF is defined as the whole plastic optical fibers including the SI type and the GI type.

As mentioned above, the plastic optical cable includes the POF whose circumference is coated with the coating material to form the protective layer. The plastic optical cable is widely used for the purpose of transmitting large volume data at high speed. For coating the circumference of the POF with the coating material, some methods are known. In one of the methods, a first coating layer of a low extrusion temperature is extruded onto the circumference of the POF, and after that, a second coating layer

of a high extrusion temperature is extruded onto the first coating layer to form a double protective layer (see Japanese Patent Laid-Open Publication No. 6-167642, for instance). In another method, a tension member layer working as a heat insulating layer is formed on the circumference of the POF, and the tension member layer is coated by a coating material to form a protective layer (see Japanese Patent Laid-Open Publication No. 10-96840, for instance).

In the coating method described in the above-noted Publication No. 6-167642, the protective layer is formed in two steps of the different extrusion temperatures. Since rapid changes of the temperature are not caused, it is possible to prevent the transmission loss of the POF from increasing. Further, it is possible to obtain the plastic optical cable of which terminal processing is easy. In the coating method described in the above-noted Publication 10-96840, the tension member layer working as the heat insulating layer is formed so that the strong plastic optical cable is obtained.

However, since the method described in the Publication No. 6-167642 requires two coating steps, there arises a problem in that production efficiency deteriorates. Meanwhile, in the method described in the Publication No. 10-96840, since the tension member layer is strong, it is difficult to cut the optical cable at a time of terminal processing. Thus, there arises a problem in that workability deteriorates. When the circumference of the POF is coated, sometimes the transmission loss increases. In case the transmission loss increases, there arises a problem in that transmission performance remarkably degrades.

In the meantime, methods for producing the GI-type POF are

generally classified into two categories, in one of which a columned preform is made and this preform is drawn in a longitudinal direction to produce the POF. In the other category, copolymer being as a raw material of the POF is formed in a fibrous shape by means of melt extrusion to produce the POF. In comparison with the method for producing the POF via the preform, the method according to the melt extrusion is performed by smaller and simpler production equipment and is excellent in easy continuous production.

As to melt-extruding methods for producing the GI-type POF, there are various proposals. For example, in the following patent documents (1) to (4), it is proposed that polymerizable substances are polymerized so as to change the refractive index on its section, and are melted and drawn to produce the POF. From among these documents, the documents (3) and (4) propose producing methods in which fluorine-containing material is used to realize low optical transmission loss. Meanwhile, for the purpose of equalizing an outside diameter of the POF, the document (5) proposes a method for drawing the POF in a predetermined magnification, thermally processing the POF by a heated gas flowing in a predetermined direction. The document (6) proposes a heat treatment device comprising a sealing mechanism for preventing heat medium of a heating chamber from flowing to the outside. The sealing mechanism is disposed at the outside of each of a fiber inlet and a fiber outlet of the heating chamber for the purpose of solving the lack of heat at the time of heat drawing of the POF and for the purpose of preventing deterioration of optical transmission properties to be caused by drawing. The heat treatment device further comprises a constant-speed supplier and a constant-speed puller in order to forward the POF into the

heating chamber at a constant speed. The document (7) proposes a method for regulating a drawing magnification on the basis of a stress-strain curve of a thermoplastic resin in order to prevent fluctuation of a diameter from occurring at a time when a fibrous preform made of the thermoplastic resin is drawn.

(1) Japanese Patent Laid-Open Publication No. 8-334635

(2) Japanese Patent Laid-Open Publication No. 2000-356716

(3) Japanese Patent Laid-Open Publication No. 8-334634

(4) Japanese Patent Laid-Open Publication No. 8-336911

(5) Japanese Patent Laid-Open Publication No. 5-11128

(6) Japanese Patent Laid-Open Publication No. 2000-121842

(7) Japanese Patent Laid-Open Publication No. 2002-266189

However, the documents (1) to (4) relate to the methods for producing the POF by melt-extruding the polymer, and there is no description therein about diameter fluctuation and mechanical strength. When the POF is actually produced by means of melt extrusion, there arise problems in that the diameter fluctuation is great and the mechanical strength is too weak. If the diameter fluctuation is great, the optical transmission properties deteriorate and connection accuracy relative to a connector scatters. If the mechanical strength is too weak, practical utility deteriorates due to restriction of workability and so forth. This kind of the problems are especially remarkable in a case using fluorinated material proposed in the documents (3) and (4). The documents (5) to (7) propose methods for drawing the fibrous preform. According to these methods, the mechanical strength is improved to some extent in comparison with the methods described in the documents (1) to (4). However, there is a problem in that practical strength of the POF and the diameter fluctuation are not satisfied at the same time in view of the optical

transmission properties.

Meanwhile, the GI-type POF is coated with the coating layer to produce the plastic optical cable. The highest importance concerning the plastic optical cable is transmission loss. Various proposals are made for the purpose of improving the transmission loss. For example, Japanese Patent Laid-Open Publication No. 5-224033 proposes that polymethylmethacrylate (PMMA) and fluorine polymer are respectively used as a core material and a clad material in order to improve physical and chemical properties. In this proposal, spinning conditions and drawing conditions are controlled to adjust thermal shrinkage factor and degree of molecular orientation. Japanese Patent Laid-Open Publication No. 7-234033 proposes a drawing method of the plastic optical fiber in which drawing tension is set to 100g or less in order to reduce the transmission loss until the plastic optical fiber is taken up. In virtue of this, the plastic optical fiber is prevented from shrinking after heat deterioration (heat history).

After consideration, the inventors have figured out that the transmission loss of the plastic optical cable is different in accordance with coating conditions of the POF, and especially, this feature is remarkable with respect to the POF produced by melt extrusion. The conventional methods such as described in the above-noted Publication Nos. 5-224033 and 7-234033 propose the producing methods of the POF itself in order to reduce the transmission loss. However, the problem in that the transmission loss is lowered by coating is not solved.

It is an object of the present invention to provide a method and an apparatus for producing a plastic optical fiber, in which mechanical strength of the plastic optical fiber is improved and

an outside diameter thereof is prevented from fluctuating.

It is another object of the present invention to provide a method for coating a plastic optical fiber, in which transmission loss is prevented from increasing when a circumference of the plastic optical fiber is coated with a coating material, and at the same time, a plastic optical cable having excellent workability is produced.

It is the other object of the present invention to provide a method and an apparatus for coating a plastic optical fiber, in which the plastic optical fiber is continuously coated without lowering transmission loss thereof.

Disclosure of Invention

In order to achieve the above objects, in the method and the apparatus for producing a plastic optical fiber according to the present invention, a raw optical fiber is continuously advanced and a part thereof corresponding to a range of 0.1m to 1m is heated by a heating device. While this range is heated, the raw optical fiber is drawn by a drawing device at draw magnification of 1.5 to 3.5 times to produce the plastic optical fiber.

In a preferred embodiment, the drawing device comprises first and second rollers for carrying the raw optical fiber. The first and second rollers are disposed at upstream and downstream sides of the heating device. It is preferable that the drawing magnification is adjusted by controlling rotating speeds of the first and second rollers. Further, it is preferable that at least one of the first and second rollers comprises a nip member for nipping the raw optical fiber.

The raw optical fiber is preferable to be formed from a

fluorine-containing polymer. Moreover, the raw optical fiber is preferable to comprise a clad constituting a circumferential part, and a core constituting the inside of the clad and having refractive index changing in a radius direction.

According to the producing method and apparatus of this embodiment, mechanical strength is improved and fluctuation of an outside diameter is reduced. Thus, it is possible to produce the POF being excellent in optical transmission properties, workability and so forth.

The inventors of this application have investigated a relation between coating conditions of a POF and the transmission loss thereof, and as a result, the inventors have found out the following relation. First of all, at the time of coating, the POF is likely to be plastically deformed due to heat and tension applied thereto. However, as to a heat amount of this time, the heat is hardly applied to the POF so as to melt the whole of the POF. A clad part, which is proximate to a melted resin used for coating, is most greatly influenced. On this occasion, there is a possibility that the heat and the tension cause irregularity at a boundary of the clad part and a core part. In a case that the core part has refractive-index distribution, composition is an uneven state even if the refractive index is given by refractive-index regulating agents or copolymers. Due to this state, thermal stability of polymer matrix becomes unevenness. Thus, it is considered that profile of the refractive-index distribution is distorted by receiving the heat and the tension. In order to eliminate the influence of the heat and the tension, the heat is prevented from being transmitted to the boundary in the present invention, and at the same time, the tension to be applied to the whole POF is lessened to prevent the deformation

of the POF. In order to do this, a diameter of the clad part is adapted to be 1.5 times or more relative to a diameter of the core part, and elongation percentage of the POF is adapted to be 1% or less at a time when the POF is coated with the resin. Incidentally, when the core part is composed of a plurality of layers, a diameter of the outermost layer is regarded as the diameter of the core part.

In another embodiment, when the outside diameters of the clad part and the core part are respectively represented by D1 and D2, the relation of $D1 \geqq D2 \times 1.5$ is satisfied. Further, the resin is used as a coating material to coat the circumference of the POF. Thus, at the time of coating, the thickness of the clad part prevents the heat of the melted resin from being transmitted to the boundary of the clad part and the core part so that heat damage is reduced.

The other embodiment of the present invention relates to a method and an apparatus for continuously coating the plastic optical fiber. In this embodiment, the plastic optical fiber is coated with a coating material so as to set a percentage of length change (unit; %), which is calculated by $\{(L2-L1)/L1\} \times 100$, within a range of ± 1, wherein L1 represents a length of the plastic optical fiber of a pre-coating state and L2 represents a length the coated plastic optical fiber.

It is preferable that tension applied to the plastic optical fiber is detected by a tension detecting device. On the basis of a detection result, the tension of the plastic optical fiber carried to a coater is controlled by a tension controller to adjust the percentage of length change. When T (unit; N) represents the tension applied to the coated plastic optical fiber and D1 (unit; mm) represents a diameter of the plastic optical fiber, it is

preferable to satisfy a relation of $T=\alpha\times(D1)^2$ ($0.5 \leqq \alpha$ (unit; N/mm^2) $\leqq 6.0$). It is preferable that the tension controller is a dancer pulley. Moreover it is preferable that the plastic optical fiber has refractive-index distribution in which a refractive index changes so as to become lower from the center toward the periphery. Further, it is preferable that coating is performed by the coater in a state that the coating material is pressurized.

According to this continuous coating method and apparatus, it is possible to perform coating without deteriorating transmission loss of the plastic optical fiber.

Brief Description of Drawings

Fig. 1 is a flow diagram for producing a plastic optical cable according to the present invention;

Fig. 2 is a section view of a POF;

Fig. 3 is an illustration showing refractive index in a radial direction of the POF shown in Fig. 2;

Fig. 4 is a schematic illustration partially showing a melt-extruding apparatus;

Fig. 5 is a schematic illustration showing a heat-drawing apparatus;

Fig. 6 is a section view of another POF;

Fig. 7 is a schematic illustration showing a coating apparatus;

Fig. 8 is a section view of a primary coated POF;

Fig. 9 is a graph showing a relationship between elongation percentage of the POF and fluctuation range of transmission loss;

Fig. 10 is a graph showing a relationship between the elongation percentage and tension of the coated POF;

Fig. 11 is a graph showing a relationship between tensions

of the coated POF and the uncoated POF;

Fig. 12 is a schematic illustration partially showing a coater;

Fig. 13 is a graph showing a change of tension at a time of coating performed by a conventional method;

Fig. 14 is a graph showing transmission-loss fluctuation of the primary coated POF according to a conventional coating method; and

Fig. 15 is a schematic illustration showing another coating apparatus.

Best Mode for Carrying Out the Invention

A preferred embodiment of the present invention is described below with the drawings. The present invention, however, is not limited to the following embodiment. Although the present invention is not restricted regarding a layer number of a plastic optical fiber (POF), the POF having a three-layer structure is produced in this embodiment. Fig. 1 is a flow diagram for producing a plastic optical cable to which the present invention is applied. Fig. 2 is a section view of the obtained POF. Fig. 3 is a graph showing refractive index in a radial direction of the POF shown in Fig. 2. In Fig. 3, a horizontal axis represents the radial direction of the POF, and a vertical axis represents the refractive index, a value of which becomes larger in an upward direction. A process for producing the plastic optical cable includes a melt-extruding process 13, a heat-drawing process 16 and at least one coating process. In the melt-extruding process 13, polymers for forming three layers of the POF 11 are melted and extruded as a raw POF 12. In the heat-drawing process 16, the raw POF 12 is heated and drawn to

produce the POF having a predetermined diameter. In the coating process, a circumferential surface of the POF 11 is coated with a coating material to form a protective layer. In a case of a single coating process, the POF 11 is coated in this process to produce the plastic optical cable. However, the coating process may include a first coating process 18 and a second coating process 19. In this case, the POF 11 is coated in the first coating process 18 to produce a primary coated POF 17, and then the primary coated POF 17 is coated in the second coating process 19 to produce the plastic optical cable.

The POF 11 for which the coating process has been performed is called as plastic optical fiber strand or as plastic optical fiber code (collectively dubbed as plastic optical code). In the present invention, the sole fiber strand further coated as necessary is called as single-fiber cable, and the fiber strands bundled together with a tension member or the like and further coated with a coating material are called as multi-fiber cable. Both of the single-fiber cable and the multi-fiber cable are included in the plastic optical cable 17.

As shown in Fig. 2, the POF 11 obtained by the present invention comprises a core 25 for transmitting the light. The POF 11 further comprises an inner clad 24 and an outer clad 22 surrounding the core 25. An outside diameter and an inside diameter of the outer clad 22 are constant in a longitudinal direction, so that the outer clad 22 has a tube shape of which thickness is uniform. The outside diameter of the outer clad 22 is represented by D1 (unit; μm). Moreover, an outside diameter of the inner clad 24 is represented by D2 (unit; μm), and an outside diameter of the core 25 is represented by D3 (unit; μm). The outside diameter D2 of the inner clad 24 is equal to the inside

diameter of the outer clad 22, and the outside diameter D3 of the core 25 is equal to the inside diameter of the inner clad 24.

In Fig. 3, an area denoted by reference letter (A) represents the refractive index of the outer clad 22 shown in Fig. 2. Moreover, an area denoted by reference latter (B) represents the refractive index of the inner clad 24 shown in Fig. 2. Further, an area denoted by reference latter (C) represents the refractive index of the core 25.

As shown in Fig. 3, the refractive index of the core 25 consecutively increases toward the center from a boundary with the inner clad 24. The outer clad 22 has the lower refractive index in comparison with the inner clad 24. The inner clad 24 has the lower refractive index in comparison with the core 25. Incidentally, before drawing the POF 11, the raw POF 12 has larger diameters in comparison with D1 to D3 of the POF 11. However, since a basic structure of the raw POF 12 is identical with that of the POF 11, illustration thereof is abbreviated. Meanwhile, although the boundary between the inner clad 24 and the core 25 is shown in Fig. 2 as a matter of explanatory convenience, clarity of the boundary is different in accordance with production conditions and so forth. The boundary may be not always confirmed.

Such as shown in Fig. 3, the inner clad 24 of this embodiment has the substantially constant refractive index. However, the refractive index may increase toward the core 25. In this case, the refractive index may change stepwise or may consecutively change toward the core 25.

By the way, besides the structure of this embodiment, the present invention is applicable to the other structures. For example, the core 25 may comprise an outer core part and an inner

core part, and the refractive index may increase stepwise or consecutively from a circumference of the outer core part toward the center of the inner core part. The core 25 may comprise three or more parts. In this embodiment, there are the outer clad and the inner clad. The present invention, however, is not limited to this. The clad may have a single-layer structure and may have a three or more layer structure as need arises. As to the POF 11 of this embodiment, the light is reflected by a boundary surface of the core and the clad. Regarding the POF to be produced, the present invention is applicable to a single mode and a multi mode. Further, the present invention is applicable to any type of the SI type and the GI type. However, by using the GI-type POF such as described above, it is possible to obtain the POF which is excellent in optical transmission properties in comparison with the SI-type POF.

In the present invention, it is preferable that the core and the clad composing the POF 11 are made of organic material having high optical transparency. Moreover, it is preferable that at least one of the core and the clad is made of fluororesin. Further, it is preferable that primary constituent is polymer of (meth)acrylic ester. These materials are described later in detail. Incidentally, there is no problem as far as the clad is made of material having a lower refractive index in comparison with the core. However, when the clad is made of the fluororesin, there is an advantage in terms of the refractive index concerning the optical transmission. Especially, when the material of the clad is the fluororesin, it is possible to easily produce the clad having a low refractive index and having no optical problems.

For the purpose of totally reflecting the light, which is transmitted in the core, by the boundary of the core and the clad,

the material of the clad is adapted to be a polymer having a lower refractive index in comparison with the core. It is preferable that the materials of the clad and the core are amorphous polymers so as not to cause light scattering. Further, it is preferable that the polymers are excellent in adhesiveness, mechanical properties represented by toughness and so forth, and wet heat resistance. Since it is desirable to prevent moisture from entering the core, the material of the clad is preferred to have low coefficient of water absorption. For example, it is preferable that the primary constituent of the clad is a polymer having saturation water-absorption coefficient being less than 1.8%. It is much preferable that the inner clad 24 is made of a polymer having saturation water-absorption coefficient being less than 1.5%, much preferably less than 1.0%. Incidentally, the above-mentioned saturation water-absorption coefficient is based on D570 in conformity with ASTM. Concretely, the saturation water-absorption coefficient is a value of the water-absorption coefficient measured at a time when a sample has been dipped in water of 23 °C for one week. In addition, it is preferable that the core and/or the clad are made of the fluororesin. The polymers to be used for the core and the clad are described later in detail.

For example, the material of the core 25 is polymerized by using polymerizable compound of (meth)acrylic acid esters [(a) (meth)acrylic ester without fluorine, (b) (meta)acrylic ester containing fluorine], (c) styrenic compounds, (d) vinyl esters, (e) monomer for forming chain cyclic fluorine-containing polymer, bisphenol-A being raw material of polycarbonates, and so forth. As to the polymer for forming the clad, polyvinylidene fluoride (PVDF) is also preferable. As the other examples, there are homopolymers in which the respective materials are polymerized,

and copolymers in which two or more kinds of the above-noted materials are combined and are polymerized. Further, there are mixtures in which the above homopolymers and copolymers are variously combined. In the case using the mixture, the boiling point Tb is defined as the lowest temperature among the boiling points of the raw-material compounds composing the mixture. Alternatively, when the boiling point lowers due to the azeotropic mixture, the boiling point Tb is defined as a temperature to be set after decrease of the boiling point. Meanwhile, in the case of blend polymers and the copolymers obtained from the mixtures, glass transition points of the blend polymer and the respective copolymers are defined as the Tg. Among these, the preferred one for composing the optical transmission member includes the (meth)acrylic acid ester or the fluorine-containing polymer as its constituent. Successively, the above examples are described below in detail.

Examples of the (a) (meth)acrylic ester without fluorine as the polymerizable monomer are methyl methacrylate; ethyl methacrylate; isopropyl methacrylate; tert-butyl methacrylate; benzyl methacrylate (BzMA); phenyl methacrylate; cyclohexyl methacrylate, diphenylmethyl methacrylate; tricyclo [5·2·1·$0^{2,6}$] decanyl methacrylate; adamanthyl methacrylate; isobonyl methacrylate; norbonyl methacrylate; methyl acrylate; ethyl acrylate; tert-butyl acrylate; phenyl acrylate, and the like.

Examples of (b) (meth)acrylic ester with fluorine are 2,2,2-trifluoroethyl methacrylate; 2,2,3,3-tetrafluoro propyl methacrylate; 2,2,3,3,3-pentafluoro propyl methacrylate; 1-trifluoromethyl-2,2,2-trifluoromethyl methacrylate; 2,2,3,3,4,4,5,5-octafluoropenthyl methacrylate; 2,2,3,3,4,4,-hexafluorobutyl methacrylate, and the like.

Further, in (c) styrenic compounds, there are styrene; α-methylstyrene; chlorostyrene; bromostyrene and the like. In (d) vinylesters, there are vinylacetate; vinylbenzoate; vinylphenylacetate; vinylchloroacetate; and the like. In (e) monomer for forming chain cyclic fluorine-containing polymer, there are monomer for forming polymer which forms fluorine-containing polymer having cyclic structure as a monomer or having cyclic structure on amorphous chain by cyclic polymerization; monomer for forming polymer having aliphatic ring or heterocyclic ring on the chain such as polyperfluorobutanylvinyl ether and such as described in Japanese Patent Laid-Open Publication No. 8-334634; monomer described in Japanese Patent Application No. 2004-186199; and the like. It is needless to say that the monomers are not limited to the above. It is preferable to determine a kind of the monomer and a relative proportion thereof such that the refractive index of the polymer, which comprises the sole polymerizable compound or the copolymer, has prescribed refractive-index distribution at a time when the optical transmission member has been produced.

As to the preferred polymer for forming the clad, besides the above-mentioned various compounds, there are copolymers including methylmethacrylate (MMA), trifluoroethyl methacrylate (FMA) and fluoro(meth)acrylate of hexafluoro isopropyl methacrylate and so forth, for example. Moreover, there are copolymer including MMA, tert-butyl methacrylate having branch, alicyclic (meth)acrylate of isobonyl methacrylate, norbonyl methacrylate, tricyclodecanyl methacrylate and so forth. Further, it is possible to use polycarbonate (PC), norbornene-based resin (for example, ZEONEX (registered trademark: produced by ZEON corporation)), functional

norbornene-based resin (for example, ARTON (registered trademark: produced by JSR)), fluororesin (for example, polytetrafluoroethylene (PTFE), polyvinylidene fluoride (PVDF) and so forth). Furthermore, it is possible to use copolymer of fluorine resin (for example, PVDF-based copolymer), tetrafluoroethylene perfluoro (alkylvinyl ether (PFA) random copolymer, chlorotrifluoroethylene (CTFE) copolymer), and so forth.

Incidentally, when the above-mentioned polymer includes hydrogen atom (H), it is preferable to substitute deuterium atom (D) for the hydrogen atom. By virtue of this, transmission loss may be reduced. Especially, the transmission loss may be reduced relative to wavelengths of a near-infrared region.

In order to use the POF 11 for the near-infrared rays, polymers such as described in Japanese Patent No. 3332922 and Japanese Patent Laid-Open Publication No. 2003-192708 are utilized. In this polymer, deuterium atom, fluorine and so forth are substituted for the hydrogen atom of a C-H bond constituting the polymer, since absorption loss is caused by the C-H bond. By using this kind of the polymer, the wavelength region causing the transmission loss is shifted to the longer-wavelength side, and it is possible to reduce the loss of the transmission signal light. With respect to this kind of the polymer, for instance, there are deuteriated polymethylmethacrylate (PMMA-d8), polytrifluoroethylmethacrylate (P3FMA), and polyhexafluoro isopropyl-2-fluoroacrylate (HFIP2-FA). Incidentally, it is desirable that the impurities and foreign materials in the raw compound that causes dispersion should be sufficiently removed before polymerization so as to keep the transparency of the POF after polymerization.

Weight-average molecular weight of the polymer for forming the core and the clad is preferable to be from ten thousands to one million, in consideration of extrusion forming of a thread shape and suitable drawing described later. Much preferably, the weight-average molecular weight is from thirty thousands to a half of one million. Drawing properties concern molecular weight distribution (MWD: weight-average molecular weight / number average molecular weight) as well. In a case that the MWD is too large, the drawing properties deteriorate when a constituent having extremely large molecular weight is mixed. In this case, sometimes it becomes impossible to perform drawing. The range of the preferred MWD is four or less, and much preferably is three or less. Among the above-mentioned polymer, the fluorine-containing polymer is especially preferable.

When the polymerizable compound is polymerized to produce a polymer, polymerization initiators are sometimes used. As to the polymerization initiators, there are various kinds to produce radicals. For example, there are benzoil peroxide (BPO); tert-butylperoxy-2-ethylhexanate (PBO); di-tert-butylperoxide (PBD); tert-butylperoxyisopropylcarbonate (PBI); n-butyl-4,4-bis(tertbutylperoxy)valarate (PHV), and the like. Other examples of the polymerization initiators are azo compounds, such as 2,2'-azobisisobutylonitril; 2,2'-azobis(2-methylbutylonitril); 1,1'-azobis(cyclohexane-1-carbonitryl); 2,2'-azobis(2-methylpropane); 2,2'-azobis(2-methylbutane) 2,2'-azobis(2-methylpentane); 2,2'-azobis(2,3-dimethylbutane); 2,2'-azobis(2-methylhexane); 2,2'-azobis(2,4-dimethylpentane); 2,2'-azobis (2,3,3-trimethylbutane); 2,2'-azobis(2,4,4-trimethylpentane); 3,3'-azobis(3-methylpentane); 3,3'-azobis(3-methylhexane);

3,3'-azobis(3,4-dimethypentane); 3,3'-azobis(3-ethylpentane); dimethyl-2,2'-azobis(2-methylpropionate); diethyl-2,2'-azobis(2-methylpropionate); di-tert-butyl-2,2'-azobis(2-methylpropionate), and the like. Note that the polymerization initiators are not limited to the above substances. More than one kind of the polymerization initiators may be combined.

In order to keep the physical properties, such as mechanical properties, thermal properties and so forth of the polymer, over the whole plastic optical fiber to be manufactured, it is preferable to control the polymerization degree by use of the chain transfer agent. The kind and the amount of the chain transfer agent are selected in accordance with the kinds of the polymerizable monomer. The chain transfer coefficient of the chain transfer agent to the respective monomer is described, for example, in "Polymer Handbook, 3rd edition", (edited by J. BRANDRUP & E.H.IMMERGUT, issued from JOHN WILEY&SON). In addition, the chain transfer coefficient may be calculated through the experiments in the method described in "Experiment Method of Polymers" (edited by Takayuki Ohtsu and Masayoshi Kinoshita, issued from Kagakudojin, 1972).

Preferable examples of the chain transfer agent are alkylmercaptans [for instance, n-butylmercaptan; n-pentylmercaptan; n-octylmercaptan; n-laurylmercaptan; tert-dodecylmercaptan, and the like], and thiophenols [for example, thiophenol; m-bromothiophenol; p-bromothiophenol; m-toluenethiol; p-toluenethiol, and the like]. It is especially preferable to use n-octylmercaptan, n-laurylmercaptan, and tert-dodecylmercaptan in the alkylmercaptans. Further, the hydrogen atom on C-H bond may be substituted by the fluorine atom

(F) or a deuterium atom (D) in the chain transfer agent. Note that the chain transfer agents are not limited to the above substances. More than one kind of the chain transfer agents may be combined.

With respect to loadings of the polymerization initiator, the chain transfer agent, and a refractive-index regulating agent, it is possible to properly determine a preferable range in accordance with the kind and so forth of the polymerizable compound to be used for the core. In this embodiment, the polymerization initiator is added so as to be 0.005 to 0.050 mass% relative to the polymerizable compound to be used for the core. It is much preferable to set this additive rate within a range of 0.010 to 0.020 mass%. Meanwhile, the chain transfer agent is added so as to be 0.10 to 0.40 mass% relative to the polymerizable compound to be used for the core. It is much preferable to set this additive rate within a range of 0.15 to 0.30 mass%.

Other additives may be contained in the core and the clad so far as the transmittance properties do not decrease. For example, the additives may be used for increasing resistance of climate and durability. Further, induced emissive functional compounds may be added for amplifying the optical signal. When such compounds are added to the monomer, attenuated signal light is amplified by excitation light so that the transmission distance increases. Therefore, the optical member with such additive may be used as an optical fiber amplifier in an optical transmission link. These additives may be contained in the core, the clad and a part thereof by polymerizing the additives with the various polymerizable compounds being as the raw material.

At least one of the polymers for respectively forming the inner clad 24 and the core 25 includes a refractive-index

regulating agent (dopant) by a predetermine amount. With respect to this dopant, a non-polymerizable compound is preferable. When the dopant is added in only the core 25, the additive rate thereof is preferable to be 0.01 wt% or more and to be 25 wt% or less relative to the polymer being as the primary constituent of the core 25. This additive rate is much preferable to be 1 wt% or more and to be 20 wt% or less. In virtue of this, the refractive index distribution coefficient is easily controlled in the radial direction so as to be set within the preferable range.

In this embodiment, the dopant to be used is a low-molecular compound which has high refractive index and large molecular volume and which is not concerned in polymerization and having prescribed diffusion velocity in the polymer of a molten state. By adding this low-molecular compound, the refractive index of the core is changed in the radius direction. The dopant is not limited to the monomer, and may be oligomer (including dimmer, trimmer and so forth). Even if a certain monomer has polymerization reactivity relative to the core and the monomer used therefor, oligomer of this monomer may be used as the dopant on condition that this oligomer does not polymerize with the core and the monomer used therefor.

Examples of the dopants are benzyl benzoate (BEN); diphenyl sulfide (DPS); triphenyl phosphate (TPP); benzyl n-butyl phthalate (BBP); diphenyl phthalate (DPP); diphenyl (DB); diphenylmethane (DPM); tricresyl phosphate (TCP); diphenylsoufoxide (DPSO). Among them, BEN, DPS, TPP and DPSO are preferable. It is possible to alter the refractive index of the POF 11 to a desired value by controlling the density and the distribution of the dopant to be mixed in the core.

In the following description, the polymer to be used for the outer clad 22 is referred to as a first raw material. Further, the polymer for forming the inner clad 24 is referred to as a second raw material, and a substance for forming the core 25, which is a mixture of polymer and dopant, is referred to as a third raw material. Although the polymer included in the first to third raw materials may be a pellet state or may be a powered state, it is preferable to perform a drying process for the polymer before the melt-extruding process 13. In virtue of this, air bubble and crack are prevented from occurring in the product.

The polymerizing process for producing the respective polymers may be successively performed for the melt-extruding process, which is described below, to supply the respective polymerized polymers of a melted state as it is to the melt-extruding process 13. In this case, the dopant may be added into the melted polymer advanced to the melt-extruding process. Alternatively, the dopant may be added into the melted polymer at a mixer and so forth of an extruding machine (not shown) performing melt extrusion.

Fig. 4 is a schematic illustration showing a relevant portion of a melt-extruding apparatus 141. In the present invention, however, the method for producing the raw POF is not limited to the equipment shown in Fig. 4. In this drawing, the first, second and third raw materials are respectively denoted by reference numerals 143, 144 and 145. The melt-extruding apparatus 141 comprises an extrusion die 148, a cooling device 151 and a first diameter measuring device 155. The extrusion die 148 is attached to a body of an extruding apparatus (not shown), which is a part of a commercially-manufactured melt-extrusion machine (not shown). The cooling device 151 cools the raw POF

12 discharged from the extrusion die 148. The first diameter measuring device 155 measures an outside diameter of the raw POF 12 cooled by the cooling device 151. Incidentally, a first roller pair 156 for nipping and carrying the raw POF 12 is provided at the next melt-drawing process. The first roller pair 156 includes a roller 157, a motor 158 for controlling a rotating speed of the roller 157, and a pressure roller 159 for nipping the raw POF 12 with the roller 157.

The melt-extruding apparatus 141 is described below in more detail. The extrusion die 148 may be a well-known die which is capable of producing a fibrous product having concentrically formed multi layers. The extrusion die 148 is not especially limited. As to the extrusion die 148 used in this embodiment, first to third die bodies 161 to 163 are integrally assembled. By the respective die bodies 161 to 163, are formed a core forming passageway 164, an inner-clad forming passageway 165 and an outer-clad forming passageway 166. The third raw material 145 is supplied to the core forming passageway 164. Supply routes 167 of the second raw material 144 are formed between the first die body 161 and the second die body 162 to supply the second raw material 144 to the inner-clad forming passageway 165. Similarly, supply routes 168 of the first raw material 143 are formed between the second die body 162 and the third die body 163 to supply the first raw material 143 to the outer-clad forming passageway 166. A lower end of the outer-clad forming passageway 166 has a taper shape such that a diameter of the passageway reduces toward the bottom. Incidentally, the extrusion die 148 shown in Fig. 4 extrudes the raw POF 12 downward. However, the direction of the extrusion die 148 is not limited to this state. For example, the

extrusion die 148 may extend in a lateral direction to horizontally extrude the raw POF 12.

The periphery of the third die body 163 having the outer-clad forming passageway 166 is provided with a temperature controller (not shown) comprising a plurality of heaters to have temperature gradient along the outer-clad forming passageway 166. In virtue of the temperature gradient, the dopant is gradually diffuses so that the raw POF 12 has the change of the refractive index, which is shown in Fig. 3, in the radial direction.

As to the cooling device 151, it is preferable to continuously cool the fibrous product successively carried. In this embodiment, a water bath is used in view of easy and sufficient cooling. Besides this, for example, a pipe comprising a jacket, which is capable of transmitting refrigerant, may be used as the cooling device 151. By transmitting the substance to be cooled through the pipe, it is possible to cool this substance. Alternatively, as the cooling device 151, a blower mechanism may be used for blowing the air to the substance to be cooled. In this embodiment, a guide pulley 169 having a shifting mechanism is provided in the water bath. However, the usage of the guide pulley 169 is not essential to the present invention. In the case using the guide pulley 169, a relative position of the guide pulley 169 to the water bath is not especially restricted. Further, instead of the guide pulley 169, a roller or the like may be used.

Regarding the first diameter measuring device 155, various measuring devices commercially produced may be used. However, it is preferable that the measuring device is capable of continuously measuring the diameter of the successively-carried substance in a non-contact manner. For instance, there is a

digital sizer (type; LS-7010 (measuring portion), LS-7500 (controller), manufactured by Keyence Corporation).

When the above-described melt-extruding apparatus 141 is used, the following raw POF 12 is produced. At the outset, the first to third raw materials 143 to 145 are respectively melted by the different extruding machines (not shown), and respectively enter the extrusion die 148 though supply ports 164a, 167a and 168a, which are openings of the core forming passageway and the supply routes 167 and 168. In the extrusion die 148, the circumference of the third raw material 145 is coated with the second raw material 144 at the inner-clad forming passageway 165 to form two-layer structure. And then, the circumference of the two-layer structure is coated with the first raw material 143 at the outer-clad forming passageway 166. The first to third raw materials 143 to 145 are extruded to the outside of the extrusion die 148 through the inside of the outer-clad forming passageway 166 in a state of three-layer structure.

In the outer-clad forming passageway 166, the dopant included in the third raw material 145 diffuses inside and over the respective layers by controlling the temperature of the passageway. In virtue of this, the refractive index of the raw POF 12 in the radial direction becomes such as described in the above. Incidentally, it is possible to diffuse the dopant by the other methods. For example, the raw POF may be merely extruded without diffusing the dopant in the extrusion die 148, and after that, the extruded raw POF may be heated by a heating unit to diffuse the dopant. In this case, a cooling unit may de disposed between the extrusion die 148 and the heating unit to temporarily cool the extruded raw POF before heating it.

Then, the extruded raw POF 12 solidifies. The raw POF 12 is carried by the first roller pair 156 while the first diameter measuring device 155 measures the outside diameter of the raw POF 12. At this time, the carrying speed of the first roller pair 156 is adapted to be controlled in accordance with the measurement result of the outside diameter so that the outside diameter of the raw POF 12 is adjusted. By the way, instead of or in addition to the carrying-speed control of the first roller pair 156, a position of the guide pulley 169 may be adjusted to make the diameter of the raw POF 12 constant. Meanwhile, controlling the tension of the raw POF 12 extruded from the extrusion die 148 is performed by controlling the speed of the first roller pair 156 and by changing the position of the guide pulley 169. The control of the tension may be performed by the other well-known methods.

The melt-extruding apparatus 141 is not clearly distinguished from a heat-drawing apparatus of the next process. Although two processes are continuously performed in this embodiment, the continuousness of the processes is not exclusive to the present invention. For example, there is a method in which the raw POF 12 is taken up around a bobbin and drawing is performed during rewind of the raw POF 12.

Fig. 5 shows a schematic illustration of the heat-drawing apparatus 171, which comprises a heating device 172, a second roller pair 173, a blower duct 176, a blower controller 177, a second diameter measuring device 178 and a take-up device 182. The heating device 172 heats the raw POF 12. The second roller pair 173 nips and carries the raw POF 12 cooled after melting. The blower duct 176 and the blower controller 177 constitute a cooling device. The second diameter measuring device 178 measures the outside diameter of the POF 11 having passed through

the heating device 172. The heat-drawing apparatus 171 further comprises a tension measuring device 183 for measuring take-up tension at the time of winding, and a roller 186 being capable of moving on the basis of a measurement result of the tension measuring device 183.

The heating device 172 comprises a heater 187 for heating the raw POF 12 in an advancing direction thereof. The heater 187 is capable of changing the temperature in the carrying direction of the raw POF 12. When a range of the heater for heating the raw POF 12 is represented as La (hereinafter, this range is called as heat-range length), the La is 0.1m to 1m in the present invention. Since the heater 187 heats the whole of the inside of the heating device 172 employed in this embodiment, an interior length of the heating device 172 in the carrying direction is referred to as the hest-range length La. Meanwhile, the second roller pair 173 is provided with a roller 191 for carrying the POF 11, a motor 192 for controlling a rotating speed of the roller 91, and a pressure roller 193 disposed so as to nip the POF 11 with the roller 191.

As to the second diameter measuring device 178, a non-contact type is preferable. For example, a digital sizer (type of measuring portion; LS-7010, type of controller; LS-7500, both of them are manufactured by Keyence Corporation) is employed in this embodiment.

By means of the heat-drawing apparatus 171, the POF 11 is produced from the raw POF 12 in the following method. At the outset, the raw POF 12 produced by the above-described melt-extruding apparatus 141 is nipped and carried by the first roller pair 156 and is continuously forwarded into the heating device 172. The carrying speed of the raw POF 12 is controlled

by the rotating speed of the roller 157, and a nipping force of the first roller pair 156 can be set to a predetermined value by the pressure roller 159 to which an elastic member of a spring and so forth is attached.

The raw POF 12 enters the heating device 172 and is heated by the heater 187 while nipped and carried by the second roller pair 173. The carrying speed of the heated POF 11 is controlled by the rotating speed of the roller 191. By making the rotating speed of the roller 191 greater than the rotating speed of the roller 157, the raw POF 12 is drawn in the longitudinal direction. In the present invention, the heat-range length La of the heating device 172 is 0.1m to 1m such as described above. Inside the heating device 172, the raw POF 12 is drawn so as to become 1.5 to 3.5 times relative to the length of the undrawn raw POF 12. In this way, the POF 11 having a predetermined diameter is produced.

In the present invention, the raw POF is produced by the melt-extruding process. However, this is not exclusive. For example, the raw POF may be obtained by a method in which a preform such as described in WO03/019252 is drawn. Moreover, the raw POF, which is slightly thicker than the POF, may be produced and drawn. By doing so, it is possible to orient the constituent so that strength is improved. The drawing magnification for producing the POF 11 from the raw POF 12 is set to the above-noted range so that molecular orientation of the polymer is sufficient and uniform. Thus, strength of the POF 11 can be improved. This strength means mechanical strength measured in conformity with JIS C6862. For example, the strength is yield strength and rupture strength. If the drawing magnification is 1.5 times or less, the strength of the POF 11 is weak and sufficient drawing

result is not obtained, since the molecular orientation of the polymer of the POF 11 is not sufficient and uniform. Meanwhile, if the drawing magnification exceeds 3.5 times, the raw POF 12 is sometimes broken and the change of the refractive index is distorted in the radius direction to prevent the refractive-index distribution from becoming the mountain-like shape shown in Fig. 3. Moreover, the POF is likely to shrink with time and tighten winding is caused at the bobbin around which the POF is wound by the take-up device 182. Thus, there arises a problem in that transmission loss increases due to so-called micro-bending. By the way, even if the POF is produced by the above-described method, slightly tighten winding is sometimes caused on the bobbin. However, as to such slightly tighten winding, it is possible to reduce the distortion by performing thermal treatment in a wind-off state.

By setting the heat-range length La within the above range, it is possible to uniform the outside diameter of the POF 11. The heat-range length La is much preferable to be 0.2m to 0.5m. If the heat-range length La is 1m or more, the outside diameter of the POF is likely to become unevenness and fluctuation thereof is large. It is considered that the unevenness of the outside diameter is caused by reasons that the heated range is too long and drawing points are too many. If heat efficiency of the heating device is too low, sometimes it is impossible to set the drawing magnification within the above range under the condition of the heat-range length La. In this case, the heating devices of which the heat-range length La is set within the above range are disposed in series to repeat the drawing process by plural times. In other words, by repeating the melt-extrusion and the solidification, a ratio of the finally drawn length to the undrawn length becomes

the above drawing magnification. Although the heat-range length La is preferable to be shorter as much as possible on condition that it is possible to perform drawing, the shortest value thereof is about 0.1m in consideration of practical production efficiency and heating method.

In the present invention, the method for heating the raw POF 12 is not limited to the heater 187 and the heated-gas blowing method. For example, another heating device of a radiation heat type utilizing infrared rays and near infrared rays may be employed instead of the heating device 172.

The outside diameter of the POF 11 is measured by the second diameter measuring device 178. On the basis of the measurement result, are controlled the respective rotating speeds of the rollers 157 and 191 of the first and second roller pairs 156 and 173. In this embodiment, for the purpose of making the outside diameter of the raw POF 12, which has been extruded from the extrusion die, a predetermined value, the rotating speed of the roller 157 is determined first, and then, the rotating speed of the roller 191 is controlled in accordance with the rotating speed of the roller 157. Alternatively, the rotating speeds of the rollers 191 and the 157 are determined to decide the drawing conditions, and then, the extruding speed is determined in accordance with the drawing conditions. In the present invention, however, regarding both of the rollers 157 and 191, setting order of the rotating speeds concerning the conditions of extruding and drawing is not limited to this embodiment. In the case that the roller for carrying the fibrous polymer extruded from the extrusion die is separately disposed at the upstream side of the first roller pair 156 such as described above, the first roller

pair 156 may be used only for controlling the drawing magnification of the POF.

The second roller pair 173 is disposed at a place where a heated portion is positioned at the outside of the heating device 172 and is sufficiently cooled by the outside-air temperature so as not to deform the heated portion by nipping. In this embodiment, the blower duct 176 is provided to blow the air to the heat-drawn portion so that the production line is shortened. Incidentally, the blower duct 176 being as the cooling device is disposed at the downstream side of the heating device 172 in this embodiment. Instead of this, however, the blower duct 176 may be disposed in the heating device 172 and at the downstream side of the heater 187. The cooling method is not limited to the method in which the cold air is blown such as described in this embodiment. Various well-known cooling methods may be adopted. For example, there is a method in which the melted portion runs along the inside of a tube having a jacket through which refrigerant passes.

The POF 11 is taken up by the take-up device 182 in a bobbin shape while the take-up tension is controlled. The take-up tension is measured by the tension measuring device 183. On the basis of the measurement result, the rotating speeds of the take-up device 182 and the roller 186 are controlled. As to the tension measuring device 183, various well-known measuring devices may be used. For example, there is a commercially produced measuring device of a load cell type. In this embodiment, is used PLC load cell (manufactured by NIDEC-SHIMPO CORPORATION).

In this embodiment, the raw POF 12 is produced by melt extrusion. The present invention, however, does not depend on the producing method of the raw POF 12. For instance, the raw POF 12 may be obtained such that the preform is heated and drawn

in a fibrous shape thicker than the POF. According to this method, the obtained POF has greater mechanical strength and smaller fluctuation of the outside diameter in comparison with the method in which the POF is produced from the preform by one-time melt extrusion. Further, there is an advantage that the POF is prevented from being tightly wound with time at the bobbin around which the POF is wound.

The POF according to the present invention is ordinarily used after its surface has been coated with one or more protective layers, for the purpose of improving flexural and weather resistance, preventing decrease in property by moisture absorption, improving tensile strength, providing resistance to stamping, providing resistance to flame, protecting damage by chemical agents, noise prevention from external light, increasing the value by coloring, and so forth.

The POF becomes the primary coated POF via the first coating process. The sole primary coated POF or the bundled state thereof is coated in the second coating process to produce the optical cable. In the case of the single-fiber cable, the primary coated POF is used as the optical cable without passing through the second coating process. As to the manners of coating, there are tight coating and loose coating. In the tight coating, the coating material comes into contact with the whole of the circumference of the POF. In the loose coating, a gap resides between the coating material and the POF. If the protective layer separates at a joint portion with a connector in the case of loose coating, moisture having entered the gap of an edge of the separation portion is likely to spread in a longitudinal direction. In view of this, the tight coating is usually preferable in comparison with the loose coating.

In the case of loose coating, however, it is possible to ease the stress to be applied to the optical cable, and most damage of heat and so forth by the protective layer, since the coating material does not come into contact with the POF tightly. Thus, the damage to be caused on the POF may be reduced so that loose coating is preferably utilized for certain purposes. With respect to the moisture spread, it is possible to prevent the moisture from spreading, by filling the gap with particles and gelatinous semisolid having flowability. By giving a function, which is different from the moisture-spread preventing function, to the semisolid and the particles, it is possible to form the coating having higher performance. Incidentally, the different function concerns heat resistance, improvement of mechanical functions, and so forth. When the loose coating is performed, a gap layer can be made by adjusting a position of an extrusion-port nipple of a cross head die and further by adjusting a decompression device. It is possible to adjust a thickness of the gap layer by pressurizing/depressurizing a thickness of the nipple and the gap layer.

The coating materials of the first and second coating processes may include additives of fire retardant, ultraviolet absorber, antioxidant, radical trapping agent, lubricant, and so forth.

In order to grant the other functions to the optical cable, the other coating layers may be further formed as appropriate functional layers. As examples of such layers besides the flame resistance layer, there are a barrier layer for preventing moisture absorption of the POF, and a hygroscopic material layer for removing moisture included in the POF. As to the method for forming the hygroscopic material layer, for instance, there is

a method in which a hygroscopic tape and a hygroscopic gel are provided in the coating layer and between the coating layers. As the other functional layer, there are a flexible material layer for reducing stress at a flexure time, and a foaming material layer for buffering outside stress, and a reinforcement layer for improving rigidity. With respect to the coating layer of the plastic optical cable, besides the resin, it is possible to use a fiber having high elasticity (so-called tensile strength fiber) and/or thermoplastic resin including wire material of a metal wire and so forth having high rigidity. It is preferable to use this kind of the materials, since the mechanical strength of the cable to be obtained may be reinforced.

As the tensile strength fiber, there are aramid fiber, polyester fiber and polyamide fiber, for example. As the metal wire, there are stainless wire, zinc alloy wire, copper wire and so forth. However, these are not exclusive. In addition, the periphery of the plastic optical cable may be provided with a metal tube armor, which is used for protection, an aerial support wire, and a mechanism for improving workability of a wiring time.

The form of the optical cable is selected in accordance with usage pattern and intended purpose. For example, the optical fibers are concentrically gathered or are aligned such as a tape shape. Alternatively, the optical fibers are gathered by a holding spool, a wrap sheath and so forth.

The optical cable obtained from the POF of the present invention has high tolerance relative to axis misalignment in comparison with a conventional optical cable. Thus, the optical cable of the present invention may be used inn a style of heading joint. However, it is preferable that the end of the optical cable is provided with an optical connector to securely fix joint

portions of the optical fibers. As to the connector, it is possible to utilize various commercially-produced connectors of PN type, SMA type, SMI type and so forth, which are well known.

The optical cable obtained from the POF of the present invention is suitably used in combination with an optical processing equipment and so forth including optical parts of various light emitting/receiving elements, an optical switch, an optical isolator, optical integrated circuit, optical transmitter and receiver modules and so forth. At this time, the other optical fiber may be combined as need arises. As to techniques concerning these, any well-known techniques are adoptable. For instance, it is possible to refer to "Basis and Practice of Plastic Optical Fiber" (issued by NTS INC.), Nikkei Electronics 2001.12.3 pp. 110 to 127, and so forth. By combination with the various techniques described in these documents, the optical cable is suitably used for inner wiring of a computer and various digital equipments, interior wiring of a car, a ship and so forth, optical terminal equipments, digital devices, optical link of the digital equipments, optical LAN of home, collective housing, factory, office, hospital, school and so forth, and the other optical transmission system suitable for short distance.

Further, other techniques to be combined with the optical transmission system are disclosed, for example, in "'High-Uniformity Star Coupler Using Diffused Light Transmission' in IEICE TRANS. ELECTRON., VOL. E84-C, No.3, MARCH 2001, pp. 339-344", "'Interconnection in Technique of Optical Sheet Bath' in Journal of Japan Institute of Electronics Packaging., Vol.3, No.6, 2000, pp. 476-480". Moreover, there are arrangement of light-emitting elements (disclosed in Japanese

Patent Laid-Open Publication No. 2003-152284); an optical bus (disclosed in Japanese Patent Laid-Open Publications No.10-123350, No.2002-90571, No.2001-290055 and the like); an optical branching/coupling device (disclosed in Japanese Patent Laid-Open Publications No.2001-74971, No.2000-329962, No.2001-74966, No.2001-74968, No.2001-318263, No.2001-311840 and the like); an optical star coupler (disclosed in Japanese Patent Laid-Open Publications No.2000-241655); an optical signal transmission device and an optical data bus system (disclosed in Japanese Patent Laid-Open Publications No.2002-62457, No.2002-101044, No.2001-305395 and the like); a processing device of optical signal (disclosed in Japanese Patent Laid-Open Publications No.2000-23011 and the like); a cross connect system for optical signals (disclosed in Japanese Patent Laid-Open Publications No.2001-86537 and the like); a light transmitting system (disclosed in Japanese Patent Laid-Open Publications No.2002-26815 and the like); multi-function system (disclosed in Japanese Patent Laid-Open Publications No.2001-339554, No.2001-339555 and the like); and various kinds of optical waveguides, optical branching, optical couplers, optical multiplexers, optical demultiplexers and the like. When the optical system having the optical member according to the present invention is combined with these techniques, it is possible to construct an advanced optical transmission system to send/receive multiplexed optical signals. The optical member according to the present invention is also applicable to other purposes, such as for lighting, energy transmission, illumination, and sensors.

[Example 1]

The POF was produced by the producing method of this embodiment. Regarding the obtained POF, the mechanical strength

and the fluctuation range of the outside diameter were measured. Incidentally, Experiments 2 to 4 were conducted as comparative experiments relative to Experiment 1, and Experiment 6 was conducted as a comparative experiment relative to Experiment 5.

[Experiment 1]

Perfluoro (butenyl vinyl ether) (PBVE) of 35 wt. part, 1,1,2-trichlorotrifluoroethane (R113) of 5 wt. part, and $((CH_3)_2CHOCOO)_2$ of 0.09 wt. part being as polymerization initiator were put into an autoclave made of pressure-resistant glass. After replacing the inner constitution with nitrogen, suspension polymerization was performed at 40 °C to obtain polymer A being as the first raw material 143 having molecular weight of about 150,000. The refractive index of the polymer A was 1.34.

Next, the polymer A was dissolved in perfluoro (2-butyltetrahydrofuran) (PBTHF) being as solvent. And then, chlorotrifluoroethylene (CTFE) oligomer having molecular weight of 800 was added to obtain mixed solution. Incidentally, a ratio of the TFE oligomer to the polymer mixture was 30 wt.%. The solvent of the mixed solution was removed to obtain polymer B being as the raw material of the core (hereinafter, called as core material). The refractive index of the polymer B was 1.41.

The first raw material 43 and the core material of pellet state were sufficiently dried and were respectively supplied to the different extrusion machines. In Experiment 1, the core did not have two-layer structure and the produced POF had two-layer structure of the clad and the core. Thus, the extrusion machine had two screw mixers, wherein a screw diameter was 16 mm. Into the extrusion die, the first raw material 143 and the core material were supplied through the supply routes such that a proportion of amounts thereof was one to two. Inside the extrusion die, the

two-layer structure was formed and the predetermined refractive-index distribution was given thereto at the outer-clad forming passageway having the taper shape.

A spreading portion, at a downstream side of which a discharge port having a radius of 1 mm was formed, had a radius of 15 mm and a length of 1 m. A temperature was set to 190 °C. From the discharge port, the raw POF 12 having a diameter of about 0.800 mm was discharged and was cooled by the water bath 151 being as the cooling device. The cooled raw POF 12 was forwarded into the heating device 172 set to 130 °C, and was heated and drawn. The heat-range length La was 0.75 m and the rotating-speed ratio of the second roller pair 173 to the first roller pair 156 was two times. In this way, the POF 11 having the outer diameter of 500 μm was obtained. The mechanical strength of the obtained POF 11 was measured in conformity with JIS C6862.

The yield strength of the obtained POF was 16 to 17 N, and the rupture strength thereof was 17 to 18 N. The fluctuation range of the outside diameter measured by the second diameter measuring device 178 was plus or minus 3 to 5 μm.

[Experiment 2]

The heat-range length La was set to 1.5 m. Except this length La, Experiment 2 was conducted similarly to the Experiment 1. As to the POF of Experiment 2, the yield strength was 16 to 17 N and the rupture strength was 17 to 18 N. Although the POF of Experiment 2 is identical with that of Experiment 1 with respect to the strengths, the fluctuation range of the outside diameter measured by the second diameter measuring device 178 was plus or minus 5 to 10 μm.

[Experiment 3]

The fibrous polymer was extruded so as to make its outside diameter 0.97 mm. This fibrous polymer was drawn at a drawing magnification of 3.8 times to try production of the POF having the outside diameter of 500 μm. Except these, the conditions were similar to the Experiment 1. In Experiment 3, the raw POF was broken in the heat-drawing process and it was impossible to produce the POF.

[Experiment 4]

The fibrous polymer was extruded so as to make its outside diameter 0.61 mm. This fibrous polymer was drawn at a drawing magnification of 1.5 times to produce the POF having the outside diameter of 500 μm. Except these, the conditions were similar to the Experiment 1. As to the POF of Experiment 2, the yield strength was 8 to 10 N and the rupture strength was 12 to 14 N. Further, the fluctuation range of the outside diameter measured by the second diameter measuring device 178 was plus or minus 5 to 10 μm.

[Experiment 5]

PMMA containing diphenyl sulfide (DPS) of 15 wt.% was used as the third raw material 145. PMMA was used as the second raw material 144. PVDF (Product; KF850 manufactured by KUREHA CORPORATION) was used as the first raw material 143. The heat-range length La was set to 50 cm, and the temperature of the heating device 172 was set to 140 °C. Except these, the conditions were similar to Experiment 1 of Example 2.

The yield strength of the obtained POF was 20 to 22 N and the rupture strength thereof was 22 to 24 N. The fluctuation range of the outside diameter measured by the second diameter measuring device 178 was plus or minus 2 to 4 μm.

[Experiment 6]

The heat-range length La was set to 130 cm. Except this length La, Experiment 6 was conducted similarly to Experiment 5 as a comparative experiment thereof. The yield strength of the obtained POF was 20 to 22 N and the rupture strength thereof was 22 to 24 N. Although a result identical with Experiment 5 was obtained, the fluctuation range of the outside diameter measured by the second diameter measuring device 178 was plus or minus 5 to 7 μm.

From the results of Experiments 1 to 6, it is confirmed that the mechanical strength of the POF can be improved by controlling the heat-range length and the drawing magnification at the time when the raw POF is heated and drawn. In addition, it is also confirmed that the fluctuation of the outside diameter can be reduced by controlling the heat-range length and the drawing magnification at that time.

As described above, according to the present invention, the mechanical strength of the POF is improved and the fluctuation of the outside diameter is reduced. Thus, it is possible to produce the POF being excellent in optical transmission properties, workability and so forth.

When producing the POF, thicknesses of a core part and a clad part are defined such as described below, in order to reduce heat damage in the coating process.

With respect to the POF 11, which is taken up by the take-up device 182 after the heat-drawing process, the structure thereof is adapted to satisfy the following expression (A), wherein D1 represents the outside diameter of the outer clad 22, D2 represents the outside diameter of the inner clad 24, and D3 represents the outside diameter of the core 25, such as shown in Fig. 2. In this embodiment, a part comprising the core 25 and

the inner clad 24 is defined as the core part. Consequently, D2 means the outside diameter of the core part. Meanwhile, the outer clad 22 is defined as the clad part having lower refractive index in comparison with the core part. In other words, the core part is defined as the part having higher refractive index in comparison with the clad part. It is preferable to satisfy the following expression (B), and it is much preferable to satisfy the following expression (C). In the case that the structure of the POF 11 satisfies the following expression before coating, the heat damage to the POF 11 is prevented when the periphery thereof is coated with the coating material, such as described later. Thus, it is possible to prevent the transmission loss of the POF itself from increasing. In the expressions (A) to (C), when the core part is formed with three or more layers, the outside diameter of the outermost layer of the core part is used.

(A) $D1 \geqq D2 \times 1.5$

(B) $D1 \geqq D2 \times 1.8$

(C) $D1 \geqq D2 \times 2.0$

The raw POF 12 is produced by adopting the melt-drawing method of co-extrusion. However, this is not exclusive. For example, fibrous polymer may be obtained by heating and drawing a preform in a state of fiber thicker than the POF. According to this method, the obtained POF has greater mechanical strength and smaller fluctuation range of the diameter in comparison with a method in which melt-extrusion of one time is performed for the preform to produce the POF. Further, there is an advantage that the POF wound around a bobbin is prevented from tightening with time.

The POF according to the present invention is ordinarily used after its surface has been coated with the coating material

to form one or more protective layers, for the purpose of improving flexural and weather resistance, preventing decrease in property by moisture absorption, improving tensile strength, providing resistance to stamping, providing resistance to flame, protecting damage by chemical agents, noise prevention from external light, increasing the value by coloring, and so forth. A method for coating the POF with the coating material is described below in detail.

Although the form and so forth of the POF 11 are not especially limited at the time of coating (see Fig. 2), the diameter D (μm) thereof (which is equal to the outside diameter of the outer clad 22) is preferable to be 200 μm or more and 1500 μm or less. Much preferably, the diameter D is 200 μm or more and 800 μm or less.

Although a carrying speed of the POF 11 is not especially limited as well, the preferred range thereof is 10 m/min to 100 m/min. If the carrying speed is less than 10 m/min, productivity deteriorates and cost increases. If the carrying speed is 100 m/min or more, adhesiveness of the coating material and the POF 11 deteriorates and problems concerning change of mechanical properties are likely to be caused due to separation of the coating material and crystallization of resin.

It is preferable to use thermoplastic resin as the coating material on condition that the POF 11 does not suffer the heat damage (for instance, deformation, denaturalization and thermal decomposition). The preferred thermoplastic resin to be used is capable of hardening at Tg °C or less and at (Tg-50) °C or more, wherein Tg is a glass-transition temperature of the material forming the POF 11. In order to reduce the production cost, it is preferable that a molding time (which is a time for hardening

the material) of the thermoplastic resin to be used is 1 second or more and 10 minutes or less. Much preferably, the molding time is 1 second or more and 5 minutes or less. By the way, in a case that the POF 11 is formed from a plurality of polymers, Tg (°C) is regarded as the lowermost one of the glass-transition temperatures of the respective polymers. Meanwhile, in a case that the polymers composing the POF 11 have no glass-transition temperature, Tg (°C) is regarded as the lowermost one of phase transition temperatures (for example, melting point and so forth).

As the above-mentioned thermoplastic resin, for example, there are polyethylene (PE), polypropylene (PP), vinyl chloride (PVC), ethylene-vinyl acetate copolymer (EVA), ethylene-ethyl acrylate copolymer (EEA), polyester, nylon and so forth. As to the coating material, various kinds of elastomer may be used. When the elastomer is used as the coating material, mechanical properties of bending and so forth may be obtained in virtue of its high elasticity. As the elastomer, there are rubbers of isoprene rubber, butadiene rubber, diene special rubber and so forth. Moreover, there are liquid rubbers of polydiene-base, polyorefin-base and so forth, which exhibit fluidity in a room temperature and become solidified by application of heat. Further, there are various kinds of thermoplastic elastomer, which exhibit rubber elasticity at a room temperature, and become plasticized at a high temperature for easy molding. Furthermore, substances obtained by thermally hardening the mixed liquid of a polymer precursors and reaction agent may be used. In addition, one-pack type thermosetting urethane composition comprising urethane pre-polymer with NCO group, which is described in WO

95/26374 for example, and solid amine having the size of 20μm or less may be also used.

The coating material is not especially limited on condition that molding can be performed at the temperature Tg or less, wherein Tg is the glass-transition temperature of the polymer used for the POF 11. It is possible to use copolymer and mixed polymer of the above described materials or other materials. Besides these, it is possible to use additives and various fillers for the purpose of improving the performance. The additives are fire retardant, antioxidant, radical trapping agent, lubricant, and so forth. The fillers comprise organic compound or inorganic compound.

The POF according to the present invention may be provided with the first and second (or a plurality of) protective layers as need arises. The second protective layer is disposed at the periphery of the first protective layer. When the first protective layer has a sufficient thickness, restriction of curing temperature relative to the material of the second protective layer may be relaxed in comparison with coating of the first protective layer, since the heat damage may be reduced by the first protective layer. The second protective layer may also include additives of fire retardant, ultraviolet absorber, antioxidant, radical trapping agent, lubricant, and so forth.

Examples are shown below to concretely describe the present invention. However, the present invention is not limited to the following examples.

[Example 2]

The raw POF 12 was produced by using a POF producing line. After that, the raw POF 12 was forwarded to the coating process and the circumference thereof was coated with the coating material

to produce the plastic optical cable. As the melt-extruding apparatus, was used a three-layer co-extrusion fiber-forming apparatus comprising three screw-extrusion devices (ϕ 16 mm). As the first raw material for forming the outer clad 22, PVDF was used by 100 pts. wt. As the second raw material for forming the inner clad 24, PMMA was used by 100 pts. wt. As the third raw material for forming the core 25, PMMA+DPS (20%) was used by 100 pts. wt. When the respective raw materials were extruded from the extrusion device to the passageway, extrusion temperatures were respectively 230 °C, 240 °C, and 210 °C. As to the extruded raw POF 12, the outside diameter D1 of the outer clad 22 was 1 mm. The outside diameter D2 of the inner clad 24 of this raw POF 12 was 500 μm, and the outside diameter D3 of the core 25 was 250 μm.

The raw POF 12 was cooled by using a water bath as the cooling device. And then, the raw POF 12 was pulled by a low-speed godet roll at a speed of 5 m/minute. Further, an oven adjusted to 150 °C was used as the heating unit to heat the raw POF 12, and during this heating, a high-speed godet roll drew the raw POF 12 at a speed of 9 m/minute to produce the POF 12. After that, the POF 11 was taken up by a winding unit. As to the POF 11 obtained at this time, the outside diameter D1 of the outer clad 22 was about 750 μm, the outside diameter D2 of the inner clad 24 was about 420 μm and the outside diameter D3 of the core 25 was about 187 μm. In this case, the outside diameter D1 of the outer clad 22 and the outside diameter D2 of the inner clad 24 satisfied $D1 \geqq D2 \times 1.5$, which is the above-mentioned expression. In Example 2, after the POF 11 was taken up, the POF 11 was heated in a thermostatic bath of 190 °C for five minutes. And then, the POF 11 was naturally cooled at room temperature.

The produced POF 11 was consecutively forwarded into a coater with the tension of 0.49 N. After that, the circumference of the POF 11 was coated with the coating material by using a coating apparatus (ϕ30 mm screw extrusion apparatus not shown) to produce the plastic optical cable. At this time, LDPE (MFR=50) was used as the coating material, and coating was performed so as to make the coated outside diameter D1 of the outer clad 1.2 mm under coating conditions of 130 °C and 20 m/minute. The plastic optical cable whose circumference was coated with the coating material was forwarded into a cooler and was cooled. At this time, a water bath containing water of 15 °C was used as the cooler. After cooling, the plastic optical cable was forwarded into a puller, and then, was taken up by the take-up device. The tension was adjusted so as to be 0.98 N at the take-up time. Incidentally, elongation percentage was 0.1 % to 0.3 % before and after coating.

[Comparative Example 1]

The plastic optical cable was produced by using the same material and the same producing method (including the conditions and the devices) with the Example 1. As to the raw POF 12 extruded form the excursion die, the outside diameter D1 of the outer clad 22 was 1 mm, the outside diameter D2 of the inner clad 24 was 600 μm, and the outside diameter D3 of the core 25 was 300 μm. The extruded raw POF 12 was heated and drawn to produce the POF 11. When the POF 12 was taken up by the take-up unit, the outside diameter D1 of the outer clad 22 was about 750 μm, the outside diameter D2 of the inner clad 24 was about 502 μm, and the outside diameter D3 of the core 25 was about 224 μm. Incidentally, the elongation percentage was 0.3% to 0.8% before and after coating.

[Comparative Example 2]

The plastic optical cable 17 was produced by using the same material and the same producing method (including the conditions and the devices) with the Example 1. The produced POF 11 had the same form with the Example 1. In the coating process, however, the coating temperature was changed to 140 °C, although the coating material and the coating speed were same with the Example 1. Incidentally, the elongation percentage was 2.0% to 4.0% before and after coating.

[Evaluation Method]

The transmission loss of the POF 11 was measured at the time of coating by a cutback method. When the transmission loss was 200 dB/km or less, it was regarded as a level (○) at which there are no practical problems. Judgment and evaluation were made in three steps including a level (△) and a level (×) besides the level (○). The level (△) means that the POF 11 is equivalent or slightly inferior. The level (×) means that the POF 11 is unusable.

Table 1 shows evaluation results of Example 1, Comparative Example 1 and Comparative Example 2.

【Table 1】

	D1 (μm)	D2 (μm)	Elongation Percentage (%)	Transmission Loss (db/km)	Level
Example 1	750	420	0.1 to 0.3	140 to 160	○
Comparative Example 1	750	502	0.3 to 0.8	200 to 230	△
Comparative Example 2	750	420	2.0 to 4.0	230 to 250	×

As will be apparent from Table 1, in Example 1, D1 and D2 were respectively equal to 750 μm and 420 μm, and the POF 11

satisfying $D1 \geqq D2 \times 1.5$ was employed to produce the plastic optical cable in a state that the elongation percentage was 1 % or less (0.1 % to 0.3 %). As a result, the value of the transmission loss was 140 to 160 dB/km at the time of coating, and the level (○) having no practical problems was confirmed. In Comparative Example 1, D1 and D2 were respectively equal to 750 μm and 502 μm, and the POF 11 satisfying $D1 \leqq D2 \times 1.5$ and having a larger outside diameter of the inner clad 24 was employed to produce the plastic optical cable 17 in a state that the elongation percentage was 0.3 % to 0.8 % at the time of coating. As a result, the value of the transmission loss was 200 to 230 dB/km at the time of coating. Although the transmission loss exceeded 200 dB/km, the level (△) having practical problems just a little was confirmed. Further, in Comparative Example 2, D1 and D2 were respectively equal to 750 μm and 420 μm similarly to Example 1 so that $D1 \geqq D2 \times 1.5$ was satisfied. However, the POF 11 was coated to produce the plastic optical cable in a state that the elongation percentage was 2.0 to 4.0 %. As a result, the value of transmission loss was 230 to 250 dB/km at the time of coating, and the practically unusable level (×) was confirmed. In view of the above, for the purpose of preventing the transmission loss from increasing and for the purpose of producing the plastic optical cable which is excellent in workability, it was confirmed that the employment of the POF 11 satisfying the expression of $D1 \geqq D2 \times 1.5$ is effective when the circumference of the POF 11 is coated with the coating material to produce the plastic optical cable. Further, it was confirmed that making the elongation percentage 1% or less at the time of coating is effective.

Incidentally, when the thickness of the outer clad 22 is thin in comparison with the inner clad 24 such as shown in Fig.

6, it is possible to reduce the heat damage to be applied to the core, by satisfying D11 $\geqq$ D31$\times$1.5 based on the outside diameter of the core 25.

By the way, defining the thickness of the core part and the clad part such as described above is not exclusive to the POF of the present invention and may be independently executed.

In the meantime, the POF produced in the above-described manner is coated such as described bellow, regulating a percentage of length change. The following coating way, however, is not exclusive to the POF of the present invention and may be independently executed.

As to the coating layer formed in the respective first and second coating processes 18 and 19, a number thereof are not limited to one. A plurality of the layers may be formed. In this case, sometimes the layers are simultaneously formed at the periphery of the POF 11 or the primary coated POF 17, and sometimes the layers are formed one by one in order.

A structure of the primary coated POF 17 and optical properties thereof are described below in detail with Fig. 8. Incidentally, the structure of the POF 11 and the refractive index thereof are as described in the foregoing embodiments.

The primary coated POF 17 of this embodiment is produced by forming a coating layer 230 at the periphery of the POF 11 such as shown in Fig. 8. In this embodiment, the outside diameter D1 of the POF 11 is 200 to 1500 μm and a thickness t of the coating layer is 100 to 1000 μm.

Primary constituent of each of the core and the clad is polymer, and various substances are added therein as need arises. The polymers for forming the core and the clad are as described in detail in the foregoing embodiments.

The coating layer 230 is formed at the periphery of the POF for the purpose of improving flexural and weather resistance, preventing decrease in property by moisture absorption, improving tensile strength, providing resistance to stamping, providing resistance to flame, protecting damage by chemical agents, noise prevention from external light, increasing the value by coloring, and so forth. Although the sole coating layer 230 is illustrated in this embodiment, this is not exclusive such as described above.

Material of the coating layer 230 is selected in accordance with the above-mentioned purpose. As the material, homopolymers and thermoplastic polymer are preferable. The homopolymers are ethylene, propylene, a-olefin and so forth. The thermoplastic polymer is represented by copolymer of the homopolymers. Molecular weight of the thermoplastic polymer and molecular weight distribution thereof are not limited. However, as to the preferred thermoplastic polymer, a melt temperature is 130 °C or less, and a melt flow rate (melt flow index in other words, hereinafter called as MFR) is 20 to 150 (g/10 minutes). The coating layer 230 and the coating layer formed in the second coating process may include additives of fire retardant, ultraviolet absorber, antioxidant, radical trapping agent, lubricant, and so forth.

Next, the coating apparatus and the coating method according to the present invention are described below. The inventors of this application have found out that drawing the POF at the coating time causes the transmission loss of the primary coated POF 17 to become greater than that of the POF 11. A relationship between drawing of the POF and the transmission loss is described below with Fig. 9. Since the same phenomenon occurs in the first and second coating processes, the following

description relates to only the first coating process. In Fig. 9, the horizontal axis represents percentage of length change (hereinafter, called as elongation percentage) concerning the uncoated POF and the coated POF, and the vertical axis represents a fluctuation range (dB/km) of the transmission loss, which is a difference of the transmission losses of the POF and the primary coated POF. From Fig. 9, it will be understood that the fluctuation range of the transmission loss becomes greater as the elongation percentage increases.

It is estimated that this is because the molecular constituting the POF is oriented upon drawing the POF to cause structural irregularity of an optical waveguide. The heat temperature at the coating time is lower than the heat temperature of the heat-extruding process 16. By applying the tension to the POF at the lower temperature, crystal phase and amorphous phase are mixed. It is considered that constituent molecular of the waveguide is oriented due to the mixture of the crystal phase and the amorphous phase.

It is preferable that the transmission loss of the plastic optical cable is small. Consequently, it is preferable that the elongation percentage is small. However, it is difficult to perform good coating without applying the tension to the POF 11. In view of this, an allowable fluctuation range has been found from the transmission loss of the primary coated POF 17, which is actually usable, and the transmission loss of the POF 11 itself. The allowable fluctuation range is about 20 dB/km. Accordingly, the upper limit of the allowable elongation percentage is about 1% from Fig. 9. Based on the above, the coating apparatus and the coating method of the present invention are described below.

Fig. 7 is a schematic illustration showing a coating equipment used in the first coating process. The coating equipment 251 comprises a coater 252, a feeder 253, a winder 256 and a carrier 257. The feeder 253 feeds the POF, which is rolled in a coil shape, to the coater 252. The carrier 257 carries the primary coated POF 17 to the winder 256. The carrier 257 includes a carrying unit 258, which is rotated by a motor (not shown) provided with a controller (not shown) for controlling a torque and a number of rotations. It is preferable that the carrying unit 258 stably supports the primary coated POF 17 without causing a slip thereof, and carries the primary coated POF 17 to the next process without damaging it. As the carrying unit 258, it is possible to use a drive pulley, a drive roller, godet roll and so forth, which are well known. The coating equipment 251 further comprises coolers 261 and a first tension measuring unit 262. The cooler 261 cools the primary coated POF 17 forwarded from the coater 252. The first tension measuring unit 262 measures the tension of the primary coated POF 17 and is disposed between the cooler 261 and the carrier 257.

The first tension measuring unit 262 is provided in order to measure the tension of the POF 11 at the coating time. However, it is difficult to measure the tension of the POF 11 at the same time as coating. Moreover, it is impossible to measure the tension just after coating, since the temperature of the coating layer is too high. In the present invention, the tension of the primary coated POF 17 is measured in a state cooled to a certain temperature at which it is possible to measure the tension. The measured value is regarded as the tension of the coating time. If the first tension measuring unit 262 is disposed at a just anterior position of the coater 252, the tension of the POF 11

detected just before the coater 252 may be regarded as the tension of the coating time.

The feeder 253 includes an advancing unit 271 for feeding the POF 11 to the coater 252, and a dancer pulley 272 for controlling the tension of the POF 11 to be fed to the coater 252. Instead of the dancer pulley 272, the other well-known tension-controlling member of a dancer roller and so forth may be used to control the tension. The dancer pulley 272 is provided with a controller 273 for displacing the dancer pulley on the basis of the detection result of the first tension measuring unit 262. By the way, the feeder 253 and the carrier 257 are independently drivable.

The coating equipment 251 further comprises a second tension measuring unit 266 for measuring a take-up tension of the winder 256. The second tension measuring unit 266 is provided relative to a dancer pulley 265, which is disposed at an upstream side of a winding unit 264 included in the winder 256. However, the second tension measuring unit 266 is not limited to this embodiment on condition that it is possible to measure the take-up tension.

A passage of the coating equipment 251 shown in Fig. 7 is provided with a plurality of supporters 267 for the primary coated POF 17. A number of the supporters 267 may be properly changed. Moreover, another supporter for supporting the POF 11 may be properly disposed. As the supporters, it is possible to use a guide pulley, a guide roller, a godet roll and so forth.

The coating equipment 251 may be successively connected to the respective devices of the heat-drawing process 16 and the second coating process 19. In case the coating equipment 251 is connected to the heat-drawing process 16, the advancing unit 271

may be changed to a carrying unit or the like provided in the heat-drawing process 16. In case the coating equipment 251 is connected to the second coating process 19, the winding unit 264 may be changed to a carrying unit or the like provided in the second coating process 16.

In the coating equipment 251, the coater 252 forms the coating layer 230 (see Fig. 8) with a predetermined coating material 268 on the POF 11 fed from the feeder 253 to produce the primary coated POF 17. The coater 252 heats and melts the forwarded coating material 268 to coat the POF 11. The primary coated POF 17 sometimes has a high temperature just after passing through the coater 252. Thus, in general, the primary coated POF 17 is cooled by using the cooler 261 in order to prevent adhesion to the carrying unit 258. Meanwhile, the passage of the primary coated POF 17 is provided with the supporters 267, and at this passage, internal stress distortion of the primary coated POF 17 is reduced.

The primary coated POF 17 is pulled out of the cooler 261 by the carrier 257. And then, the tension of the primary coated POF 17 is measured by the first tension measuring unit 262 in the carrying direction. The measurement result is sent to the controller 273. Upon input of the measurement result of the first tension measuring unit 262, the controller 273 determines a displacement amount of the dancer pulley 272 on the basis of the measurement result and displaces the dancer pulley 272 by this displacement amount. A relationship between the tension of the primary coated POF 17 and the displacement amount is obtained in advance. On the basis of data of this relationship, the displacement amount is determined. In this way, feedback control of the tension of the POF 11 is performed at the coating time so

that the predetermined tension is always applied to the POF 11 and the primary coated POF 17.

The primary coated POF 17 carried by the carrier 257 is taken up by the winder 256 while the second tension measuring unit 266 measures the take-up tension.

Next, the method for coating the POF 11 by the coating equipment 251 is described below. First of all, the predetermined coating material 268 is supplied to the coater 252 in which the coating material 268 is heated and melted. Moreover, the POF 11 is fed to the coater 252 by the feeder 253. Incidentally, a coating mechanism of the coater 252 is described later in detail with another drawing. The primary coated POF 17 forwarded from the coater 252 is cooled so as to become a predetermined temperature, and is carried by the carrier 257. The tension applied to the primary coated POF 17 by the carrier 257 is not necessarily coincident with the tension applied to the POF 11 by the feeder 253 and the coater 252. Thus, in this embodiment, operational conditions of the carrier 257 and the advancing unit 271 are determined so as to be capable of controlling the tension by the dancer pulley 272. The tension of the POF 11 is controlled by the displacement of the dancer pulley 272 at the coating time such that the elongation percentage of the POF 11 is set within a range of $\pm 1\%$. By setting the elongation percentage within this range, it is possible to prevent the transmission loss of the primary coated POF 17 and the plastic optical cable 20 from deteriorating.

In this embodiment, the first tension measuring unit 262 is disposed at the downstream side of the coater 252, and the dancer pulley 272 is disposed at the upstream side of the coater 252. This arrangement is based on the following point of view. Fig.

10 shows a relationship between the elongation percentage and the measurement result of the first tension measuring unit 262. The former is represented by the vertical axis, and the latter is represented by the horizontal axis. Further, Fig. 11 is a graph of a case in that the dancer pulley 272 is provided with another tension measuring unit and coating is performed without displacing the dancer pulley. A measurement value of this tension measuring unit is represented by the horizontal axis as the tension measured before coating, and the measurement result of the first tension measuring unit 262 is represented by the vertical axis.

Based on Fig. 10, it will be understood that the elongation percentage is greater as the tension of the coated POF 11, or the primary coated POF, is stronger. The graph shows monotonous increment and has a cubic-function-like shape. The elongation percentages of points where an increasing rate suddenly becomes small and large are about -1.0 and 1.0. In view of this, it is considered that the allowable range of the elongation percentage is about ±1%. Thus, it will be understood that the tension of the coated POF is 36 to 50 (×9.8mN) to set the elongation percentage within the allowable range. However, when the tension of the primary coated POF 17 is controlled, sometimes the good coating layer is not formed due to influence given to molecular behavior and so forth of the coating material. Since it will be understood from Fig. 11 that the tension of the coated state becomes greater as the tension of the uncoated state becomes greater, tension control of the coating time is performed at the upstream side of the coater in this embodiment.

By the way, the above-mentioned elongation percentage is the value calculated by {(L2-L1)/L1}×100, wherein L1 is a length

of the uncoated POF and L2 is a length of the primary coated POF having passed through the coater. Incidentally, it is unnecessary to actually and correctly measure the whole lengths of the uncoated POF 11 and the primary coated POF. For example, the elongation percentage can be obtained by the following method, in which the elongation percentage can be easily obtained during the coating time so that production loss is reduced by efficiently controlling the tension during the coating time. First of all, marking is performed in advance for the uncoated POF at regular intervals. A place of marking is referred to as a marking point, and an interval of the adjacent marking points is represented by L1. At this time, it is preferable that the coating material has transparency so as to confirm the marking point of the POF after coating. However, the coating material does not necessarily have the high transparency. In case the single optical cable is used as it is after the first coating process, it is preferable to use a material by which external light is prevented from entering the POF. When the coating material has high transparency, marking is performed every length (interval) L2, which is identical with the interval L1 of the uncoated POF, for the primary coated POF 17 coming out of the coater 252. And then, a difference between the marking points of L1 and L2 is confirmed to know a change of the interval. In contrast, when the coating material has low transparency, marking is performed on the POF in advance or just before coating by using a marking material including metal of aluminum and so forth. Then, after coating, marking of the primary coated POF 17 is detected by a marking detector to obtain a distance of the marking points. In this regard, the present invention does not depend on the method for obtaining the elongation percentage.

In the present invention, it is preferable that the tension T (unit; N) applied to the POF 11 at the coating time satisfies the following expression (1), wherein α is a constant of proportion having a unit of N/mm^2 and D1 represents the outside diameter (unit; mm) of the POF 11 similarly to Fig. 2.

$$T = \alpha \times (D1)^2 \quad (0.5 \leqq \alpha \leqq 6.0) \cdots (1)$$

If the tension T is smaller than $0.5\times(D1)^2$, resin stress is applied in a reverse direction to the carrying direction. Due to this, sometimes the POF 11 shrinks and slacks. Meanwhile, if the tension T is greater than $6.0\times(D1)^2$, the POF 11 is drawn at the elongation percentage of 1% or more and the transmission loss increases.

In the above expression (1), the tension T is expressed as the function of D. Thus, it is possible to control the elongation percentage of the POF in accordance with the outside diameter D of the POF 11 so as to set the elongation percentage within the above range. Even if the elongation percentage is not always measured during the coating time, abnormal tension of the POF 11 and increment of the elongation percentage caused thereby are immediately detected by monitoring whether or not the tension measured by the first tension measuring unit 262 satisfies the expression (1). Thus, it is possible to rapidly find out a defective portion of the POF during the production process.

The above expression (1) is obtained on the basis of $E=(T1/A)/(\lambda/L3)$, which is a well-known equation for finding longitudinal elastic modulus (Young's modulus) E (N/mm^2). In this equation, as well known, T1 represents a force (unit; N) applied in a measurement-axis direction, and A represents a section area (a value obtained by $\pi D^2/4$; unit is mm^2) of a substance to be measured, and (λ/L3) represents an elongation

percentage of the substance to be measured. In other words, T1 corresponds to the tension T of the above expression, and A corresponds to square of the diameter D1 of the POF 11. The expression (1) is obtained in this way and availability thereof is confirmed regarding various POFs made of different materials and having different diameters.

Next, the coater 252 and the coating method using this coater are described below in detail. The coater 252 includes a melting portion for heating and melting the coating material 268, and a coating portion for coating the forwarded POF 11 with the melted coating material 268. The coating portion is described below in detail with Fig. 12, which is a schematic illustration partially showing the coater. The coating portion 281 is assembled so as to unify a coating dies 282 and a nipple 283, by which an interspace is formed. This interspace is a passageway 286 of the melted coating material 268. A first passage 287 of the POF 11 is formed through the nipple 283. The passageway 286 is connected to the first passage 287, and a downstream side of a juncture of them is defined as a second passage 288 along which the POF 11 runs and is coated with the coating material 268. The coating dies 282 and the nipple 283 are provided with a temperature controller 291 for controlling the coating material 268 at a predetermined temperature to obtain desired flowability. Meanwhile, the coater 252 is provided with a tube 294 for sending the melted coating material 268 into the coating portion 281. The tube 294 is disposed so as to connect the melting portion and the passageway 286. The dies 282 performs coating of the POF in a state that the heated and melted coating material is pressurized.

In the coating portion 281, an outlet of the primary coated POF 17 is referred to as a dies outlet port 282a, and a position

where the coating material 268 reaches the second passage 288 is referred to as a coating-material supply port 286a. Moreover, an end of the coating-material supply port 286a, which is positioned at the side of the dies outlet port 282a, is referred to as a land-start position 282b. Further, a downstream side of the land-start position 282b within the second passage 288 is referred to as a land portion 290. Reference letter L (μm) represents a land length extending from the land-start position 282b to the dies outlet port 282a. Reference letter d (μm) represents a supply length of the coating-material supply port 286a in the advancing direction of the POF. Reference letter Ta (μm) represents a diameter of the dies outlet port 282a. Reference letter Tb1 (μm) represents an outside diameter of the nipple 283 of the land-start position 282b side, namely represents an outside diameter of a downstream end of the nipple 283. Reference letter Tb2 (μm) represents a diameter of the first passage 287.

As to the coater 281, the POF 11 passes through the first passage 287 and the second passage 288, and then comes out of the dies outlet port 282a. The first passage diameter Tb2 is slightly larger than the outside diameter D1 of the POF 11 so as to prevent the circumferential surface of the POF from being damaged. The coating material 286 guided from the tube 294 to the passageway 286 reaches the second passage 288 through the passageway 286 to coat the circumferential surface of the POF 11 at this second passage 288. And then, the POF 11 comes out to the outside as the primary coated POF 17, which is coated with the coating material 282.

In the coating method using the coater having the above-described coating portion 281, it is preferable that a speed

for carrying the POF 11 in the coating portion 281 is 10 m/minute to 100 m/minute. If the carrying speed is less than 10 m/minute, production efficiency is too low. Moreover, since the POF takes too long time for passing the heated first passage 287, sometimes the POF 11 elongates due to the heat applied from the nipple 283. If the carrying speed is faster than 100 m/minute, a flow velocity of the coating material 268 reaches the limit shear velocity and melt fracture is caused. Moreover, since a cooling period of the cooler 261 is likely to lack and the heat energy of the coating time is transmitted to the POF, there is a possibility that the transmission loss increases. The other problems are likely to be caused, in that adhesiveness between the coating material 268 and the POF 11 deteriorates and mechanical properties are changed due to crystallization of the coating material 268.

By adjusting a relative position of the coating dies 282 and the nipple 283 and by altering the respective forms of them, it is possible to effectively prevent the transmission loss from deteriorating due to heat deterioration of the POF 11.

TD (unit; °C) represents a temperature (hereinafter, called as coating temperature) of the time when the coating material 68 is coated. It is preferable that the coating temperature is low as much as possible in order to reduce the heat quantity to be given to the POF 11. The coating temperature TD may be determined in consideration of thermal conductivity and specific heat of the raw material of the POF 11. For example, when the polyethylene is used as the coating material 268, it is preferable that the coating temperature is 140 °C or less, and much preferably, the coating temperature is 130 °C or less. At this time, the coating material 268 needs to have flowability. For example, when the coating material 268 has a melt point Tm (°C), it is preferable

to satisfy $Tm \leqq TD \leqq (Tm+30)°C$, and much preferable to satisfy $Tm \leqq TD \leqq (Tm+20)°C$, and especially preferable to satisfy $Tm \leqq TD \leqq (Tm+10)°C$. For example, when the coating material 268 is low-density polyethylene having a melt point of 120 °C, it is preferable that the coating temperature is 120 °C to 130 °C.

A preferable range of the diameter Ta of the outlet port 282 is $D2 \leqq Ta(\mu m) \leqq 1.3 \times D2$. A range of $1.05 \times D2 \leqq Ta(\mu m) \leqq 1.25 \times D2$ is much preferable. A range of $1.1 \times D2 \leqq Ta(\mu m) \leqq 1.2 \times D2$ is especially preferable.

A preferable range of the land length L is $Ta \leqq L \leqq 4 \times Ta$. A range of $Ta \leqq L \leqq 3.5 \times Ta$ is much preferable. A range of $Ta \leqq L \leqq 3 \times Ta$ is especially preferable.

A preferable range of the outside diameter Tb1 of the nipple 283 is $0.7 \times Ta \leqq Tb1 \leqq 1.2 \times Ta$. A range of $0.8 \times Ta \leqq Tb1 \leqq 1.2 \times Ta$ is much preferable. A range of $0.9 \times Ta \leqq Tb1 \leqq 1.1 \times Ta$ is especially preferable.

A preferable range of the diameter Tb2 of the first passage 287 is $(D2+10)\mu m \leqq Tb2 \leqq (D2+300)\mu m$. A range of $(D2+20)\mu m \leqq Tb2 \leqq (D2+50)\mu m$ is much preferable. A range of $(D2+30)\mu m \leqq Tb2 \leqq (D2+50)\mu m$ is especially preferable.

A preferable range of the supply length d(μm) is $Ta \leqq d \leqq 2 \times Ta$. A range of $1.1 \times Ta \leqq d \leqq 1.8 \times Ta$ is much preferable. A range of $1.2 \times Ta \leqq d \leqq 1.6 \times Ta$ is especially preferable.

The diameter Ta, the land length L, the diameter Tb2 and the supply length d affect the tension T. By controlling these parameters, it is possible to accurately adjust the tension T within the predetermined range. In general, if the supply length d is too long, the elongation percentage is likely to increase. By contrast, if the supply length d is too short, the elongation percentage becomes small, namely is likely to contract. In view

of this, it is preferable that the supply length d is roughly set within a range in which the tension is controllable by the dancer pulley 262.

As to the coating form of the second coating process 19, there are tight coating and loose coating. These coating forms are as described in the forgoing embodiments. Meanwhile, the coating materials of the first and second coating processes may include additives of fire retardant, ultraviolet absorber, antioxidant, radical trapping agent, lubricant, and so forth. Such additives are also described in the forgoing embodiments. Besides these, description overlapping with the foregoing embodiments is abbreviated in this embodiment.

[Example 3]

The primary coated POF 17 was produced by the above-described coating apparatus and method, and the transmission loss thereof was measured. Example including production of the POF is described below.

The POF 11 was produced by the melt-extruding method such that the core 25 was PMMA+DPS (20 wt.%), the inner clad 24 was PMMA, and the outer clad 22 was PVDF. The used melt-extruding apparatus comprised three screw kneading extruders, and a diameter of each of kneading portions was ϕ16mm. Temperature of the respective kneading extruders was adapted to be controlled by a temperature controller so as to keep the raw materials of the outer clad, the inner clad and the core at 210 °C, 240 °C and 230 °C respectively. The three raw materials were simultaneously extruded from the extrusion die so as to produce the raw POF 12 having an outside diameter of 1 mm. An inner diameter of the extrusion die was 1mm. Regarding the extruded raw POF 12, the

outside diameter of the inner clad 24 was 952μm and the outside diameter of the core 25 was 580μm.

The extruded raw POF 12 was cooled by the water bath, of which temperature was adjusted to 15 °C, and was pulled at a speed of 5 m/minute by a drive pulley (godet roll) being as the carrier. And then, the raw POF 12 was heated by the heater of which temperature was set to 150 °C. At the same time, the raw POF 12 was drawn by a drive pulley, of which carrying speed was 9 m/minute, to produce the POF 11. The obtained POF 11 was taken up by the winder. The outside diameter of the POF 11 was about 316 μm. The taken-up POF 11 was heated at 190 °C for five minutes. After that, the POF was naturally cooled at a room temperature.

The obtained POF 11 was coated under the following conditions. At the outset, marking was performed for the POF 11 every 300m. The coating portion 281 was assembled such that the nipple 283 was attached to the coating dies 282 so as to have the supply length d of 2000μm. The diameter Ta of the coating dies was 1300μm, and the land length L thereof was 3000μm. The outside diameter Tb1 of the nipple 283 was 1250μm, and the diameter Tb2 of the first passage thereof was 600μm. The coating portion 281 was attached to the melting portion having the screw diameter of 30mm. The low-density polyethylene (trade name; Nipolon-L, MFR; 50 g/10 minutes, manufactured by TOSOH CORPORATION) being as the coating material was supplied to the coater 252 and was melted at 130 °C. And then, the POF 11 carried along the first passage 287 at a speed of 20 m/minute was coated with the coating material 268 to produce the primary coated POF 17 having the outside diameter D2 of 1200μm. While coating was performed for 1500m from the first marking point of the POF 11, the tension was controlled by the dancer pulley 272 so as to make the tension,

which is detected by the first tension measuring unit 262, (40 × 9.8) ± (5 × 9.8)mN. By the marking sensor disposed at the downstream side of the cooler 261, marking was detected. The distance between marking was measured to obtain the elongation percentage of the POF 11, which is caused by coating.

As a result of Example 3, the elongation percentage of the POF 11 was -0.5 to 0.5 % from the first making point of the POF 11 to the marking point of 1500m thereof. The primary coated POF 17 was cut at the respective marking points of the POF 11 to measure the transmission loss of the primary coated POF 17. As a result, the transmission loss was 0 to +1 dB in comparison with the transmission loss of the POF 11, which was cut by 300m in advance.

From the result of Example 3, it is confirmed that the elongation percentage of the POF 11 was regulated under 1% at the first coating process and the transmission loss was prevented from deteriorating.

[Example 4]

Example 4 was conducted as a comparative experiment relative to Example 3. Coating the POF 11 was started on the condition that the tension measured by the first tension was 40 ×9.8 mN. Tension control was not especially performed, and in this state, coating was continued. The tension was maintained at 40g while coating was performed within a first zone extending from the first marking point of the POF 11 to the marking point of 300m. However, the tension increased up to 70×9.8mN when the marking point of the 300m position had come out of the dies outlet port 282a. Successively, coating was performed for the next second zone of 300m. Further, the next 300m was coated. When the third zone of 300m had been coated and the marking point of the 900m position had come out of the dies outlet port 282a, the

tension became 90×9.8mN. After that, coating was continued as it is. The other conditions were similar to Example 3.

Results of this example are shown in Figs. 13 and 14. Fluctuation of the tension T is shown in Fig. 13. Incidentally, the elongation percentage of the POF 11 was 4% regarding 300m of the second zone, and was 8% regarding a fourth zone extending from 900m to 1200m. The primary coated POF 17 was cut at the marking points of the POF 11 to measure the transmission loss. Fig. 14 is a graph showing a difference between the measured transmission loss and the transmission loss of the POF 11 of 300m. Fig. 14 shows the difference as fluctuation of the transmission loss. Incidentally, a value of the fluctuation is indicated in 1 km. Such as shown in Fig. 14, in the case that the tension T was equal to 40×9.8(mN), the values of the transmission loss were same with respect to the samples of the POF 11 and the primary coated POF. However, in the case that the tension T was equal to 70×9.8(mN), the transmission loss of the primary coated POF was higher than that of the POF 11 by 20dB/km. Moreover, in the case that the tension T was equal to 90×9.8(mN), the transmission loss of the primary coated POF was higher than that of the POF 11 by 40dB/km.

From the result of Example 4, it is confirmed that the POF was elongated at the coating time. Further, it is confirmed that the transmission loss of the primary coated POF was grater than that of the POF in the case that the elongation percentage was 1% or more. By comparing Example 4 with Example 3, it is understood that tension control of the coating time is effective to control the elongation percentage.

As described above, according to the present invention, it is possible to obtain the primary coated POF by continuously coating without deteriorating the transmission loss.

Finally, Fig. 15 schematically shows another embodiment of the coating device included in the coater. The coating device 90 includes a coating-material passageway 92 along which the coating material 91 runs, and a discharge port 93. The POF 11 fed from the fiber feeder 72 is forwarded into the coating device 90 with prescribed tension. The circumference of the POF 11 is coated with the coating material 91 near the discharge port 93 to form the protective layer 94. Thereupon, the plastic optical cable is produced.

The coating material 91 is contained in a tank (not shown) provided with a temperature adjuster. It is preferable that an inside temperature of the tank is set so as to keep a melt state having viscosity by which the coating material 91 is capable of obtaining desired flowability. The inside temperature of the tank is different in accordance with a kind of the coating material 91. Further, it is preferable that the inside of the coating-material passageway 92 is adjusted to a desired temperature. For this reason, it is preferable to provide a temperature adjuster (not shown) inside the coating device 90 to adjust the inside temperature thereof. When the circumference of the POF 11 is coated with the coating material 91, a temperature (coating temperature) of the coating material 91 is preferable to be low as much as possible in order to reduce heat quantity to be moved to the POF 11. For example, in a case using polyethylene as the coating material 91, the coating temperature is preferable to be 140 °C or less. Much preferably, the coating temperature is 130 °C or less. Incidentally, although the lower limit of the coating temperature is not especially restricted, the coating temperature needs to be a temperature at which the coating material 91 has flowability. For instance, when

low-density polyethylene is used as the coating material 91, the coating temperature is preferable to be 110 °C to 130 °C.

Industrial Applicability

The present invention relates to a method and an apparatus utilized in producing a plastic optical fiber, and further relates to a method and an apparatus utilized in coating the plastic optical fiber.

CLAIMS

1. A producing method for a plastic optical fiber, which is produced by drawing a raw optical fiber continuously advanced, said producing method comprising the steps of:

heating a region of 0.1m to 1m of said raw optical fiber by a heating device; and

drawing said region by a drawing device at a magnification of 1.5 to 3.5 times while said range is heated.

2. A producing method for a plastic optical fiber according to claim 1, wherein said raw optical fiber is produced by a melt-extruding process.

3. A producing method for a plastic optical fiber according to claim 1, wherein said drawing device includes first and second rollers, which are disposed at upstream and downstream sides of said heating device to support said raw optical fiber, and said magnification is adjusted by controlling a rotating speed of the respective first and second rollers.

4. A producing method for a plastic optical fiber according to claim 3, wherein at least one of said first and second rollers comprises a nip member for nipping said raw optical fiber.

5. A producing method for a plastic optical fiber according to claim 1, wherein said raw optical fiber includes a clad, which constitutes a circumferential part, and a core, which constitutes the inside of said clad, said core having a circular section and a refractive index thereof gradually increasing toward a central portion.

6. A producing method for a plastic optical fiber according to claim 5, wherein at least one of said core and said clad has polymer of (meth)acrylic ester as primary constituent.

7. A producing method for a plastic optical fiber according

to claim 5, wherein at least one of said core and clad contains fluorine.

8. A producing method for a plastic optical fiber according to claim 1, wherein said plastic optical fiber includes a core part and a clad part having lower refractive index in comparison with said core part, said producing method further including a coating step in which said plastic optical fiber is coated under a condition that a relation of $D1 \geqq D2 \times 1.5$ is satisfied, wherein D1 represents an outside diameter of said clad part and D2 represents an outside diameter of said core part.

9. A producing method for a plastic optical fiber according to claim 8, wherein said plastic optical fiber is coated so as to keep a percentage of length change (unit; %), which is calculated by $\{(L2-L1)/L1\} \times 100$, within a range of ± 1, wherein L1 represents a length of the plastic optical fiber of a pre-coating state and L2 represents a length the coated plastic optical fiber.

10. A producing method for a plastic optical fiber according to claim 9, wherein tension applied to the coated plastic optical fiber is detected by a tension detecting device, and said percentage of length change is adjusted by controlling tension of said plastic optical fiber, which is carried to said coater, with a tension controller on the basis of a detection result of said tension detecting device.

11. A producing method for a plastic optical fiber according to claim 10, wherein the tension T (unit; N) applied to the coated plastic optical fiber, and an outside diameter D1 (unit; mm) of said plastic optical fiber satisfy the following relation,

$$T = \alpha \times (D1)^2$$

wherein α (unit; N/mm^2) is 0.5 or more and is 6.0 or less.

12. A producing method for a plastic optical fiber according to claim 10, wherein said tension controller is a dancer pulley for controlling the tension of said plastic optical fiber on the basis of the detection result of said tension detecting device.

13. A producing method for a plastic optical fiber according to claim 9, wherein said plastic optical fiber has a circular section and a refractive index thereof changes so as to become lower from a central portion toward a circumferential surface.

14. A producing method for a plastic optical fiber according to claim 9, wherein at least one of a core part and a clad part of said plastic optical fiber has polymer of (meth)acrylic ester as primary constituent.

15. A producing method for a plastic optical fiber according to claim 9, wherein at least one of a core part and a clad part of said plastic optical fiber contains fluorine.

16. A producing method for a plastic optical fiber according to claim 9, wherein said plastic optical fiber is coated by a coater in a state that a coating material is pressurized.

17. A producing method for a plastic optical fiber according to claim 1, further including a coating step in which said plastic optical fiber is coated so as to keep a percentage of length change (unit; %), which is calculated by $\{(L2-L1)/L1\}\times 100$, within a range of ± 1, wherein L1 represents a length of the plastic optical fiber of a pre-coating state and L2 represents a length the coated plastic optical fiber.

18. A coating method for a plastic optical fiber, which includes a core part and a clad part having lower refractive index in comparison with said core part, said coating method comprising the step of:

coating said plastic optical fiber under a condition that

a relation of D1≧D2×1.5 is satisfied, wherein D1 represents an outside diameter of said clad part and D2 represents an outside diameter of said core part.

19. A coating method for a plastic optical fiber according to claim 18, wherein said plastic optical fiber is coated so as to keep a percentage of length change (unit; %), which is calculated by {(L2-L1)/L1}×100, within a range of ±1, wherein L1 represents a length of the plastic optical fiber of a pre-coating state and L2 represents a length the coated plastic optical fiber.

20. A coating method for continuously coating a plastic optical fiber by a coater, said plastic optical fiber being coated with a coating material including thermoplastic resin, said coating method comprising the step of:

coating said plastic optical fiber with said coating material so as to keep a percentage of length change (unit; %), which is calculated by {(L2-L1)/L1}×100, within a range of ± 1, wherein L1 represents a length of the plastic optical fiber of a pre-coating state and L2 represents a length the coated plastic optical fiber.

21. A producing apparatus for a plastic optical fiber which is produced by drawing a raw optical fiber continuously advanced, said producing apparatus comprising:

a heating device for heating a region of 0.1m to 1m of said raw optical fiber; and

a drawing device for drawing said heated region of said raw optical fiber, said drawing device including a first roller for carrying the unheated raw optical fiber and a second roller for carrying the heated raw optical fiber, and a rotating speed of said second roller being controlled independently from said first

roller.

22. A producing apparatus for a plastic optical fiber according to claim 21, wherein at least one of said first and second rollers comprises a nip member for nipping said raw optical fiber.

23. A producing apparatus for a plastic optical fiber according to claim 21, wherein said drawing device draws said heated region of said raw optical fiber at a magnification of 1.5 to 3.5 times.

24. A coating apparatus for continuously coating a plastic optical fiber, comprising:

a coater for continuously coating said plastic optical fiber with a coating material including thermoplastic resin;

a carrier for carrying the coated plastic optical fiber to a successive process;

a tension measuring device for detecting tension of said plastic optical fiber , said tension detecting device being disposed at a passage residing between said coater and said carrier; and

a tension controller for controlling the tension of said plastic optical fiber, which is carried to said coater, so as to set a percentage of length change of said plastic optical fiber within a predetermined range at a coating time.

25. A coating apparatus according to claim 24, wherein said tension controller controls the tension of said plastic optical fiber in accordance with a detection result of said tension measuring device.

26. A coating apparatus according to claim 24, wherein said coater has a pressure-type dies for coating said plastic optical fiber in a state that said coating material melted by heating is pressurized.

FIG. 1

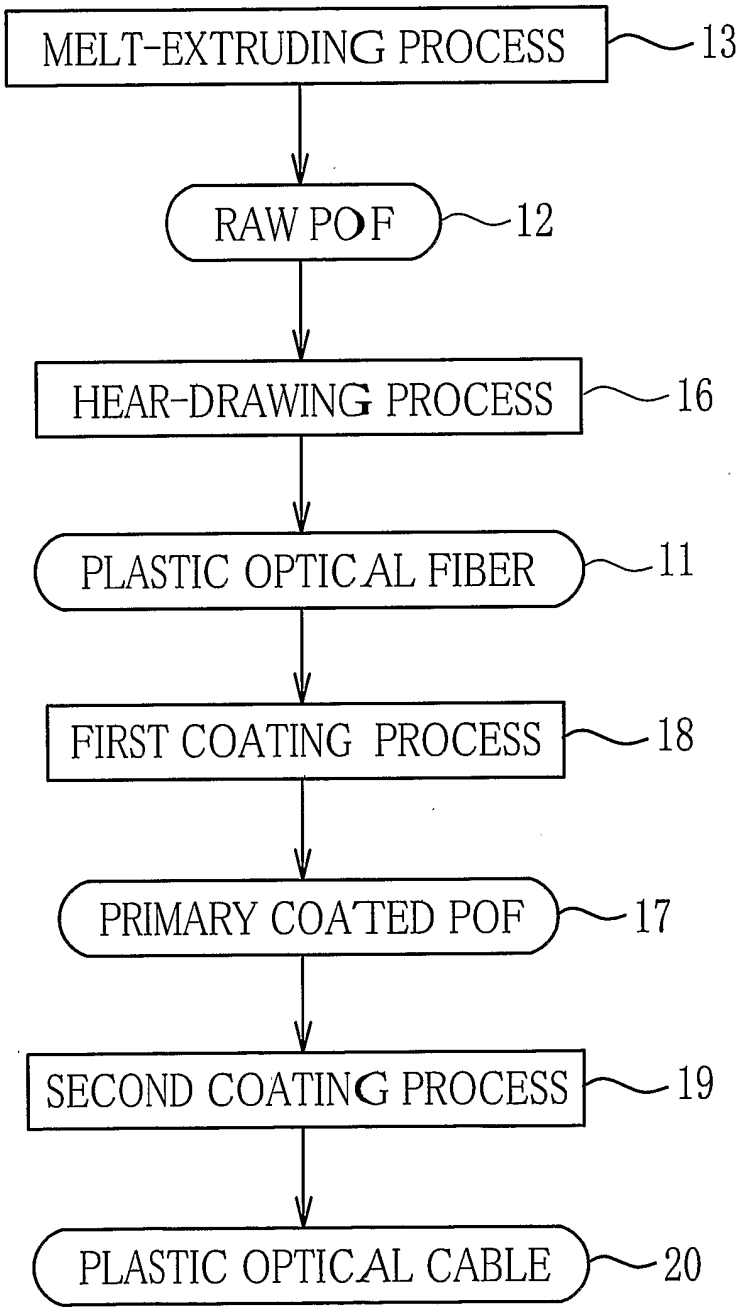

MELT-EXTRUDING PROCESS
13
RAW POF
12
HEAR-DRAWING PROCESS
16
PLASTIC OPTICAL FIBER
11
FIRST COATING PROCESS
18
PRIMARY COATED POF
17
SECOND COATING PROCESS
19
PLASTIC OPTICAL CABLE
20

FIG. 2

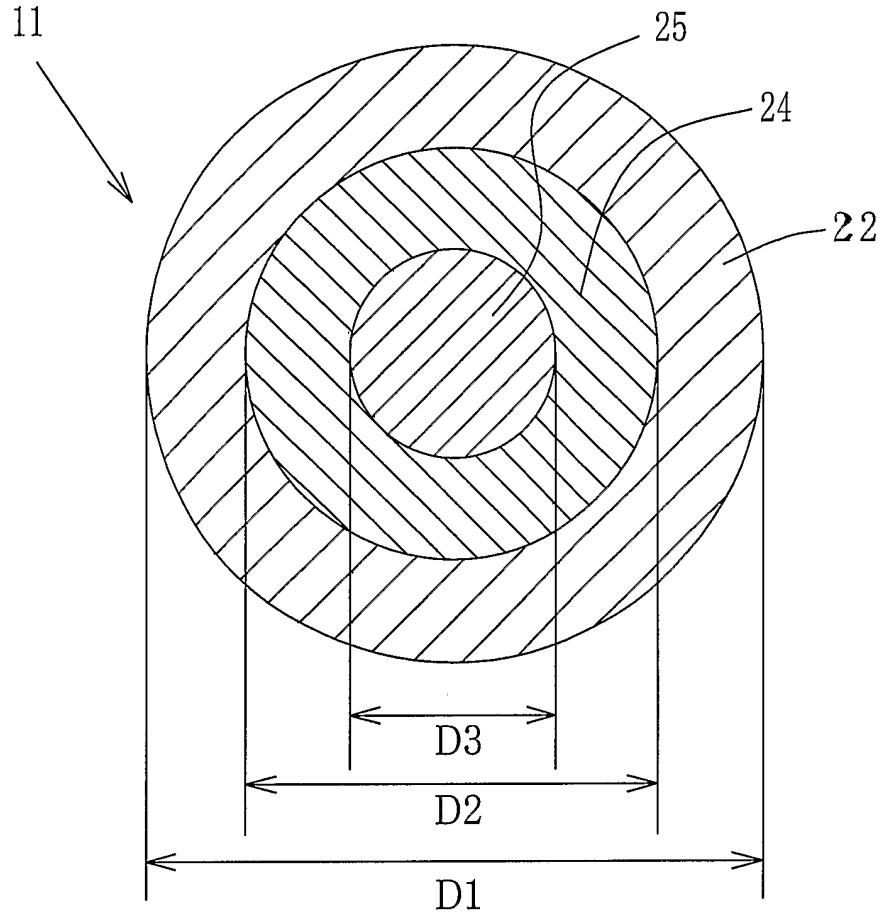


FIG. 3

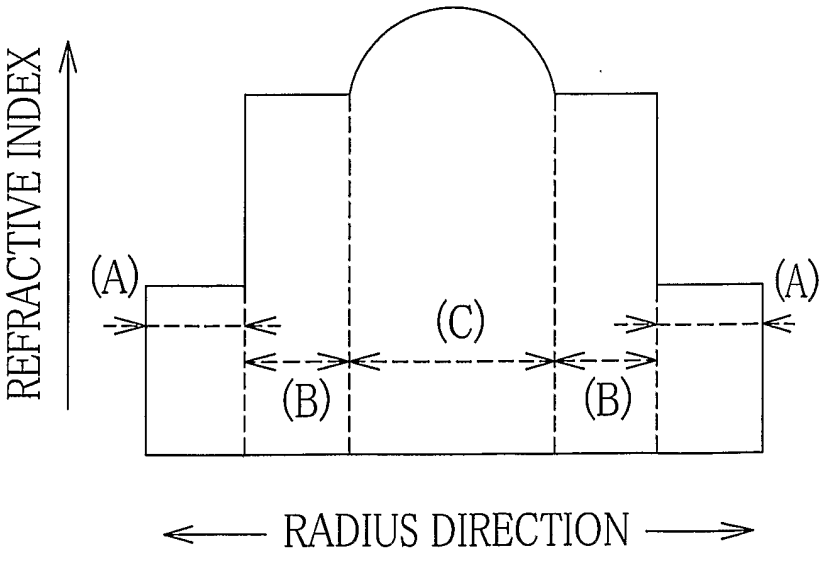


FIG. 4

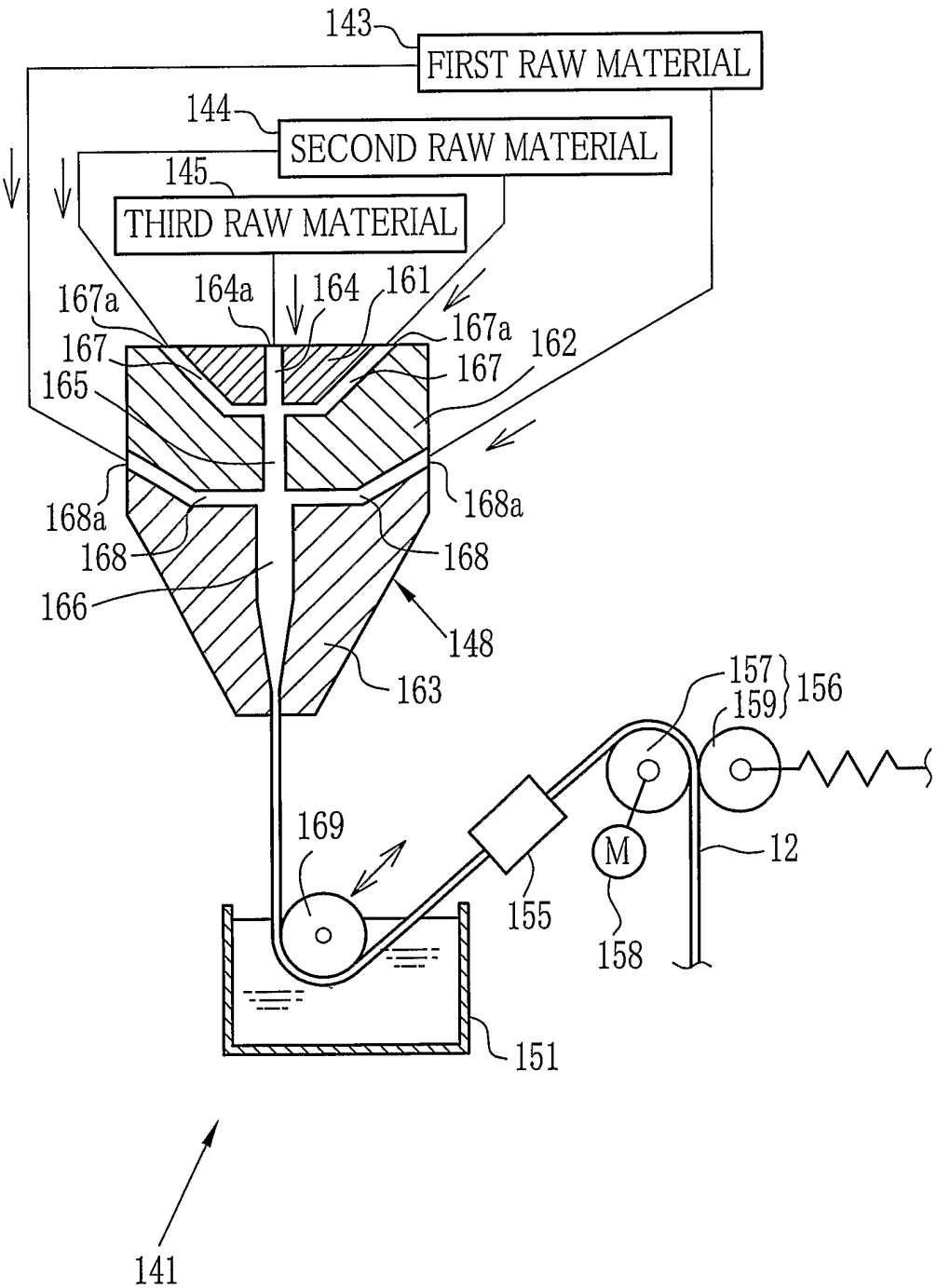

143
FIRST RAW MATERIAL
144
SECOND RAW MATERIAL
145
THIRD RAW MATERIAL
167a
164a
164
161
167a
167
167
162
165
168a
168a
168
168
166
148
163
157
156
159
169
M
12
155
158
151
141

FIG. 5

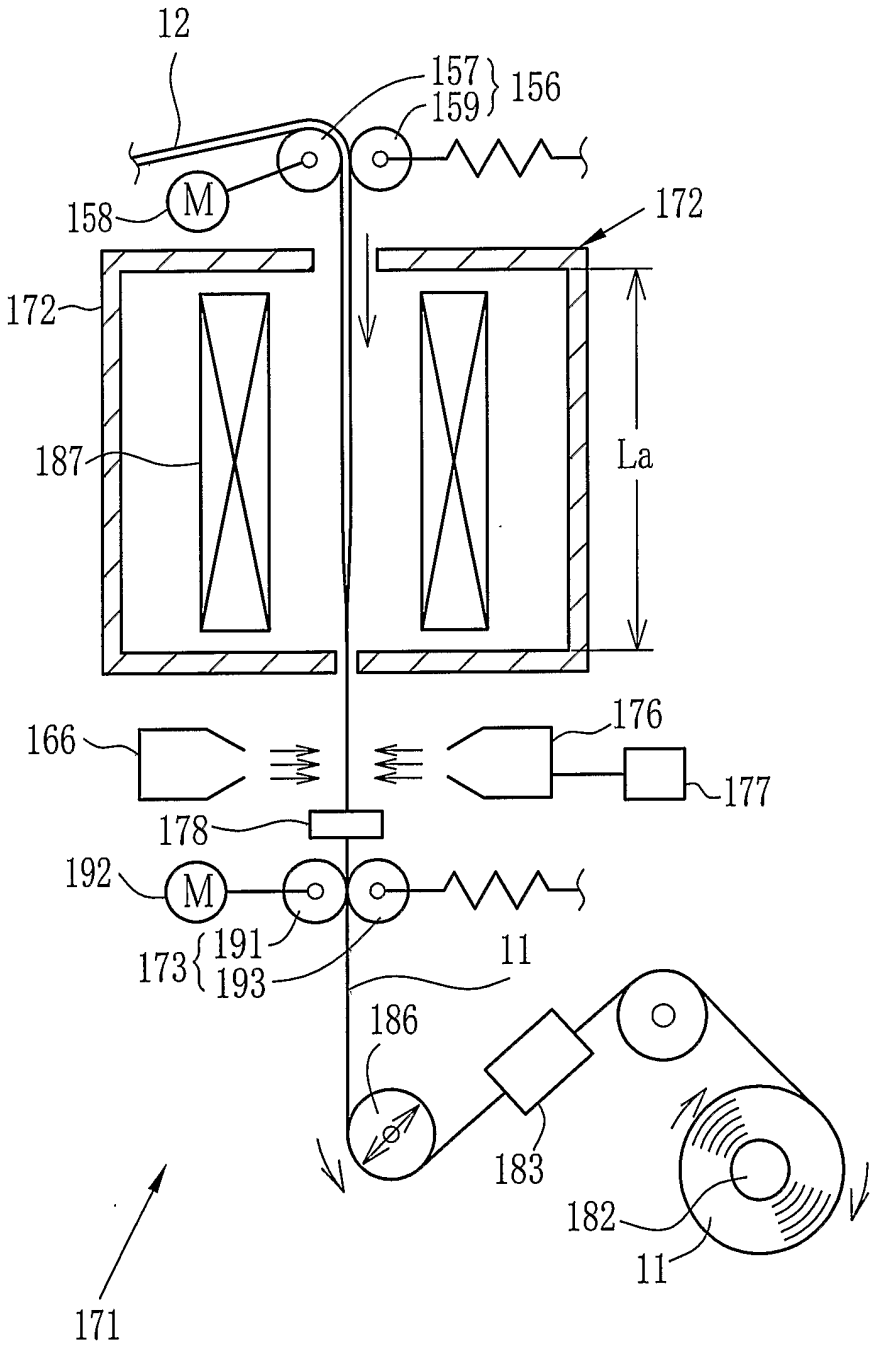

12
157
159
156
158
M
172
172
187
La
166
176
177
178
192
M
173
191
193
11
186
183
182
11
171

FIG. 6

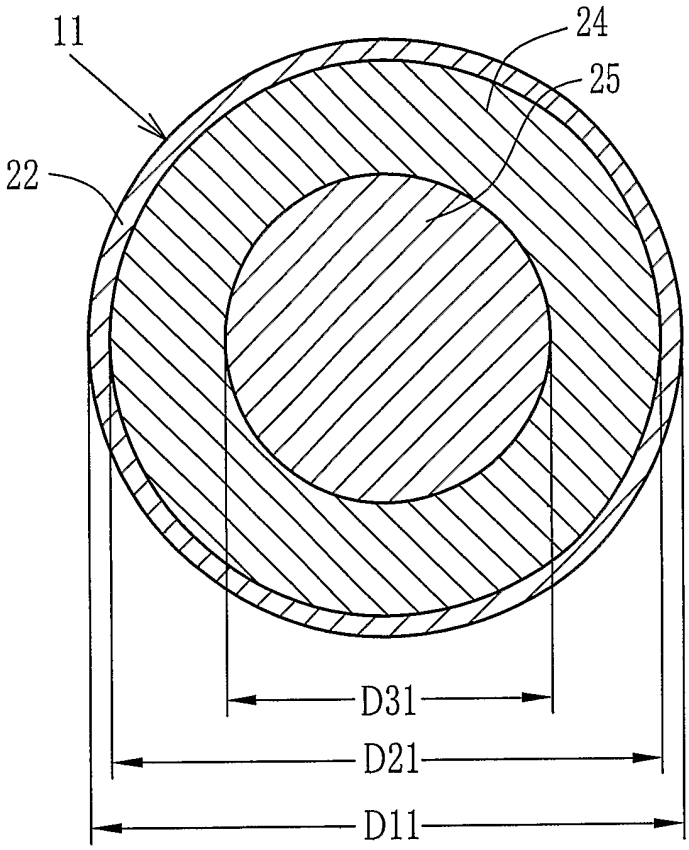


FIG. 7

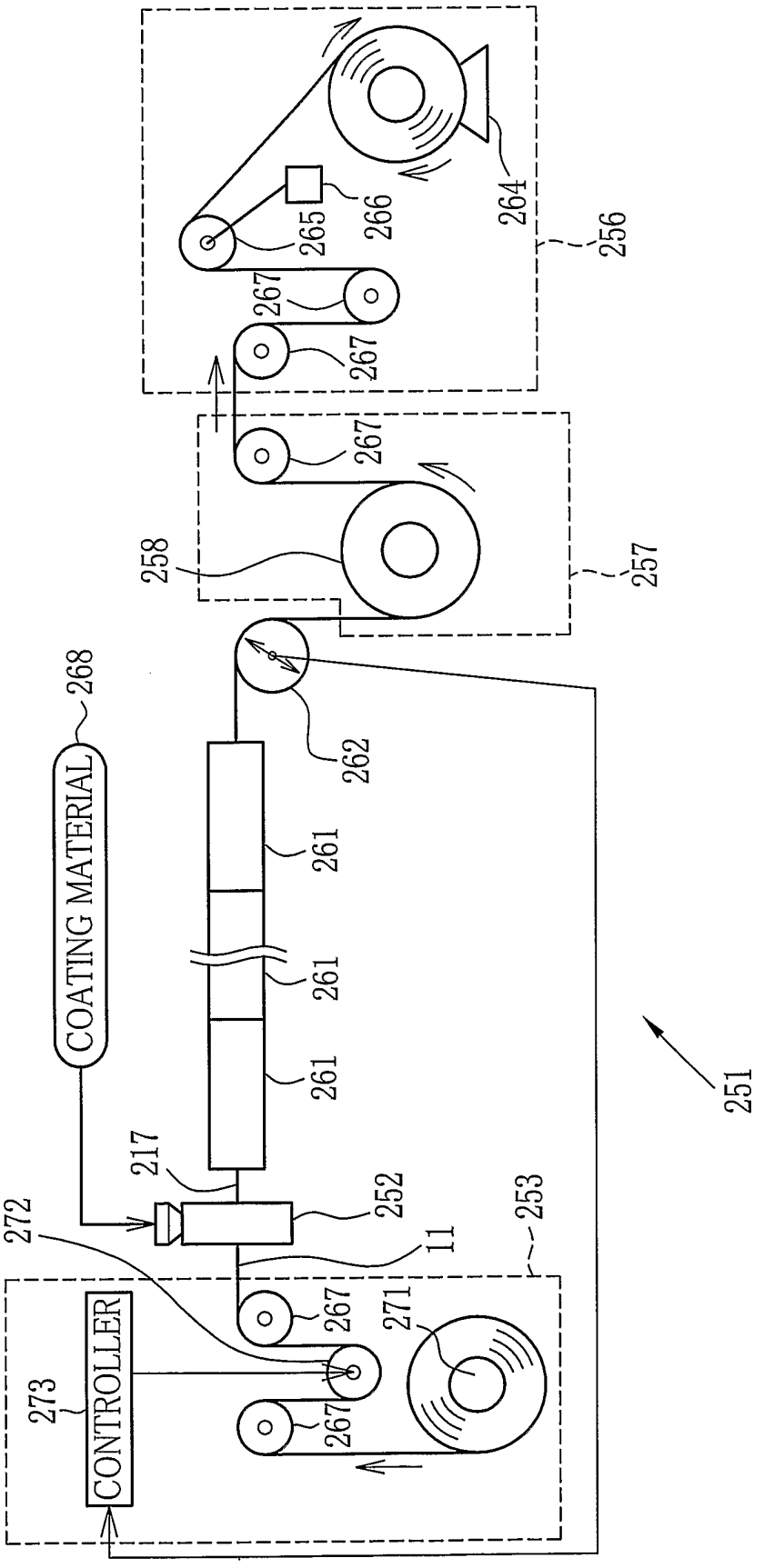

264
265
266
256
267
267
267
258
257
268
COATING MATERIAL
262
261
261
261
217
252
253
272
11
271
267
267
273
CONTROLLER
251

FIG. 8

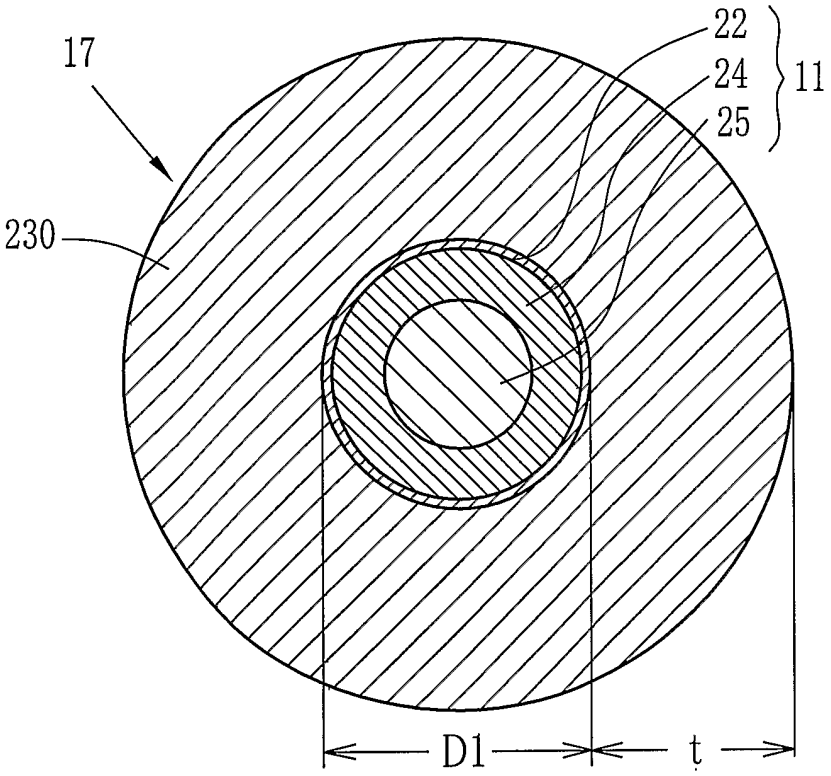

17
230
22
24
25
11
D1
t

FIG. 9

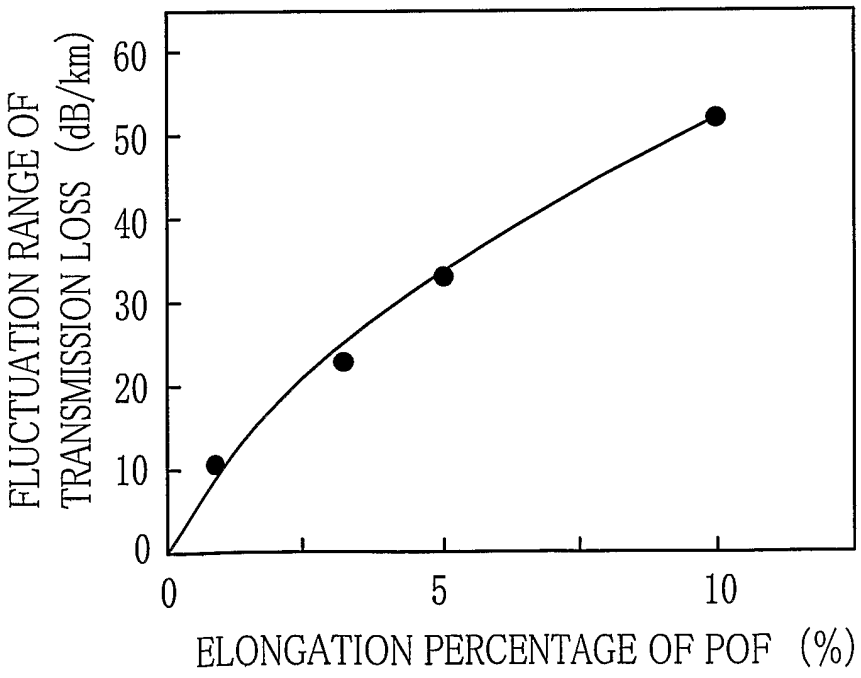

FLUCTUATION RANGE OF TRANSMISSION LOSS (dB/km)
60
50
40
30
20
10
0
0
5
10
ELONGATION PERCENTAGE OF POF (%)

FIG. 10

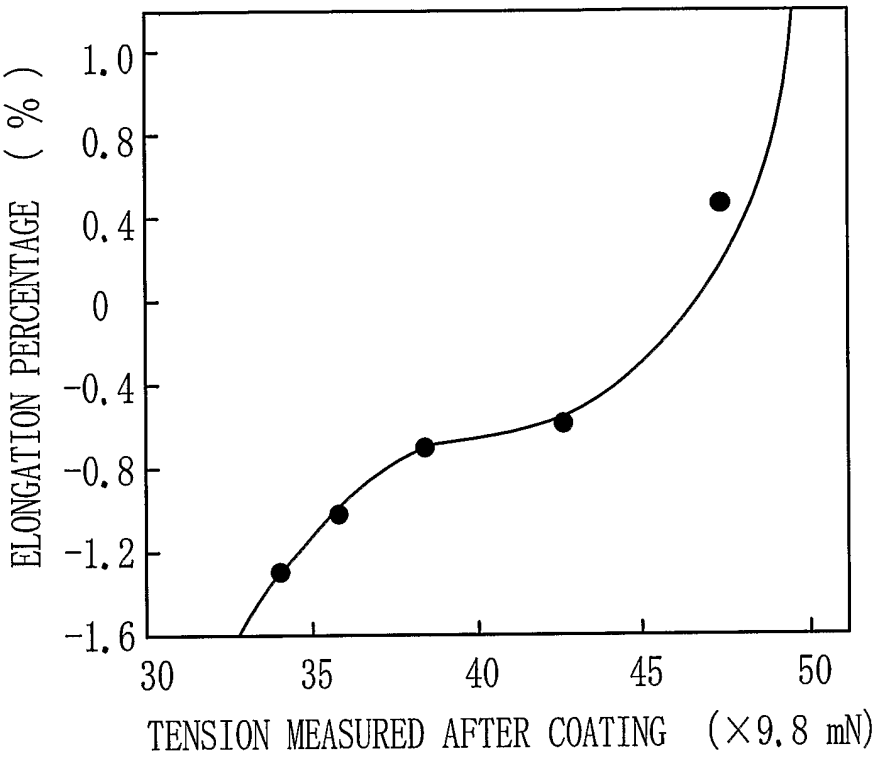

ELONGATION PERCENTAGE (%)
1.0
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
30
35
40
45
50
TENSION MEASURED AFTER COATING (×9.8 mN)

FIG. 11

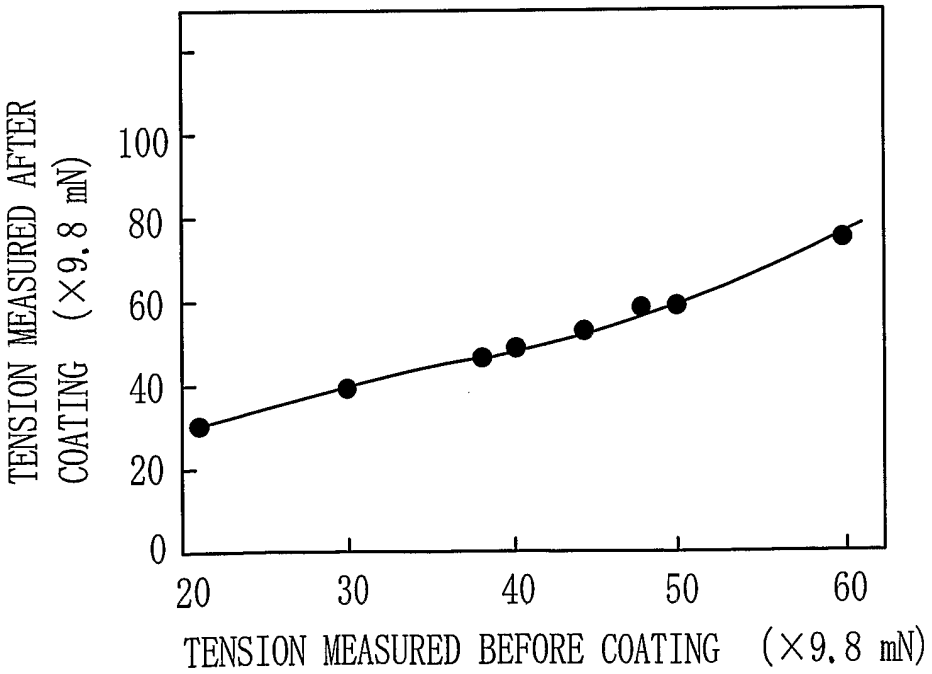

TENSION MEASURED AFTER COATING (×9.8 mN)
100
80
60
40
20
0
20
30
40
50
60
TENSION MEASURED BEFORE COATING (×9.8 mN)

FIG. 12

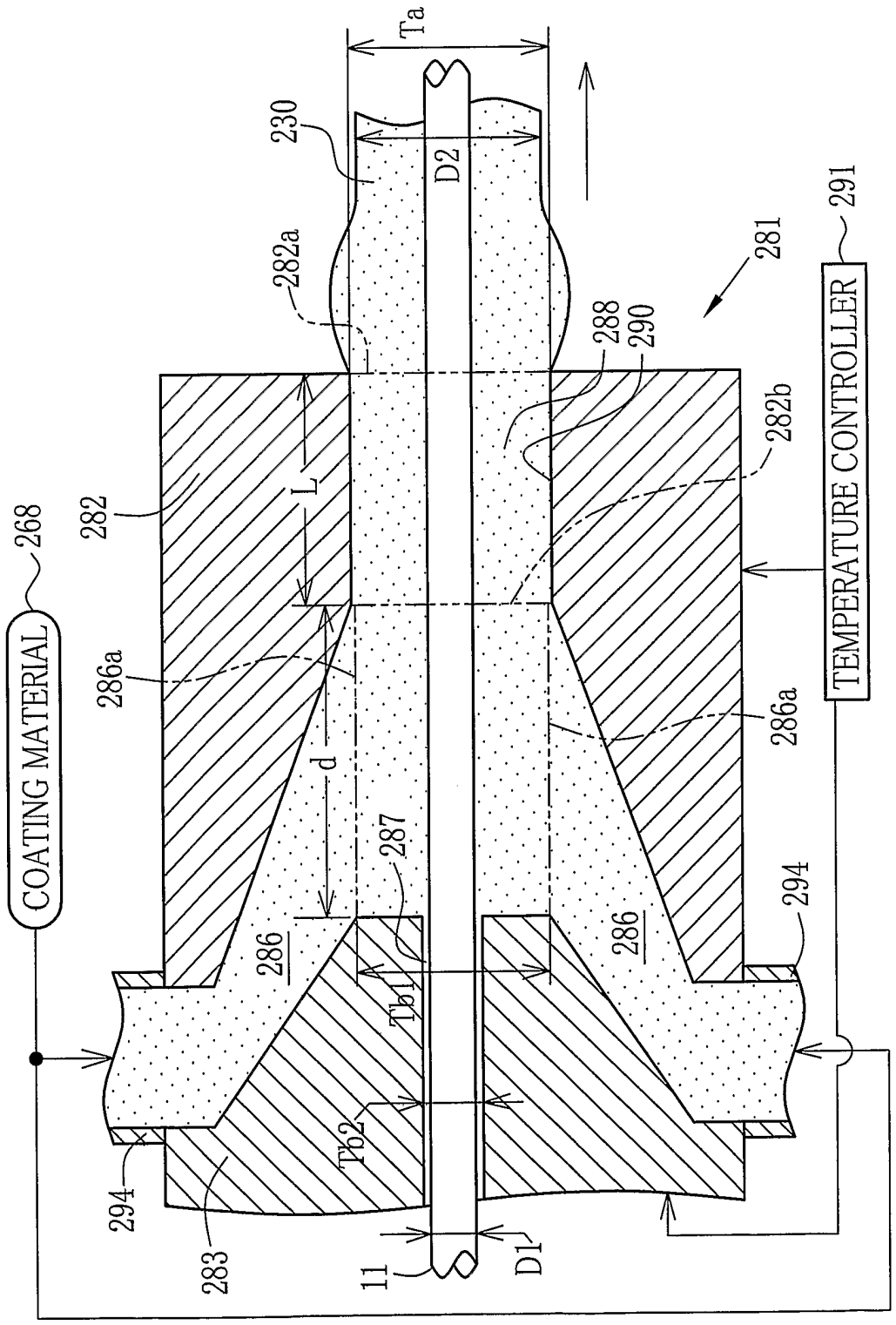

Ta
230
D2
282a
281
291
288
290
TEMPERATURE CONTROLLER
282b
282
L
268
COATING MATERIAL
286a
d
286a
287
294
286
286
Tb1
Tb2
294
283
11
D1

FIG. 13

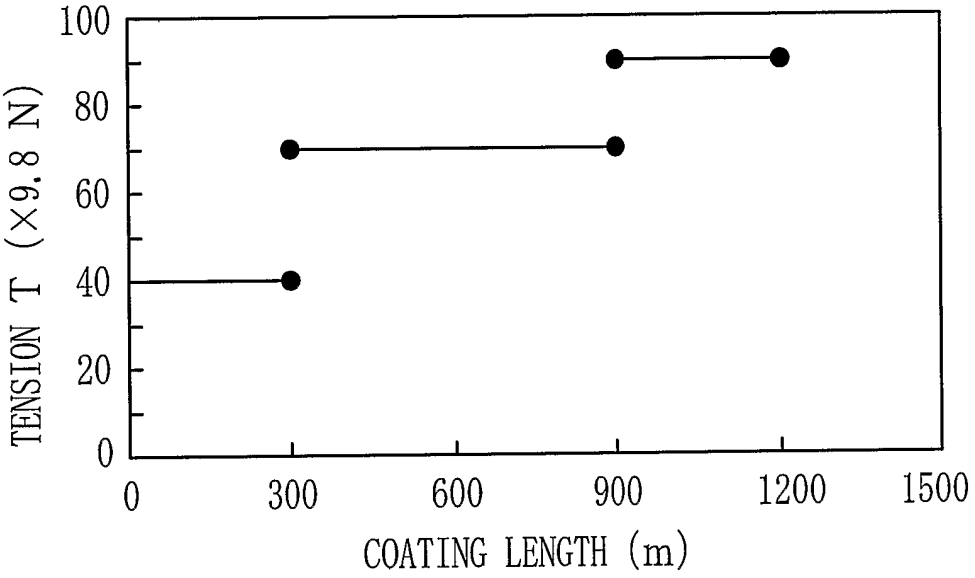

100
80
60
40
20
0
TENSION T (×9.8 N)
0
300
600
900
1200
1500
COATING LENGTH (m)

FIG. 14

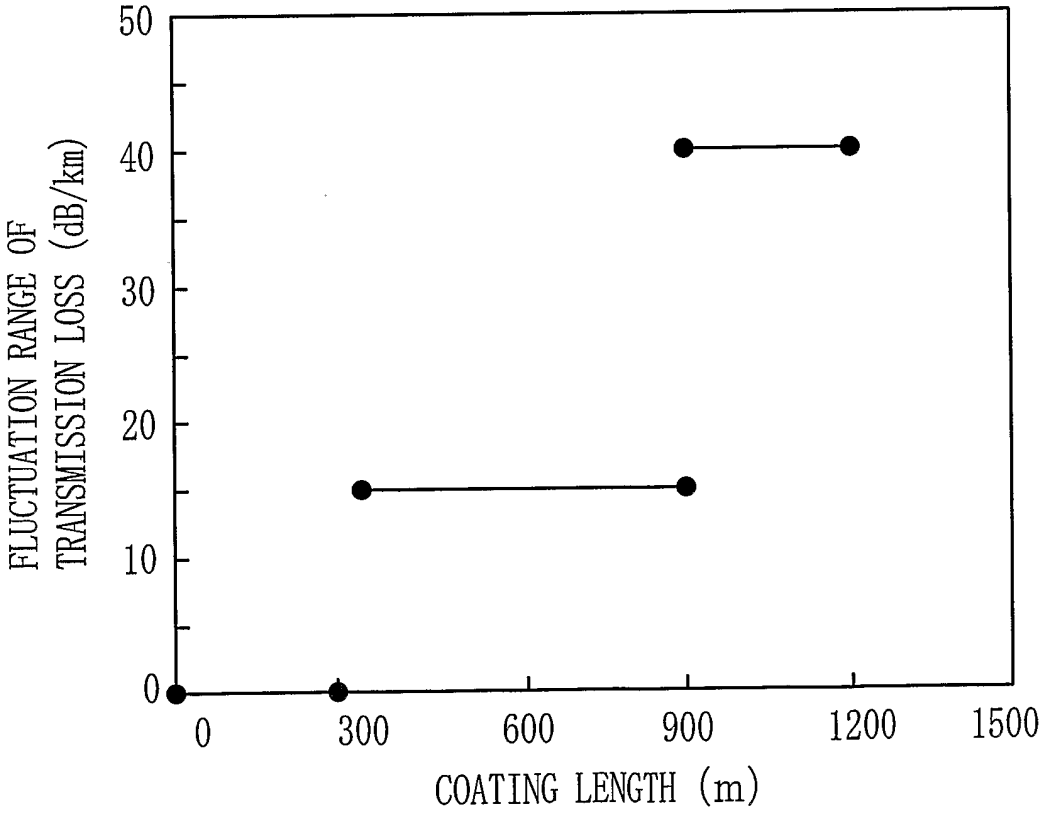
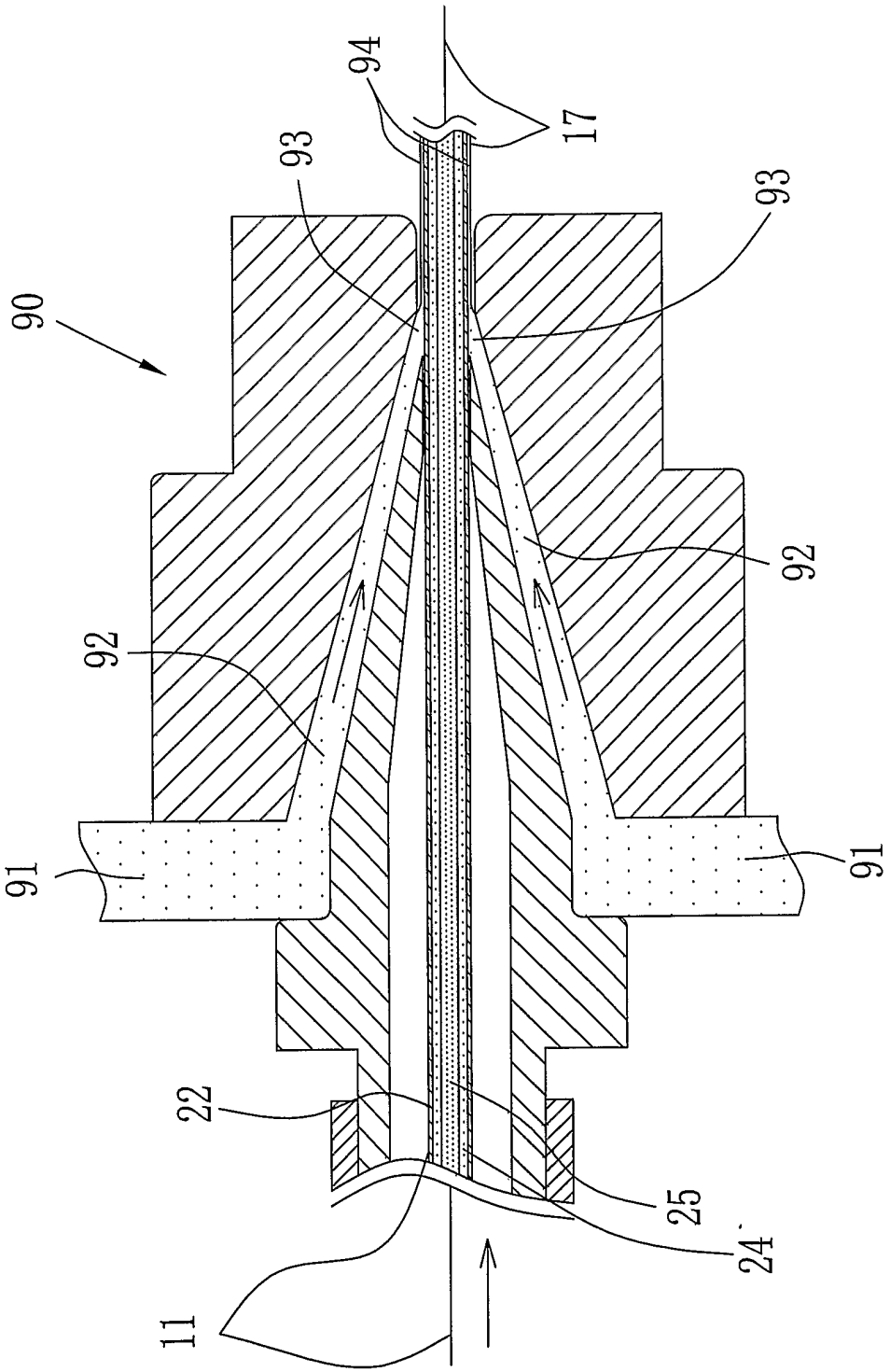

50
40
30
20
10
0
FLUCTUATION RANGE OF TRANSMISSION LOSS (dB/km)
0
300
600
900
1200
1500
COATING LENGTH (m)

FIG. 15



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2005/020328

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. *G02B6/00*(2006.01), *G02B6/44*(2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. G02B6/00, G02B6/44

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2006
Registered utility model specifications of Japan 1996-2006
Published registered utility model applications of Japan 1994-2006

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2000-121842 A (MITSUBISHI RAYON Co., Ltd.) 2000.04.28, paragraph 2,26,36 and figure 1 (Family: none)	1-4,6,7, 21-23 5,8-17
X Y	JP 63-303304 A (TORAY Co., Ltd.) 1988.12.09, example, table 1 and figure 1 (Family: none)	1-4,6,7, 21-23 5,8-17
Y	EP 1219982 A1 (MITSUBISHI RAYON Co., Ltd.) 2002.07.03, paragraph 39 & WO 2001/020376 A1 & TW 469351 B	5
X Y	JP 2003-270453 A (FUJI PHOTO FILM Co., Ltd.) 2003.09.25, paragraph 36 (Family: none)	18 8-16,19

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02.02.2006	14.02.2006

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	GOTO, Masao Telephone No. +81-3-3581-1101 Ext. 3294

2X 3103

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2005/020328

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 11-174242 A (KURABE Co., Ltd.) 1999.07.02, paragraph 26 (Family: none)	20 9-17,19
X Y	JP 63-272518 A (TATSUTA DENSEN Co., Ltd.) 1988.11.10, 11-13 line of page 1 lower right column and 13-20 line of page 3 lower left column (Family: none)	20 9-17,19
X Y	EP 662620 A1 (SUMITOMO ELECTRIC INDUSTRIES, LTD.) 1995.07.12, 20-42 line of page 12 and figure 13 & WO 1995/000868 A1 & US 5639512 A	24-26 10-12
A	WO 1996/036478 A1 (AKZO NOBEL N.V.) 1996.11.21, example & JP 11-505628 A	1,21
E Y	JP 2005-326502 A (SEKISUI KAGAKU KOGYO Co., Ltd. ; FUJI PHOTO FILM Co., Ltd.) 2005.11.24, claim 1 and paragraph 47,53,61 (Family: none)	10-12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2005/020328

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions which are not so linked as to form a single general inventive concept for the following reasons: Main invention: Claims 1-7,21-23 Second invention: Claims 8-20,24-26
Claim 1 is not novel and has no special technical feature within the meaning of PCT Rule 13.2, second sentence, since it makes no contribution over the prior art written in the documents cited in the partial international search report. And so, there is no technical relationship among those inventions involving one or more of the same or corresponding technical features.
Claims 1,2 are the main invention because claim 2 is the first dependent claim on claim 1. And the technical feature of claims 1-7,21-23 relates to the step of drawing a raw optical fiber. Claims 3-7,21-23 are included in the main invention, because claims 3-7,21-23 could be searched without effort in searching claims 1,2.
The special technical feature of claims 8-20,24-26 relates to the step of coating a plastic optical fiber.
Therefore, these inventions are not so linked as to form a single general inventive concept.

1. ☑ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☑ No protest accompanied the payment of additional search fees.