(19) DANMARK

(10) **DK/EP 2799920 T3**

Patent- og Varemærkestyrelsen

(12) Oversættelse af europæisk patentskrift

(51) Int.Cl.: ***G 02 B 6/44 (2006.01)*** ***G 02 B 6/036 (2006.01)*** ***G 02 B 6/04 (2006.01)***

(45) Oversættelsen bekendtgjort den: **2024-03-11**

(80) Dato for Den Europæiske Patentmyndigheds bekendtgørelse om meddelelse af patentet: **2024-02-21**

(86) Europæisk ansøgning nr.: **12861073.0**

(86) Europæisk indleveringsdag: **2012-12-06**

(87) Den europæiske ansøgnings publiceringsdag: **2014-11-05**

(86) International ansøgning nr.: **JP2012081689**

(87) Internationalt publikationsnr.: **WO2013099555**

(30) Prioritet: **2011-12-28 JP 2011288494**

(84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**

(73) Patenthaver: **Sumitomo Electric Industries, Ltd., 5-33 Kitahama 4-chome , Chuo-ku, Osaka-shi, Osaka 541-0041, Japan**

(72) Opfinder: **HAYASHI Tetsuya, c/o Yokohama Works , of Sumitomo Electric Industries Ltd., 1 Taya-cho, Sakae-ku, Yokohama-shi, Kanagawa 244-8588, Japan**

(74) Fuldmægtig i Danmark: **Plougmann Vingtoft A/S, Strandvejen 70, 2900 Hellerup, Danmark**

(54) Benævnelse: **FLERKERNET OPTISK FIBER**

(56) Fremdragne publikationer:

**EP-A1- 0 611 973**
**EP-A2- 2 365 366**
**WO-A1-2009/107414**
**WO-A1-2011/114795**
**DE-A1- 19 810 812**
**JP-A- H0 312 614**
**JP-A- H0 943 465**
**JP-A- S5 652 706**
**JP-A- S5 720 707**
**JP-A- H07 102 186**
**JP-A- 2001 183 558**
**JP-A- 2001 294 449**
**JP-A- 2004 086 026**
**JP-A- 2010 286 548**
**JP-A- 2011 197 661**
**JP-B2- S5 525 643**
**KATSUHIRO TAKENAGA ET AL.: 'Characteristics of Trench-Assisted Multi-Core Fiber' IEICE TECHNICAL**

**Fortsættes ...**

REPORT vol. 111, no. 181, 18 August 2011, pages 7 - 10, XP008171837
John M Fini ET AL: "Statistics of crosstalk in bent multicore fibers", Optics Express, vol. 18, no. 14, 30 June 2010 (2010-06-30) , pages 15122-15129, XP055141795, DOI: 10.1364/OE.18.015122
KOSHIBA MASANORI ET AL: "Heterogeneous multi-core fibers: proposal and design principle", IEICE ELECTRONICS EXPRESS, DENSHI JOUHOU TSUUSHIN GAKKAI, JP, vol. 6, no. 2, 25 January 2009 (2009-01-25), pages 98-103, XP002635350, ISSN: 1349-2543, DOI: 10.1587/ELEX.6.98

# DESCRIPTION

## Technical Field

**[0001]** The present invention relates to a multi-core optical fiber.

## Background Art

**[0002]** A multi-core optical fiber having a plurality of core portions extending along a central axis of the fiber, in a common cladding portion is expected as an optical transmission line capable of transmitting a large volume of information. Such multi-core optical fiber is required to reduce crosstalk between two neighboring core portions out of the plurality of core portions in the common cladding. With reduction of crosstalk, it becomes feasible to implement transmission of optical signals by use of a longer multi-core optical fiber. As another advantage, the crosstalk reduction allows reduction in core pitch between two neighboring core portions and thus allows a larger number of core portions to be arranged in the common cladding; as a result, it becomes feasible to transmit a much larger volume of information.

**[0003]** Non Patent Documents 1 to 3 describe the reports on relationship between bending of the multi-core optical fiber (macrobend or microbend) and crosstalk. Non Patent Document 1 reports the relationship between bending and crosstalk in the multi-core optical fiber wherein the plurality of core portions in the common cladding have the structure of the same kind. Non Patent Documents 2 and 3 report the relationship between bending and crosstalk in the multi-core optical fiber wherein two neighboring core portions out of the plurality of core portions in the common cladding have respective structures of different kinds.

## Citation List

### Non-patent Document

**[0004]**

**Non-Patent Document 1**:Tetsuya Hayashi, et al, Optics Express, Vol. 19, No. 17, pp. 16576-16592 (2011 ).

**Non-Patent Document 2:**Tetsuya Hayashi, et al, ECOC 2011, Mo.1.LeCervin.3.

**Non-Patent Document 3**:Tetsuya Hayashi, et al, ECOC 2010, We.8.F.6.

**[0005]** JP 20100286548 is concerned with a multiple core fiber and optical connector including the same. EP 0 611 973 is concerned with a multicore optical fiber. EP 2 365 366 is concerned with an optical fiber cable with coated multicore fibres being twisted around a central strength members to reduce crosstalk between the cores. WO2009107414 also relates to the crosstalk prevention between cores of a multicore fibre by applying bends.

**Summary of Invention**

**Problems that the Invention is to Solve**

**[0006]** The inventor conducted research on the conventional multi-core optical fiber and found the problem as described below.

**[0007]** Namely, according to Non Patent Documents 1-3 above, reduction of crosstalk in the multi-core optical fiber is expected by appropriately setting bending of the multi-core optical fiber. However, for example, when the multi-core optical fiber is one already laid, it is not easy to provide a mechanism for applying an appropriate bend to the multi-core optical fiber, which also raises a problem of causing an increase in cost.

**[0008]** The present invention has been accomplished in order to solve the above problem and it is an object of the present invention to provide a multi-core optical fiber capable of implementing suppression of crosstalk on an easy and inexpensive basis.

**Means for Solving the Problems**

**[0009]** A multi-core optical fiber according to the present invention is defined in claim 1. Further preferred features are defined in the dependent claims.

**Effects of the Invention**

**[0010]** The multi-core optical fiber according to the present invention successfully realizes the suppression of crosstalk on an easy and inexpensive basis.

**Brief Description of Drawings**

**[0011]**

Fig. 1 is a perspective view showing a configuration of a multi-core optical fiber with microbend applying portions;

Figs. 2A to 2C illustrate sectional views showing the configuration of the multi-core optical fiber according to figure 1;

Fig. 3 is a drawing for explaining an example of a method for manufacturing the multi-core optical fiber according to figure 1

Fig. 4 is a drawing for explaining another example of the method for manufacturing the multi-core optical fiber according to figure 1;

Fig. 5 is a perspective view showing a configuration of a multi-core optical fiber according to an embodiment;

Fig. 6 is a perspective view showing a configuration of a multi-core optical fiber with microbend applying portions;

Fig. 7 is a perspective view showing a configuration of a multi-core optical fiber with microbend applying portions;

Fig. 8 is a perspective view showing a configuration of a multi-core optical fiber with microbend applying portions;

Figs. 9A and 9B illustrate a perspective view and cross-sectional view showing a configuration of a multi-core optical fiber according to another embodiment;

Fig. 10 is a drawing showing a preferred example of a refractive index profile around each core portion in the multi-core optical fiber in each embodiment;

Fig. 11 is a drawing showing another preferred example of a refractive index profile around each core portion in the multi-core optical fiber in each embodiment;

Fig. 12 is a drawing showing a schematic structure of a multi-core optical fiber tape according to an embodiment of the present invention; and

Figs. 13A and 13B illustrate drawings showing schematic structures of a loose cable and a tight cable, as examples of multi-core optical fiber cables according to embodiments of the present invention.

**Reference Sings List**

**[0012]** 1-6 multi-core optical fibers; 10 glass region; 11 core portions; 12 cladding portion (common cladding portion); 13 depressed layer; 14 inner cladding layer; 15 trench layer; 20-22 coating layers; 31-36 microbend applying portions; 41 optical fiber preform; 42 bare optical fiber; 43-45 optical fibers; 51 drawing furnace; 52 coating device; 53 microbend applying portion forming device; 54 guide roller; 55 second bobbin; 61 first bobbin; 62 guide roller; 63 microbend applying portion forming device; 64 guide roller; 65 second bobbin; 100 multi-core optical fiber tape; 200 multi-core optical fiber cable (loose cable); and 300 multi-core optical fiber cable (tight cable).

**Description of Embodiments**

**[0013]** Embodiments of the present invention will be described below in detail with reference to the accompanying drawings. The same elements will be denoted by the same reference signs in the description of the drawings, without redundant description.

**[0014]** Fig. 1 is a perspective view showing a configuration of a multi-core optical fiber 1.

**[0015]** Fig. 2A is a cross-sectional view showing the configuration of the multi-core optical fiber 1 according to figure 1 Fig. 2B is an enlarged view of a part (region enclosed in a dashed line) in Fig. 2A, and Fig. 2C is a drawing showing a preferred example of a refractive index profile around each core part. As shown in Fig. 1, the multi-core optical fiber 1 has a plurality of (seven in Fig. 1) core portions 11 extending along a central axis AX thereof (fiber axis), a common cladding portion 12 surrounding each of outer peripheries of the core portions 11, a coating layer 20 surrounding an outer periphery of the common cladding portion 12, and a microbend applying portion 31 provided on an outer periphery (outer surface) of the coating layer 20.

**[0016]** In the cross section of the multi-core optical fiber 1 (a plane normal to the central axis AX), as shown in Fig. 2A, one core portion 11 out of the seven core portions 11 is arranged at the center and the other six core portions 11 are arranged at equal intervals on the circumference of a circle centered at the central core. Namely, the seven core portions 11 are arranged at respective grid points of a triangle grid. Each core portion 11 has the refractive index higher than that of the cladding portion 12 and can guide light (cf. Fig. 2C). The seven core portions 11 have substantially the same structure as to the core diameter and refractive index profile and have substantially equal optical transmission properties.

**[0017]** A glass region 10 including the core portions 11 and cladding portion 12 is comprised of silica glass. The coating layer 20 surrounding the outer periphery of the cladding portion 12 is comprised of resin. The coating layer 20 may have a single-layer structure or a multilayer structure, and may include a colored layer. The microbend applying portion 31 has a shape continuously extending in the longitudinal direction of the multi-core optical fiber 1 (direction along the central axis AX, which will be referred to hereinafter as fiber longitudinal direction), in a partial region on the outer periphery of the coating layer 20. The thickness d of the microbend applying portion 31 means the thickness along the radial direction of the multi-core optical fiber 1, as shown in Fig. 2B, and the thickness d in the radial direction is not less than a predetermined value. The microbend applying portion 31 having this structure can apply a microbend to the glass region 10. The core arrangement in the glass region 10 (core arrangement on the cross section normal to the central axis AX) may be twisted around the central axis AX along the fiber longitudinal direction. The thickness d in the radial direction or the width in the circumferential direction of the microbend applying portion 31 may be varied in each of sections of the microbend applying portion 31 extending along the fiber longitudinal direction.

**[0018]** When the microbend applying portion 31 applies the microscopic bend (microbend) to the glass region 10, a small-diameter macrobend is produced at a certain rate in the fiber longitudinal direction in the glass region 10. This macrobend increases a difference between the propagation constants of guided light in two neighboring core portions 11 out of the plurality of core portions 11, so as to reduce crosstalk between these two core portions 11. Such reduction of inter-core crosstalk enables optical signal transmission by a longer multi-core optical fiber. In another aspect, the reduction of inter-core crosstalk allows decrease in core pitch between two adjacent core portions and thus allows a larger number of core portions to be arranged in the common cladding; as a result, it becomes feasible to transmit a much larger volume of information.

**[0019]** The present example does not have to be provided with a mechanism for applying an appropriate bend to the multi-core optical fiber, separately from the microbend applying portion. For this reason, crosstalk can be suppressed on an easy and inexpensive basis. When a multi-core optical fiber cable is configured incorporating the multi-core optical fiber according to the present embodiment, microbend stress is applied to the multi-core optical fiber and therefore there is no need for separately providing a mechanism for applying an appropriate bend to the multi-core optical fiber, separately from the microbend applying portion. The cable may have a form like a cord as long as it has a member covering the outer periphery of the multi-core optical fiber.

**[0020]** The multi-core optical fiber 1 of the present example can be manufactured as described below. Fig. 3 is a drawing for explaining an example of a method for manufacturing the multi-core optical fiber 1. A lower end of optical fiber preform 41 set in a drawing furnace 51 is heated and melted to produce a drawn bare optical fiber 42. The bare optical fiber 42 is guided in order through a coating device 52 and a microbend applying portion forming device 53 to obtain an optical fiber 43. The coating device 52 applies a resin to the periphery of the cladding of the bare optical fiber 42 and cures the resin to form a coating layer. The microbend applying portion forming device 53 forms the microbend applying portion on the outer periphery of the coating layer. Then the optical fiber 43 is guided via a guide roller 54 to be wound up on a second bobbin 55.

**[0021]** In another method, the multi-core optical fiber 1 can also be manufactured as described below. Fig. 4 is a drawing for explaining another example of the manufacturing method of the multi-core optical fiber 1. In this example, an optical fiber 44 after formation of the coating layer is wound on a first bobbin 61. The optical fiber 44 unwound from this first bobbin 61 is guided in order via a guide roller 62 and a microbend applying portion forming device 63 to produce an optical fiber 45. The microbend applying portion forming device 63 forms the microbend applying portion on the outer periphery of the coating layer. Then the optical fiber 45 is guided via a guide roller 64 to be wound up on a second bobbin 65. The optical fiber 45 manufactured in this manner serves as the multi-core optical fiber 1.

**[0022]** It is noted that a coloring device to form a colored layer may be provided before or after the microbend applying portion forming device. Furthermore, microbend applying portions formed by the microbend applying portion forming device may have different colors for respective fibers or different shapes for respective fibers. This configuration allows individual multi-core optical fibers to be identified in an optical cable incorporating the plurality of multi-core optical fibers.

**[0023]** If the thickness d of the microbend applying portion is too large, the multi-core optical fiber cannot be regularly wound up during an operation of winding the multi-core optical fiber around the bobbin. For example, in a case where a fiber spacing per turn in winding of the multi-core optical fiber on the bobbin is 0.4 mm (i.e., 400 μm*)* and where the fiber coating diameter is 245 μm, the thickness d of the microbend applying portion is preferably not more than 77.5 μm (= (400 - 245)/2).

**[0024]** First Embodiment) Fig. 5 is a perspective view showing a configuration of a multi-core optical fiber 2 according to an embodiment. As shown in Fig. 5, the multi-core optical fiber 2 is provided with the plurality of (seven in Fig. 5) core portions 11 extending along the central axis AX, the common cladding portion 12 surrounding each of the outer peripheries of the core portions 11, the coating layer 20 surrounding the outer periphery of the common cladding portion 12, and a microbend applying portion 32 provided in the interior of the coating layer 20. The coating layer 20 has a two-layer structure comprising a first coating layer 21 surrounding the outer periphery of the common cladding portion 12 and a second coating layer 22 surrounding an outer periphery of the first coating layer 21, and the microbend applying portion 32 is provided (at an interface) between these first coating layer 21 and second coating layer 22.

**[0025]** In the present embodiment, the microbend applying portion 32 is provided on a partial region of the interface between the first coating layer 21 and the second coating layer 22 and has a shape continuously extending in the fiber longitudinal direction. The thickness d (cf. Fig. 2B) in the radial direction of the microbend applying portion 32 is not less than the predetermined value. The microbend applying portion 32 of this structure can apply a microbend to the glass region 10. The core arrangement in the glass region 10 (core arrangement on the cross section normal to the central axis AX) may be twisted around the central axis AX along the fiber longitudinal direction. The thickness d in the radial direction or the width in the circumferential direction of the microbend applying portion 32 may be varied in each of sections of the microbend applying portion 31 extending along the fiber longitudinal direction. Each of the first coating layer 21 and the second coating layer 22 may be comprised of a plurality of coating layers.

**[0026]** The multi-core optical fiber 2 of the present embodiment can also achieve the same operational effect as the multi-core optical fiber 1.

**[0027]** The multi-core optical fiber 2 of the present embodiment can be manufactured by forming the second coating layer with a second coating device further provided after the microbend applying portion forming device 53 in Fig. 3.

**[0028]** Fig. 6 is a perspective view showing a configuration of a multi-core optical fiber 3

**[0029]** As shown in Fig. 6, the multi-core optical fiber 3 is provided with the plurality of (seven in Fig. 6) core portions 11 extending along the central axis AX, the common cladding portion 12 surrounding each of the outer peripheries of the core portions 11, the coating layer 20 surrounding the outer periphery of the common cladding portion 12, and a microbend applying portion 33 provided on the outer periphery (outer surface) of the coating layer 20.

**[0030]** The microbend applying portion 33 is continuously provided in a helical shape on the outer periphery of the coating layer 20 and has the radial thickness d of not less than the predetermined value. The microbend applying portion 33 of this structure can apply a microbend to the glass region 10. The thickness, width, helical pitch, or twist direction of the microbend applying portion 33 may be varied in each of sections along the fiber longitudinal direction. The microbend applying portion 33 may be provided at the interface between the first coating layer and the second coating layer as in the previous embodiment. The helix does not have to be limited only to a helix at a constant pitch in one direction, but may be a helix a rotation direction of which is periodically reversed, or a helix the pitch of which varies in the fiber longitudinal direction. The circumferential position of the microbend applying portion around the central axis may be varied along the fiber longitudinal direction.

**[0031]** The multi-core optical fiber 3 can also achieve the same operational effect as the multi-core optical fiber The multi-core optical fiber 3 can be manufactured by rotating the optical fiber during passage of the optical fiber through the microbend applying portion forming device in Fig. 3 or in Fig. 4.

**[0032]** Fig. 7 is a perspective view showing a configuration of a multi-core optical fiber 4. In Fig. 7, the multi-core optical fiber 4 is provided with the plurality of (seven in Fig. 7) core portions 11 extending along the central axis AX, the common cladding portion 12 surrounding each of the outer peripheries of the core portions 11, the coating layer 20 surrounding the outer periphery of the common cladding portion 12, and microbend applying portions 34 provided on the outer periphery (outer surface) of the coating layer 20.

**[0033]** In the present embodiment, the microbend applying portions 34 are intermittently provided on the outer periphery of the coating layer 20 along the fiber longitudinal direction and have the radial thickness d of not less than the predetermined value. The microbend applying portions 34 of this structure can apply a microbend to the glass region 10. The thickness, width, or arrangement pitch of the microbend applying portions 34 may be varied along the fiber longitudinal direction. The microbend applying portions 34 may be provided between the first coating layer and the second coating layer as in the previous embodiment.

**[0034]** The multi-core optical fiber 4 can also achieve the same operational effect as the multi-core optical fiber 1 of the first embodiment. The multi-core optical fiber 4
be manufactured by forming the microbend applying portions 34 in an intermittent manner on the optical fiber during passage of the optical fiber through the microbend applying portion forming device in Fig. 3 or in Fig. 4.

**[0035]** Fig. 8 is a perspective view showing a configuration of a multi-core optical fiber 5. In Fig. 8, the multi-core optical fiber 5 is provided with the plurality of (seven in Fig. 8) core portions 11 extending along the central axis AX, the common cladding portion 12 surrounding each of the outer peripheries of the core portions 11, the coating layer 20 surrounding the outer periphery of the common cladding portion 12, and microbend applying portions 35 provided on the outer periphery (outer surface) of the coating layer 20. These microbend applying portions 35 may be arranged at random on the outer periphery of the coating layer 20 (provided that they do not always have to be arranged regularly). In this case, the pitch of microbend applying portions 35 can be set freely.

**[0036]** The microbend applying portions 35 are intermittently provided on the outer periphery of the coating layer 20 and have the radial thickness d of not less than the predetermined value. The microbend applying portions 35 of this structure can apply a microbend to the glass region 10. The thickness, width, or arrangement density of the microbend applying portions 35 may be varied in the fiber longitudinal direction. The microbend applying portions 35 may be provided between the first coating layer and the second coating layer as in the previous embodiment.

**[0037]** The multi-core optical fiber 4 can also achieve the same operational effect as the multi-core optical fiber 1 of the first embodiment. The multi-core optical fiber 4 can be manufactured by forming the microbend applying portions 35 in an intermittent manner on the optical fiber during passage of the optical fiber through the microbend applying portion forming device in Fig. 3 or in Fig. 4.

**[0038]** In the multi-core optical fibers 3-5, the microbend applying portion or microbend applying portions are varied along the fiber longitudinal direction and thus can apply a more microscopic bend to the glass region 10.

**[0039]** Fig. 9A is a perspective view showing a configuration of a multi-core optical fiber 6 according to another embodiment. In Fig. 9A, the multi-core optical fiber 6 is provided with the plurality of (seven in Fig. 9(a)) core portions 11 extending along the central axis AX, the common cladding portion 12 surrounding each of the outer peripheries of the core portions 11, the coating layer 20 surrounding the outer periphery of the common cladding portion 12, and microbend applying portions 36 provided in the interior of the coating layer 20.

**[0040]** In the present embodiment, the microbend applying portions 36 contain a granular substance discretely arranged at random inside the coating layer 20. In this case, the microbend applying portions 36 exist near an interface between the common cladding portion 12 and the coating layer 20, inside the coating layer 20, and near the outer periphery of the coating layer 20, as shown in Fig. 9B. The granular substance as the microbend applying portions 36 is comprised of a material with the Young's modulus higher than that of the coating layer 20, i.e., a material harder than the material of the coating layer 20. The granular substance as the microbend applying portions 36 may be a material in a gel state or in a solid state. The multi-core optical fiber 6 of the present embodiment can also achieve the same operational effect as the multi-core optical fiber 1.

**[0041]** The multi-core optical fiber 6 of the present embodiment can be manufactured as described below. A mixture of the resin material to be the coating layer 20, with the material to be the microbend applying portions 36 is applied onto the drawn bare optical fiber and then cured. As a result, the multi-core optical fiber 6 can be manufactured. In another method, the mixture of the resin material to be the coating layer 20, with the resin material to be the microbend applying portions 36 is cured at the same time as applied onto the drawn bare optical fiber. In this case, the multi-core optical fiber 6 can also be manufactured.

**[0042]** In any one of the above-described examples of fibres 1 - 6, the microbend applying portion or microbend applying portions are preferably provided throughout the entire length of the multi-core optical fiber. Since this configuration allows the microbend applying portion(s) to apply the microbend throughout the entire length of the multi-core optical fiber, it is more effective to reduction of crosstalk. However, when the microbend is applied throughout the entire length of fiber, there is a possibility of occurrence of increase in loss of the microbend depending upon the core structure. Therefore, the microbend applying portions may be provided in an intermittent manner along the fiber longitudinal direction.

**[0043]** In a general optical fiber the coating layer has a two-layer structure, in which the first coating layer positioned inside is made of a soft resin and the second coating layer positioned outside is made of a resin harder than the first coating layer. Since the Young's modulus of the resin of the second coating layer is approximately 1 GPa, the microbend can be efficiently applied to the multi-core optical fiber when the Young's modulus of the microbend applying portion in each of the above examples is not less than 1 GPa (i.e., when it has the hardness equal to or higher than that of the resin of the second coating layer).

**[0044]** In each of the first to sixth examples, the loss in each core can be increased by the microbend applied to the glass region by the microbend applying portion. The microbend loss is produced by coupling from the fundamental mode for propagation of signal to a higher-order mode or a cladding mode. The smaller the propagation constant difference (which can be replaced by effective index difference) between the fundamental mode and the higher-order mode or cladding mode, the larger the microbend loss. In the multi-mode core optical fibers, therefore, the refractive index profile near each core portion is preferably the refractive index profile as shown in Fig. 10 or in Fig. 11.

**[0045]** The refractive index profile shown in Fig. 10 is a so-called depressed type. In this depressed type refractive index profile, a depressed layer with the refractive index lower than that of the cladding portion (corresponding to the common cladding 12) is provided around each core portion (corresponding to the core portion 11). The refractive index profile shown in Fig. 11 is a so-called trench type. In this trench type refractive index profile, a trench layer with the refractive index lower than that of the cladding portion (corresponding to the common cladding portion 12) is provided around each core portion (corresponding to the core portion 11) and an inner cladding layer with the refractive index lower than that of the core portion and higher than that of the trench layer is further provided between the core portion and the trench layer. When such core structures are adopted, the effective refractive index of the cladding mode can be lowered to the refractive index of the depressed layer or the trench layer, so as to suppress the microbend loss.

**[0046]** With the use of the multi-core optical fiber having the microbend applying portion to apply the microbend to the glass region comprising the core portions and the cladding portion, as described above, the inter-core crosstalk of the multi-core optical fiber can be kept low without control on bending of fiber, cord, or cable, even in the case where the multi-core optical fiber is used as it is or in the case where the multi-core optical fiber is used as housed in a cord or a cable without a structure to apply bending.

**[0047]** As examples of application of the multi-core optical fibers, a tape and cables using the multi-core optical fiber will be described below using Fig. 12 and Figs. 13A and 13B.

**[0048]** Fig. 12 is a drawing showing a schematic structure of a multi-core optical fiber tape. The multi-core optical fiber tape 100 shown in Fig. 12 is constructed adopting four multi-core optical fibers 3 according to Fig. 6, as an example.

**[0049]** In Fig. 12, each of the four multi-core optical fibers 3 adopted in the multi-core optical fiber tape 100 is provided, as described above, with the glass region 10 comprising the seven core portions 11 and the cladding portion 12, the coating layer 20 provided on the outer periphery of the glass region, and the microbend applying portion 33 provided in the helical shape on the outer periphery of the coating layer 20 along the fiber longitudinal direction. The multi-core optical fiber tape 100 is provided with a resin coat 120 integrally covering buffer layers 110 provided on the respective outer peripheries of the four multi-core optical fibers 3 having the above-described structure, and the four multi-core optical fibers 3, in a state in which the multi-core optical fibers are separated at predetermined intervals from each other.

**[0050]** A multi-core optical fiber cable incorporates the multi-core optical fiber or multi-core optical fibers with the structure as described above. Figs. 13A and 13B illustrate drawings showing examples of multi-core optical fiber cables, wherein Fig. 13A is a drawing showing a schematic structure of a loose cable and Fig. 13B a drawing showing a schematic structure of a tight cable.

**[0051]** The loose cable 200 shown in Fig. 13A is constructed adopting three multi-core optical fibers 1 shown in Fig. 1, as an example.

**[0052]** In Fig. 13A, each of the three multi-core optical fibers 1 adopted in the loose cable 200 is provided, as described above, with the glass region 10 comprising the seven core portions 11 and the cladding portion 12, the coating layer 20 provided on the outer periphery of the glass region, and the microbend applying portion 31 continuously provided on the outer periphery of the coating layer 20 along the fiber longitudinal direction. The loose cable 200 is provided with a sheath 210 having a space 220 to house these three multi-core optical fibers 1, without applying any lateral pressure to the respective outer peripheries of the three multi-core optical fibers 1.

**[0053]** On the other hand, the tight cable 300 shown in Fig. 13B is constructed adopting the multi-core optical fiber 4 shown in Fig. 7, as an example.

**[0054]** In Fig. 13B, the multi-core optical fiber 4 adopted in the tight cable 300 is provided, as described above, with the glass region 10 comprising the seven core portions 11 and the cladding portion 12, the coating layer 20 provided on the outer periphery of the glass region, and the microbend applying portions 34 intermittently provided on the outer periphery of the coating layer 20 along the fiber longitudinal direction. The tight cable 300 is provided with a cable jacket in close contact with the outer periphery of the multi-core optical fiber 4, in order to apply a lateral pressure to the outer periphery of the multi-core optical fiber 4. In the example of Fig. 13B, the cable jacket is composed of an inner jacket 310 in direct close contact with the outer periphery of the multi-core optical fiber 4, and an outer jacket 320 provided on an outer periphery of the inner jacket 310.

# REFERENCES CITED IN THE DESCRIPTION

Cited references

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

**Patent documents cited in the description**

- JP20100286548B [0005]

- EP0611973A [0005]
- EP2365366A [0005]
- WO2009107414A [0005]


**Non-patent literature cited in the description**


- **TETSUYA HAYASHI et al.**Optics Express, 2011, vol. 19, 1716576-16592 [0004]
- **TETSUYA HAYASHI et al.**ECOC, 2011, [0004]
- **TETSUYA HAYASHI et al.**ECOC, 2010, [0004]

**Patentkrav**

**1.** Flerkernet optisk fiber omfattende:
en flerhed af kernedele (11), der strækker sig langs en central akse (AX) af fiberen;

en fælles beklædningsdel (12), der integralt holder kernedelene inde i en tilstand, hvor kernedelene er adskilt med forudbestemte intervaller fra hinanden, hvor den fælles beklædningsdel har et brydningsindeks, der er lavere end det for hver af kernedelene; og

et coatinglag (20-22), der omgiver en ydre periferi af den fælles beklædningsdel; **kendetegnet ved**: mindst en tilstand af en første tilstand og en anden tilstand;

den første tilstand er defineret af en mikrobøjningspåføringsdel (31-36) tilvejebragt i det indre af coatinglaget og indeholdende et granulært stof bestående af et materiale med et Youngs modul, der er højere end coatinglagets, idet mikrobøjningspåføringsdelen påfører mikrobøjningsspænding til et glasområde, som inkluderer kernedelene og den fælles beklædningsdel, og

den anden tilstand er defineret af en mikrobøjningspåføringsdel (31-36), der er tilvejebragt i det mindste enten på en ydre periferi af coatinglaget eller i det indre af coatinglaget, idet mikrobøjningspåføringsdelen påfører mikrobøjningsspænding på et glasområde, som inkluderer kernedelene og den fælles beklædningsdel, idet coatinglaget inkluderer et indre coatinglag fremstillet af en blød resin og et ydre coatinglag fremstillet af en resin, der er hårdere end det indre coatinglag, idet mikrobøjningspåføringsdelen har et Youngs modul på ikke mindre end 1 GPa.

**2.** Den flerkernede optiske fiber ifølge krav 1, hvor coatinglaget (20-22) i den første tilstand inkluderer en flerhed af lag, og mikrobøjningspåføringsdelen (32) er tilvejebragt ved en grænseflade mellem tilgrænsende lag ud af flerheden af lag, og
hvor mikrobøjningspåføringsdelen (32) i den anden tilstand er tilvejebragt ved en grænseflade mellem tilgrænsende lag ud af en flerhed af lag, som inkluderer det indre coatinglag og det ydre coatinglag.

**3.** Den flerkernede optiske fiber ifølge krav 1 eller 2, hvor i den første tilstand og den anden tilstand en position af mikrobøjningspåføringsdelen (33) i et tværsnit af den flerkernede optiske fiber vinkelret på den centrale akse ved et første punkt på den centrale akse er forskellig fra en position af mikrobøjningspåføringsdelen i et tværsnit af den flerkernede optiske fiber vinkelret på den centrale akse i et andet punkt, der er forskelligt fra det første punkt på den centrale akse.

**4.** Den flerkernede optiske fiber ifølge et hvilket som helst af kravene 1 til 3, hvor i den anden tilstand er mikrobøjningspåføringsdelen (31; 33-35) tilvejebragt på den ydre periferi af coatinglaget og en tykkelse af mikrobøjningspåføringsdelen i den radiale retning af den flerkernede optiske fiber er ikke mere end 77,5 μm.

**5.** Den flerkernede optiske fiber ifølge et hvilket som helst af kravene 1 til 4, hvor i den første tilstand og den anden tilstand har mikrobøjningspåføringsdelen (31-33) en form, der kontinuerligt strækker sig i en retning langs den centrale akse.

**6.** Den flerkernede optiske fiber ifølge et hvilket som helst af kravene 1 til 5, hvor mikrobøjningspåføringsdelen (34) i den første tilstand indbefatter en flerhed af mikrobøjningspåføringselementer tilvejebragt i det indre af coatinglaget i en tilstand, hvor mikrobøjningspåføringselementerne er adskilt fra hinanden i en retning langs den centrale akse, og
hvor mikrobøjningspåføringsdelen (34) i den anden tilstand indbefatter en flerhed af mikrobøjningspåføringselementer, der er tilvejebragt i det mindste enten på den ydre periferi af coatinglaget eller i det indre af coatinglaget i en tilstand, hvor mikrobøjningspåføringselementerne er adskilt fra hinanden i en retning langs den centrale akse.

**7.** Den flerkernede optiske fiber ifølge et hvilket som helst af kravene 1 til 6, yderligere omfattende: en flerhed af forsænkede lag (13) tilvejebragt svarende til de respektive kernedele på ydre periferier af de respektive kernedele,
hvor hvert af de forsænkede lag er placeret mellem den tilsvarende kernedel og den fælles beklædningsdel og har et brydningsindeks, der er lavere end den fælles beklædningsdel.

**8.** Den flerkernede optiske fiber ifølge et hvilket som helst af kravene 1 til 7, yderligere omfattende:

en flerhed af rendelag (15) tilvejebragt svarende til de respektive kernedele på ydre periferier af de respektive kernedele, idet hvert rendelag er placeret mellem den tilsvarende kernedel og den fælles beklædningsdel og har et brydningsindeks, der er lavere end brydningsindekset for den fælles beklædningsdel; og

en flerhed af indre beklædningslag (14) tilvejebragt svarende til de respektive kernedele på de ydre periferier af de respektive kernedele, idet hvert indre beklædningslag er placeret mellem den tilsvarende kernedel og det tilsvarende rendelag og har et brydningsindeks, som er lavere end brydningsindekset for den tilsvarende kernedel og højere end brydningsindekset for det tilsvarende rendelag.

**9.** Flerkernet optisk fiberbånd (100) omfattende:

en flerhed af flerkernede optiske fiberelementer, der hver har den samme struktur som den flerkernede optiske fiber som defineret i et hvilket som helst af kravene 1 til 8; og

en resincoating (120), der integralt dækker de flerkernede optiske fiberelementer i en tilstand, hvor de flerkernede optiske fiberelementer er adskilt med forudbestemte intervaller fra hinanden.

**10.** Flerkernet optisk fiberkabel (200; 300), der inkorporerer den flerkernede optiske fiber som defineret i et hvilket som helst af kravene 1 til 9.

**11.** Det flerkernede optiske fiberkabel (300) ifølge krav 10, yderligere omfattende: en kabelindkapsling (310; 320) i tæt kontakt med en ydre periferi af den flerkernede optiske fiber for at påføre et lateralt tryk på den ydre periferi af den flerkernede optiske fiber.

**12.** Det flerkernede optiske fiberkabel (200) ifølge krav 10, yderligere omfattende: en kappe (210) med et rum (220) til at rumme den flerkernede optiske fiber uden at påføre noget lateralt tryk på den ydre periferi af den flerkernede optiske fiber.

# DRAWINGS

*Fig.1*

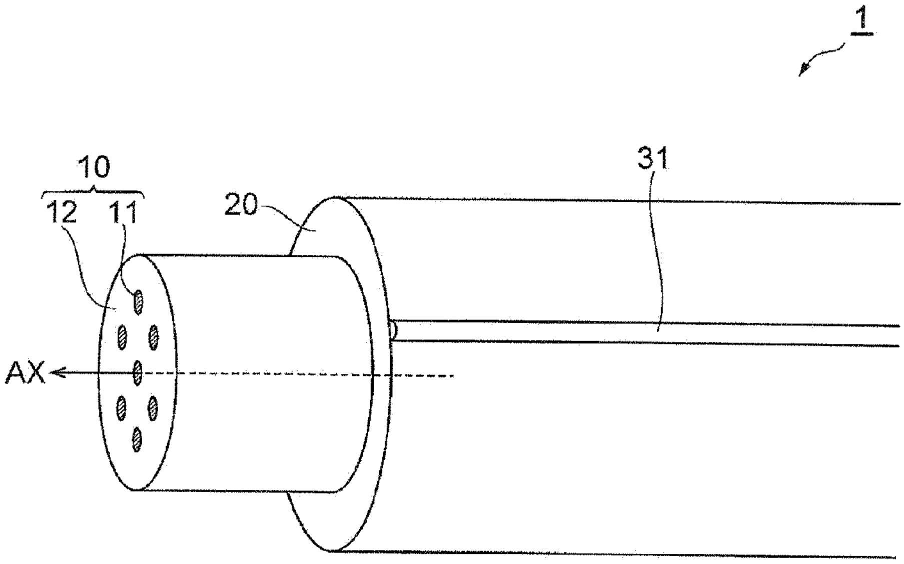


*Fig.2A*

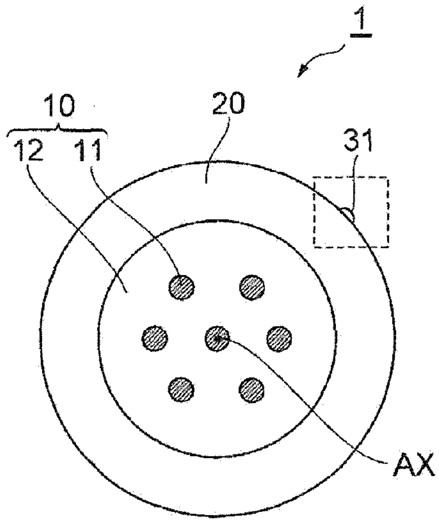



*Fig.2B*

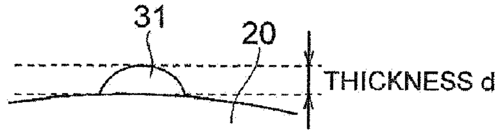



*Fig.2C*

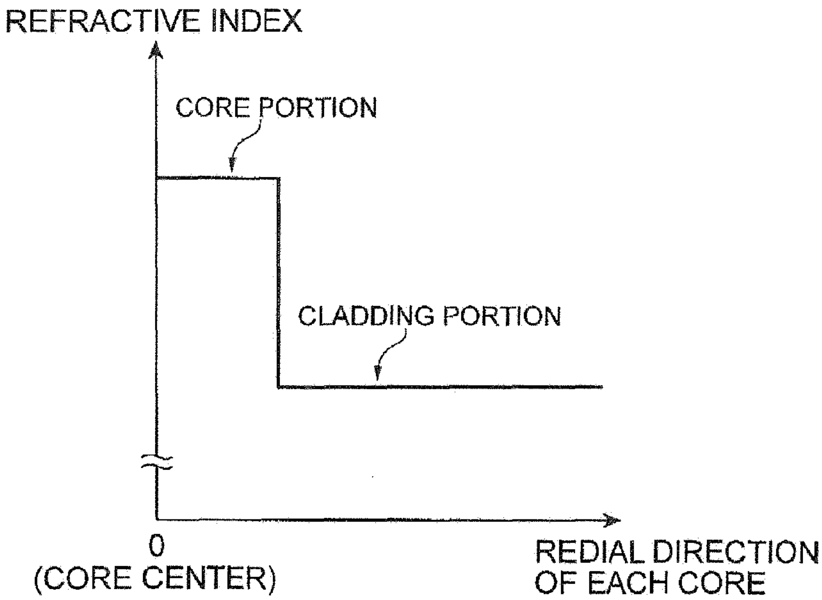
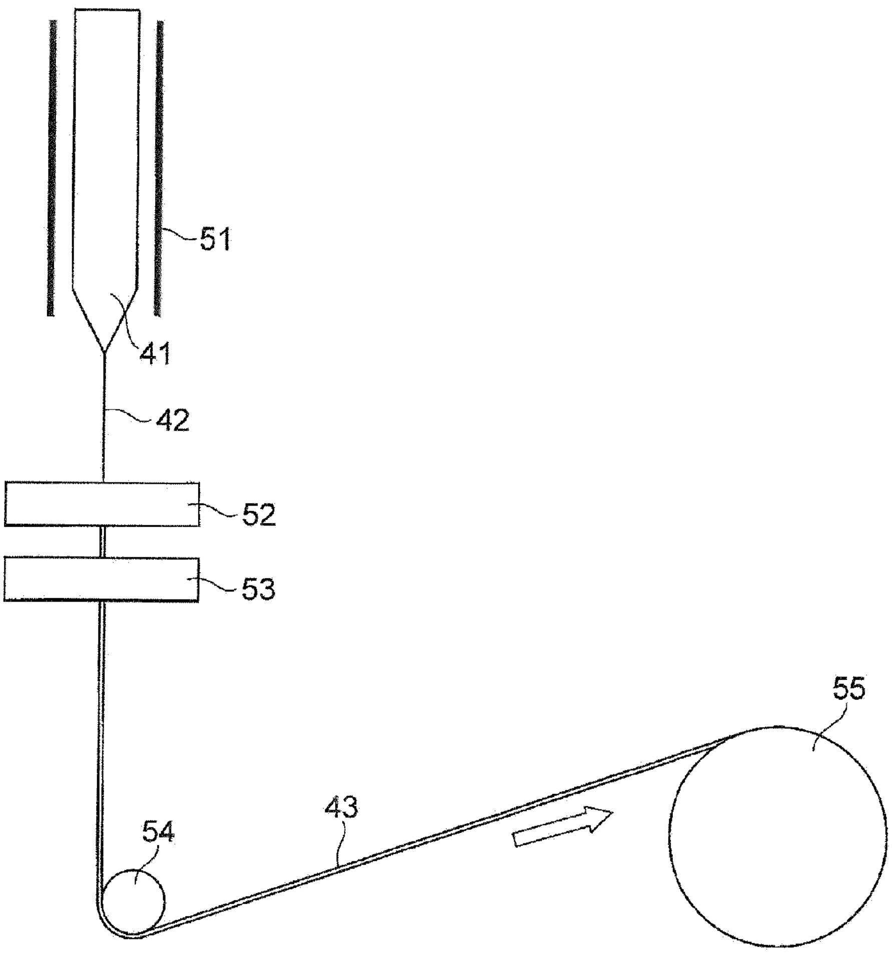


*Fig.3*



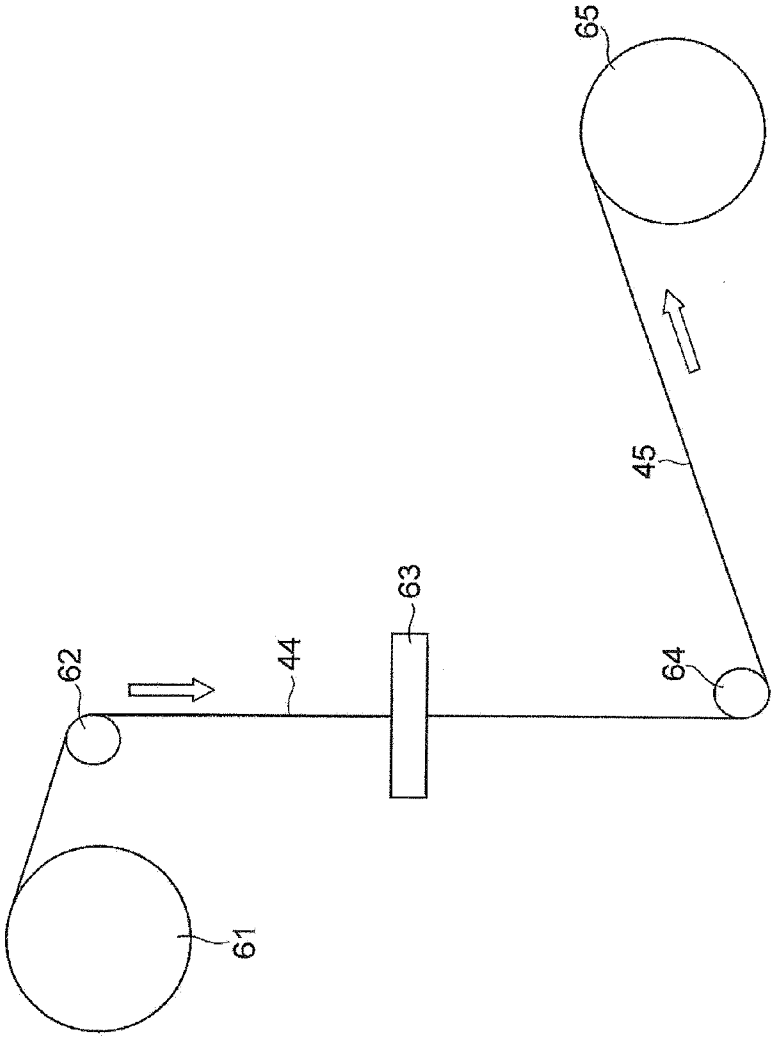



Fig.4

*Fig.5*

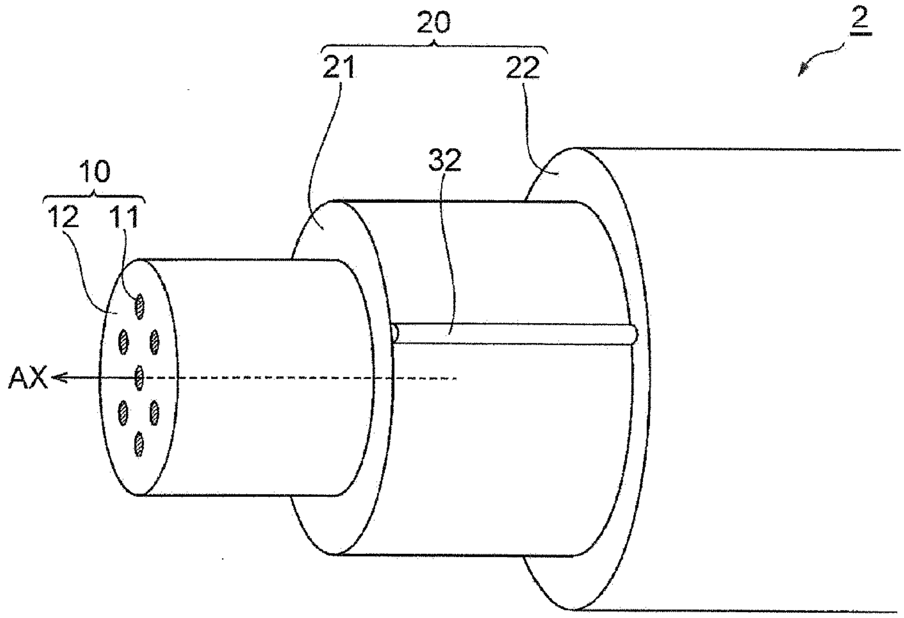


*Fig.6*

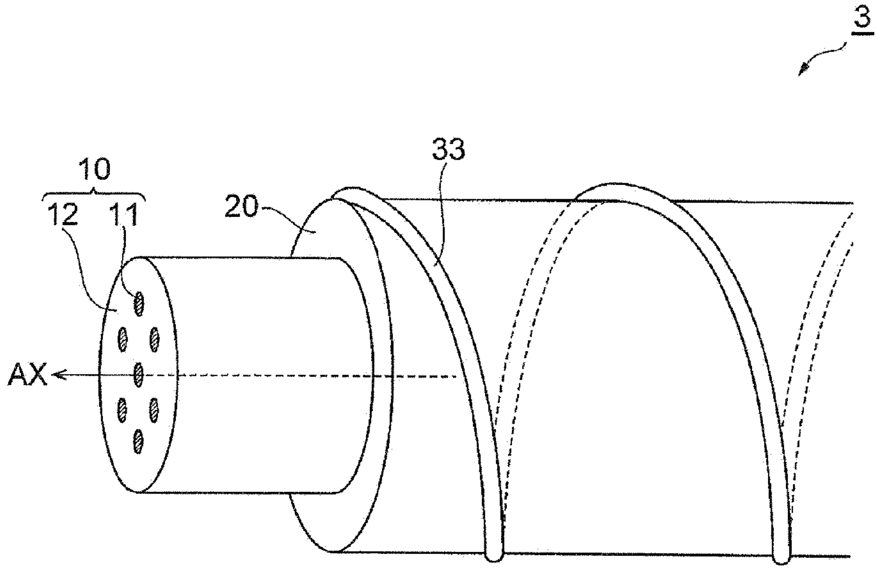


*Fig.7*

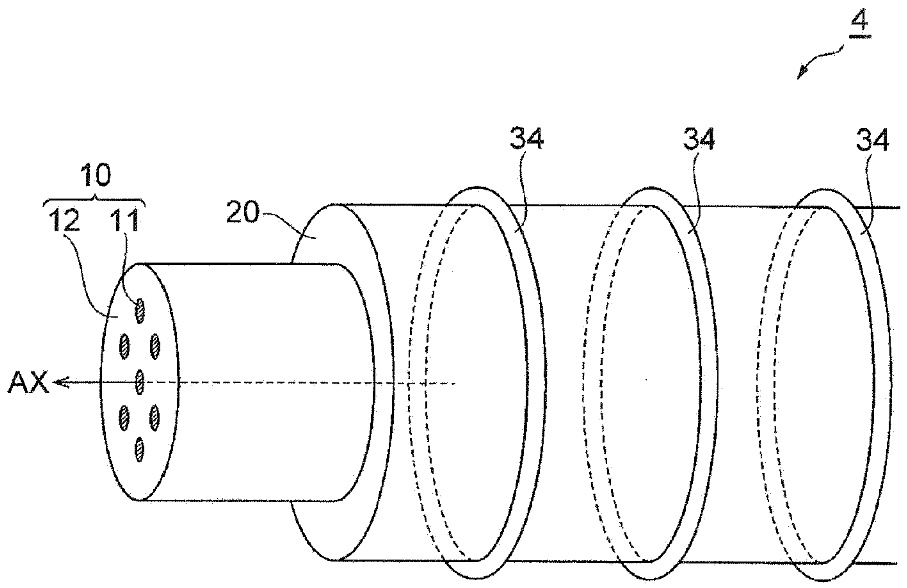


*Fig.8*

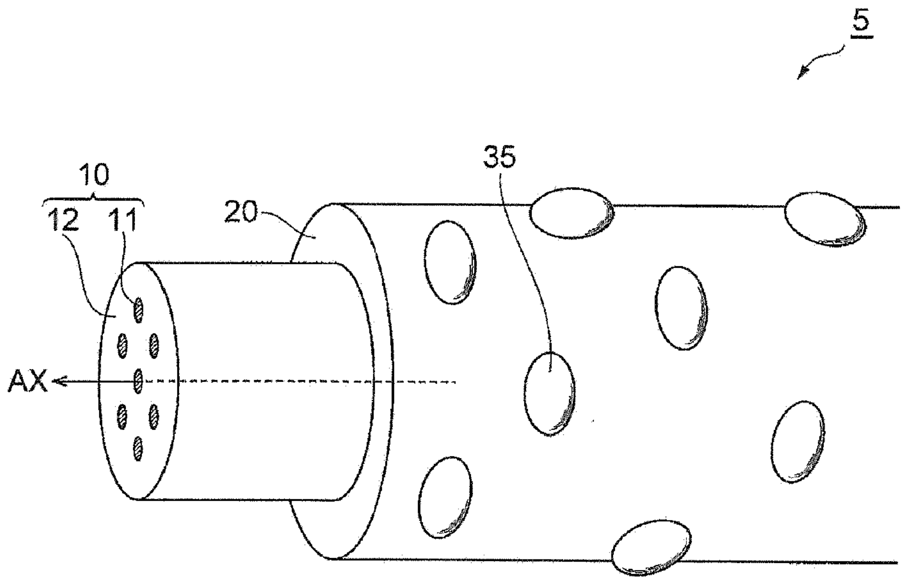


*Fig.9A*

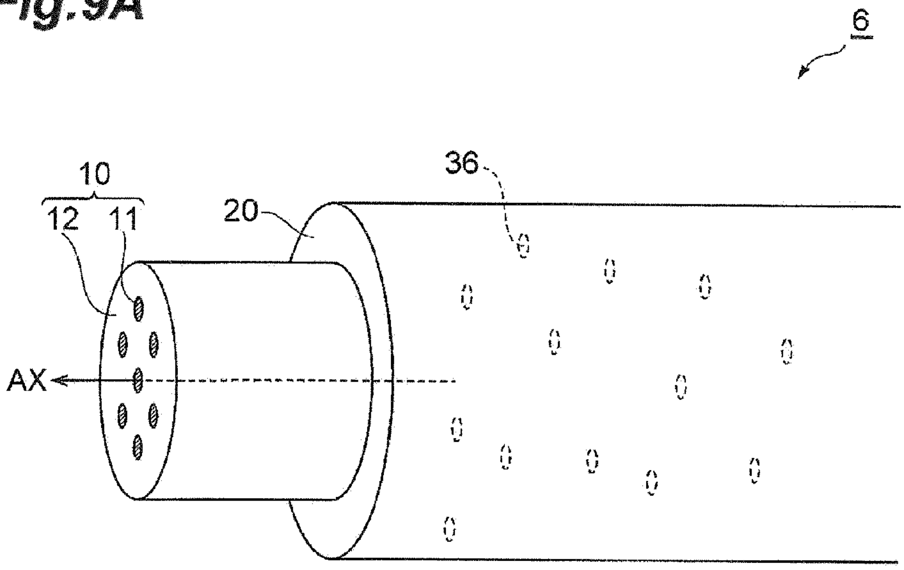



*Fig.9B*

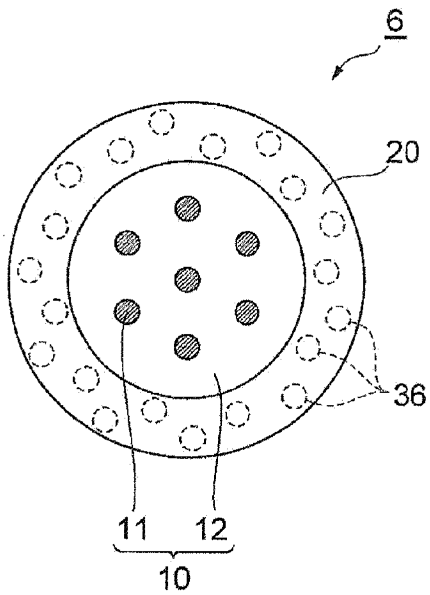


*Fig.10*

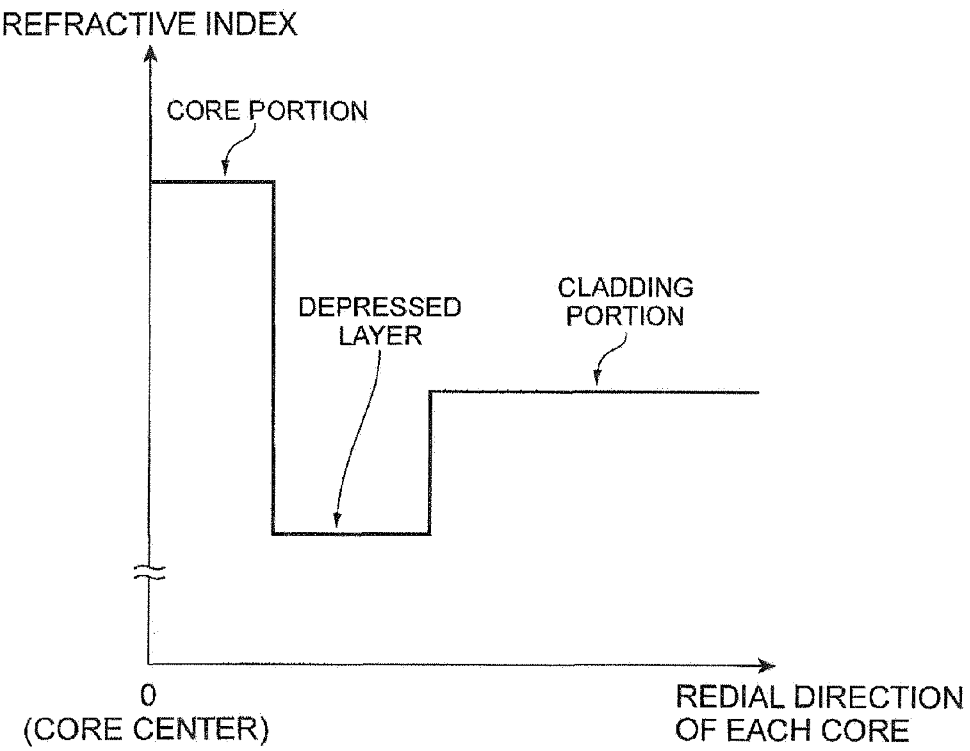

REFRACTIVE INDEX
CORE PORTION
DEPRESSED LAYER
CLADDING PORTION
0
(CORE CENTER)
REDIAL DIRECTION OF EACH CORE

*Fig.11*

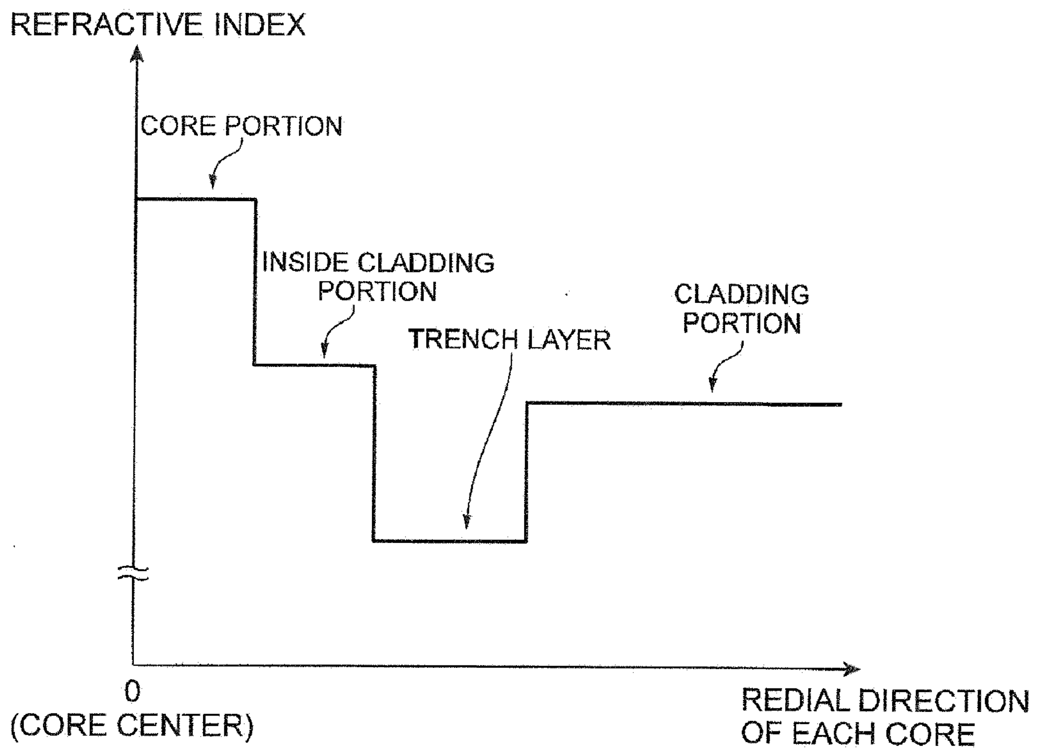

REFRACTIVE INDEX
CORE PORTION
INSIDE CLADDING PORTION
TRENCH LAYER
CLADDING PORTION
0
(CORE CENTER)
REDIAL DIRECTION OF EACH CORE

Fig.12

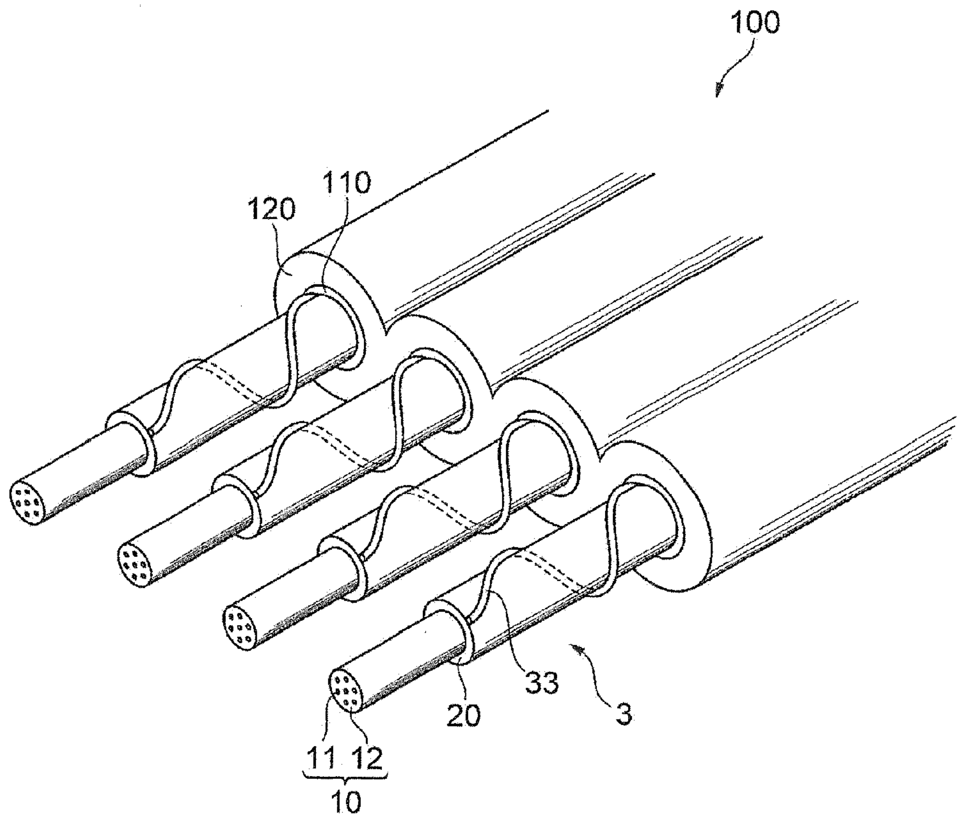


*Fig.13A*

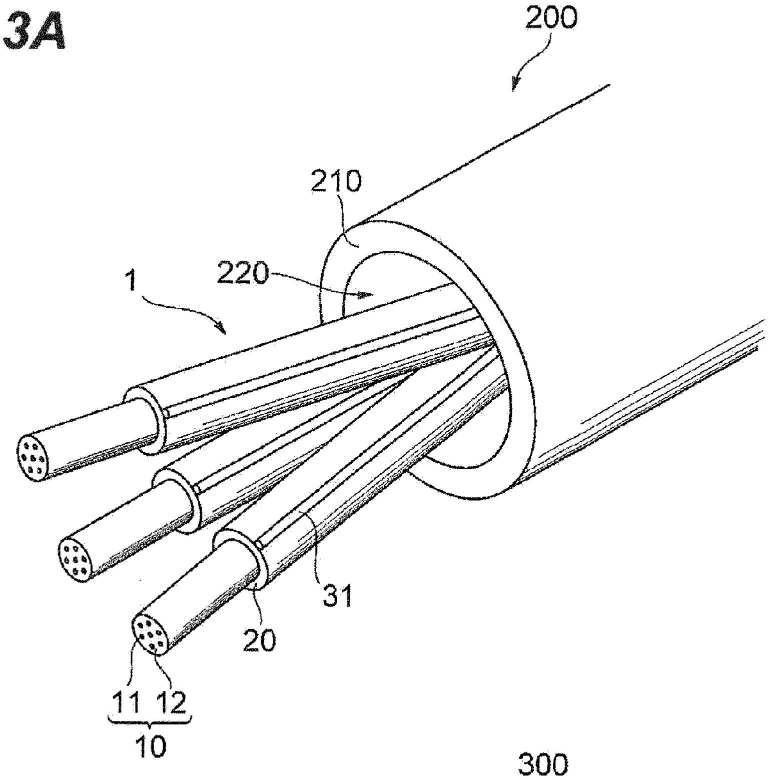



*Fig.13B*