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(21) International Application Number: PCT/US99/23578 (22) International Filing Date: 7 October 1999 (07.10.99) (30) Priority Data: 09/169,562 9 October 1998 (09.10.98) US (71) Applicant: GC TECHNOLOGIES, LTD. [US/US]; 15555 Concord Circle, Morgan Hill, CA 95037 (US). (72) Inventor: CHIA, Shin-Lo; 401 Indian Hill Place, Fremont, CA 94539 (US). (74) Agents: SAWYER, Joseph, A., Jr. et al.; Sawyer & Associates, P.O. Box 51418, Palo Alto, CA 94303 (US).		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published <i>Without international search report and to be republished upon receipt of that report.</i>
(54) Title: A METHOD AND SYSTEM FOR MODAL NOISE SUPPRESSION IN FIBER OPTIC SYSTEMS (57) Abstract The present invention provides a method and system for modal noise suppression in a fiber optics systems. In a first aspect, a single mode optical fiber (21) comprises a strongly absorbing outer cladding glass and a non-absorbing inner cladding glass (12). The fiber also includes a non-absorbing core glass (13). Through this combination modal noise is suppressed. In a second aspect, an in-line attenuator is provided. The in-line attenuator includes a single mode optical fiber, an attenuating fiber (22) coupled thereto, and a ferrule member for holding the single mode optical fiber and the attenuating fiber. In a third aspect, an isolator is provided. The isolator comprises an optics assembly and an input transmission fiber coupled to the optics assembly. The isolator further includes a first modal noise suppression (MNS) fiber coupled in the input transmission fiber and a gradient index lens (34) coupled between the optics assembly and the MNS fiber. The isolator further includes a second MNS fiber coupled to the gradient index lens (34) and an output filter (36) coupled to the second MNS fiber. In a fourth aspect, a fiber amplifier is provided. The fiber amplifier comprising first and second wavelength division multiplexers (WDMS) (41) means and first and second fibers which provide pump power into the first and second WDM means.		

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A METHOD AND SYSTEM FOR MODAL NOISE SUPPRESSION IN FIBER OPTIC SYSTEMS

FIELD OF THE INVENTION

The present invention relates generally to fiber optic connectors and more specifically to a method and system for suppressing modal noise.

BACKGROUND OF THE INVENTION

Modal noise is generated at mechanical connectors and splices in single mode fiber optic systems, especially when several connectors or splices are in close proximity, i.e., separated by a few meters or less. This type of noise is troublesome in many systems applications, and increasingly so as higher data rates and wavelength density is achieved in such systems. The modal noise results from a fraction of the signal power in the propagating mode of the system being scattered into higher, "non-propagating" modes at discontinuities, such as connectors or splices. The lowest order of the non-propagating modes are highly attenuated over distances of tens or hundreds of meters, where their energy dissipates into the outer cladding and buffer coating of the fiber.

However, within a few meters of the discontinuity, the power of the non-propagating mode in the vicinity of the core can still be considerable, and a fraction of it can be converted back to propagating mode power at a second discontinuity. The converted power then interferes with the directly transmitted propagating mode power, since the propagation velocity of the higher order modes is different from the lowest order mode. Whether the interference is constructive or destructive depends on a variety of factors, such as spacing between the discontinuities, wavelength of the signal, and propagation velocity of the dominant higher order mode.

Several applications where suppression of such modal noise is of particular interest are:

1. Coupling of in-line attenuators into systems.
2. Coupling input and output fibers to isolators, or circulators.
3. Coupling of amplifier fiber to standard transmission fiber.
4. Patch splice connectors for field repair of single mode fiber lines.

Accordingly, what is needed is a system and method for suppressing modal noise in the such applications as those identified above. The present invention addresses such a need.

SUMMARY OF THE INVENTION

The present invention provides a method and system for modal noise suppression in a fiber optics systems.

In a first aspect, a single mode optical fiber comprises a strongly absorbing outer cladding glass and a non-absorbing inner cladding glass. The fiber also includes a non-absorbing core glass. Through this combination modal noise is suppressed.

In a second aspect, an in-line attenuator is provided. The in-line attenuator includes the above-described single mode optical fiber; an attenuating fiber coupled thereto, and a ferrule member for holding the single mode optical fiber and the attenuating fiber.

In a third aspect, an isolator is provided. The isolator comprises an optics assembly and an input transmission fiber coupled to the optics assembly. The isolator further includes a first modal noise suppression (MNS) fiber coupled in the input transmission fiber and a gradient index lens coupled between the optics assembly and the first MNS fiber. The isolator further includes a second MNS fiber coupled to the gradient index lens and an output filter coupled to the second MNS fiber.

In a fourth aspect, a fiber amplifier is provided. The fiber amplifier comprising first and second wavelength division multiplexers (WDMS) means and first and second fibers which provide pump power into the first and second WDM means. The fiber amplifier further includes an amplifier section and a third fiber for providing signal power through the first WDM means to the amplifier section. Finally, the fiber amplifier includes a first modal noise suppression (MNS) fiber coupled between the first WDM and the amplifier section and a second MNS fiber coupled between the second WDM means and the amplifier section.

In a final aspect, a field repair patch for a broken optic fiber is provided. The repair patch first and second ferrule sections, each of the ferrule sections including a MNS fiber therewith; the ferrule sections adapted to retain one end of the broken optic

fiber and a transmission fiber coupling the first and second ferrule sections.

The present invention includes a special type of single mode fiber which can be fusion spliced into standard single mode fiber with very low backscatter from the splice, and a method for choosing the proper length of special fiber to optimize
5 rejection of non-propagating modes relative to the propagating mode. This rejection is accomplished by noting that the fraction of the power which propagates in the cladding is much higher for the non-propagating modes than for the propagating mode.

Therefore, mode discrimination can be accomplished by utilizing a strongly absorbing glass in most or all of the cladding. Where low loss to the propagating mode, and
10 very low backscatter are the primary concern, the design will involve a core and inner cladding material having a structure and structure identical to the standard

communications fiber to which the modal noise suppression (MNS) fiber is to be coupled, while all the outer cladding is solution doped highly absorbing high silica glass. In cases where some fixed attenuation of the propagating mode is also desired,
15 the entire cladding can be solution doped, and some of the doping can be permitted to diffuse into the core during the fiber fabrication process.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows cross sections of a preferred embodiment of this invention.

20 Figure 1a is a cross section of the tubular preform with chemical vapor deposition (CVD) layers.

Figure 1b represents the cross section of the modal noise suppression (MNS) fiber after the preform tube has been slumped and drawn into a fiber of the proper diameter.

25 Figure 2 is a schematic representation of the application to a fixed build-out attenuator.

Figure 2a shows two sections of MNS fiber 21 fused to a predetermined length of attenuating fiber 22.

Figure 2b shows the ferrule inserted into the connector housing 26, which has a
30 male 27 and female 28 end.

Figure 3 indicates the preferred application of MNS fiber in an isolator mode.

Figure 4 is a representation of the application of MNS fiber in a fiber amplifier.

Figure 5 represents the application of MNS fiber in field repair patching of optical fiber transmission line breaks.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to an improvement in fiber optic devices. The following description is presented to enable one of ordinary skill in the art to make and use the invention and is provided in the context of a patent application and its requirements. Various modifications to the preferred embodiment will be readily apparent to those skilled in the art and the generic principles herein may be applied to other embodiments. Thus, the present invention is not intended to be limited to the embodiment shown but is to be accorded the widest scope consistent with the principles and features described herein.

The present invention includes a special type of single mode fiber which can be fusion spliced into standard single mode fiber with very low backscatter from the splice, and a method for choosing the proper length of special fiber to optimize rejection of non-propagating modes relative to the propagating mode. This rejection is accomplished by noting that the fraction of the power which propagates in the cladding is much higher for the non-propagating modes than for the propagating mode.

Therefore, mode discrimination can be accomplished by utilizing a strongly absorbing glass in most or all of the cladding. (It will be shown that the optimum design of the cladding glass doping will depend on the desired application). Where low loss to the propagating mode, and very low backscatter are the primary concern, the design will involve a core and inner cladding material having a structure identical to the standard communications fiber to which the modal noise suppression (MNS) fiber is to be coupled, while all the outer cladding is solution doped highly absorbing high silica glass. In cases where some fixed attenuation of the propagating mode is also desired, the entire cladding can be solution doped, and some of the doping can be permitted to diffuse into the core during the fiber fabrication process.

One critical aspect of the present invention is preform of the fiber. The same broadband absorption characteristics of certain transition metal or rare earth oxide

dopings of silicon glass as are used for the core glass of the attenuating fiber used to fabricate in-line attenuators can be used to produce solution doped silicon glass for the outer cladding of the MNS fiber. For example, in the 1250nm to 1600nm wavelength bands used for standard optical communications systems, cobalt oxide doping of silica can provide a broadband absorption with little change in the other properties of the cladding glass. To produce the desired fiber characteristic, a tube of solution doped silica is used as the starting material for the preform. A predetermined layer of pure silica is then vapor deposited inside the preform tube, followed by a layer of germania doped silica to form the core glass, as in a conventional fiber preform. The resulting rod is then slumped to produce the preform rod from which the fiber can be drawn on standard fiber drawing machinery. The cross section of such a preform is shown in Figure 1a, while typical dimensions in the cross section of drawn fiber are shown in Figure 1b.

Figure 1 shows cross sections of a preferred embodiment of this invention. Figure 1a is a cross section of the tubular preform with chemical vapor deposition (CVD) layers. The outer tube 11 is extruded from solution doped absorbing silica glass. On its inner wall is deposited a thin layer 12 of pure silica cladding glass, followed by a layer 13 of doped silica (typically germania doping), which will form the core of the single mode fiber.

Figure 1b represents the cross section of the modal noise suppression (MNS) fiber after the preform tube has been slumped and drawn into a fiber of the proper diameter. The outer cladding 14 is the absorbing silica glass, with a thin (optional) inner cladding layer 15 of undoped silica, and the standard core glass 16 to match a standard communications fiber.

Applications of the Present Invention

A length of MNS fiber fused to attenuating core fiber to produce a low modal noise and application independent fixed in-line attenuator (see Figure 2). In this application, the attenuating core fiber is placed at the input end, with the MNS fiber section making up the output segment. This configuration results in an in-line attenuator with the same attenuation for direct coupling to a detector or insertion into a

long line, and also partly compensates the lower attenuation of longer wavelengths in the attenuating fiber segment with higher attenuation of longer wavelengths in the MNS segment.

Figure 2 is a schematic representation of the application to a fixed build-out attenuator. The fiber assembly of the fixed attenuator is inserted into a ferrule matching the tolerances of standard connector ferrules. Figure 2a shows two sections of MNS fiber 21 fused to a predetermined length of attenuating fiber 22. After insertion into the ferrule, the input end 24 and output end 25 are polished. Figure 2b shows the ferrule inserted into the connector housing 26, which has a male 27 and female 28 end.

A length of MNS fiber at the input and output of isolators and circulators to increase rejection of unwanted polarization components, significantly improving isolation (Fig. 3). Figure 3 indicates the preferred application of MNS fiber in an isolator mode. The most common type of isolator utilizes beam forming gradient index lenses 32 to project the optical signal through a "bulk optics" assembly consisting of polarizing crystals, Faraday rotating crystals and analyzer crystals, which are labeled in Figure 3 as "bulk optics assembly" 33. The input transmission fiber 30 is fusion spliced to a section of MNS fiber 31, which is coupled to the gradient index lens 32. Likewise, at the output end, the gradient index lens 34 is coupled to a section of MNS fiber 35, which is fused to the output signal filter 36. When an appropriate length of MNS fiber is used at the input and output ports of isolators or circulators, the MNS fiber not only serves to reduce modal noise, but also improves isolation by strongly rejecting unwanted polarization components primarily propagating in the cladding, a significant fraction of which normally can scatter back into the propagating mode at the connectors.

Figure 4 is a representation of the application of MNS fiber in a fiber amplifier. A dual pump amplifier has two wavelength division multiplexers (WDM) 41, which permit insertion of pump power from fibers 45 and signal power from transmission fiber 42 into the amplifier section 43. The WDM common fiber 47 is fused to a length of MNS fiber 44, the other end of which is fused to the amplifying fiber 43. Likewise, a section of MNS fiber 44 is fused to the output end of the amplifying fiber

43, the other end of the MNS fiber being fused to the common fiber 47 of the output WDM, which injects the second **pump** power into the amplifier from pump fiber 45 and delivers amplified output signal to transmission fiber 46. Not shown in this drawing are the isolators, as discussed with Figure 3, which are used in the transmission fibers to prevent backscattered signal from feeding back into the amplifier.

Figure 5 represents the application of MNS fiber in field repair patching of optical fiber transmission line breaks. The ends of the broken fiber 51 are cleaved and inserted into ferrules 52 which have sections of MNS fiber 54 bonded in them. A length of transmission fiber 53 joins the two ferrules and is coiled in the repair junction box. The coupling of the transmission fiber to the MNS fiber in the ferrule can be accomplished with low loss if an photopolymerizing index matching cement is used. Alternatively, the fibers can be fusion spliced to the MNS fiber, if field operating conditions permit. In the latter case, a prepared repair fiber with MNS fiber sections at each end could be used as the patch, minimizing modal noise due to the splices.

Clearly, any other system component where closely spaced discontinuities in the fiber are required will benefit from use of the MNS fiber inserts.

Accordingly, as is seen the present invention can be utilized in fixed inline attenuators. A low modal noise fixed attenuator can be fabricated by fusing the appropriate length of attenuating core fiber to two lengths of MNS fiber, and inserting the resulting assembly into a standard connector ferrule, as shown in Figure 2a. The ferrule is polished and inserted into a BOA connector housing for use with standard connectorized cables. Such an attenuator has the further advantage of having essentially the same attenuation when inserted into a long line or directly into a detector housing. With proper selection of the MNS fiber characteristics, the increasing attenuation of the MNS fiber with wavelength for the propagating mode can compensate the decreasing attenuation of the attenuating fiber with wavelength, improving the wavelength independence of the fixed attenuator.

When an appropriate length of MNS fiber is used at the input and output ports of isolators or circulators, the MNS fiber not only serves to reduce modal noise, but

also improves isolation by strongly rejecting unwanted polarization components primarily propagating in the cladding, a significant fraction of which normally can scatter back into the propagating mode at the connectors.

5 A length of MNS fiber fused between the amplifying fiber and the standard transmission fiber reduces modal noise which can result from the discontinuity due to the mismatch in NA between the fibers, and reduce the effect of non-propagating modes introduced by multiplexing couplers and connectors in the amplifier unit.

10 Field repair of damaged fiber optic cables often involves installing a patch section of fiber between the cleaved ends of the broken fiber. A desirable technique utilizes precision ferrules with pre-installed fiber into which the cleaved end of the broken fiber can be inserted in the presence of photopolymerizable index matching cement. While the cement removes most of the reflection due to index mismatch, such ferrules can permit significant core offset error, resulting in modal noise due to the two closely spaced junctions. Using MNS fiber in the patch coupler can reduce this modal noise without adding significantly to the connector losses for the propagating mode.

15 Clearly, any other system component where closely spaced discontinuities of the fiber path are required can benefit from the use of MNS fiber inserts. While the discontinuities need to be within a few meters to produce significant modal noise, once the modal noise is generated, it is propagated as part of the signal, and is cumulative along a transmission path. Thus, minimization at each sub-system is particularly important in long and complex transmission paths.

20 Although the present invention has been described in accordance with the embodiments shown, one of ordinary skill in the art will readily recognize that there could be variations to the embodiments and those variations would be within the spirit and scope of the present invention. Accordingly, many modifications may be made by one of ordinary skill in the art without departing from the spirit and scope of the appended claims.

CLAIMS

What is claimed is:

- 1 1. A single mode optical fiber comprising:
2 a strongly absorbing outer cladding glass; and
3 a non-absorbing core glass, wherein modal noise is suppressed.
- 1 2. The single mode optical fiber of claim 1 wherein the outer cladding
2 glass comprises a silica glass solution doped with cobalt oxide.
- 1 3. An in-line attenuator comprising:
2 a single-mode optical fiber comprising a strongly absorbing outer
3 cladding glass, a non-absorbing inner cladding glass, and a non-absorbing core
4 glass;
5 an attenuating fiber coupled to the single mode optical fiber; and
6 a ferrule member for holding the single mode optical fiber and the attenuating
7 fiber.
- 1 4. An attenuator of claim 3 wherein the outer cladding glass is silica glass
2 solution doped with cobalt oxide.
- 1 5. The attenuator of claim 4 which includes a connecting housing for
2 holding the ferrule member.
- 1 6. An isolator comprising:
2 optics assembly;
3 an input transmission fiber coupled to the optics assembly;
4 a first modal noise suppression (MNS) fiber coupled to the input transmission
5 fiber;
6 a gradient index lens coupled between the optics assembly and the first MNS
7 fiber;

8 a second MNS fiber coupled to the gradient index lens; and
9 an output filter coupled to the second MNS fiber.

1 7. The isolator of claim 6 wherein each of the first and second MNS fibers
2 comprises:

3 a strongly absorbing outer cladding glass;
4 a non-absorbing inner cladding glass; and
5 a non-absorbing core glass, wherein modal noise is suppressed.

1 8. The isolator of claim 7 wherein the outer cladding glass comprises a
2 silica glass solution doped with cobalt oxide.

1 9. A fiber amplifier comprising:
2 first and second wavelength division multiplexers (WDMS) means;
3 first and second fibers which provide pump power into the first and second
4 WDM means;
5 an amplifier section;
6 a third fiber for providing signal power through the first WDM means to the
7 amplifier section;
8 a first modal noise suppression (MNS) fiber coupled between the first WDM
9 and the amplifier section; and
10 a second MNS fiber coupled between the second WDM means and the
11 amplifier section.

1 10. The fiber amplifier of claim 9 wherein each of the first and second MNS
2 fibers comprises:

3 a strongly absorbing outer cladding glass;
4 a non-absorbing inner cladding glass; and
5 a non-absorbing core glass, wherein modal noise is suppressed.

1 11. The fiber amplifier of claim 10 wherein the outer cladding glass

comprises a silica glass solution doped with cobalt oxide.

12. The fiber amplifier of claim 11 wherein the first WDM means comprises a first WDM and a first common fiber coupled to the WDM, wherein the first MNS fiber being coupled to the first common fiber.

13. The fiber amplifier of claim 12 wherein the second WDM means comprises a second WDM and a second common fiber to the WDM, wherein the second MNS fiber being coupled to the second common fiber.

14. A field repair patch for a broken optic fiber comprising:
first and second ferrule sections, each of the ferrule sections including a MNS fiber therewith; the ferrule sections adapted to retain one end of the broken optic fiber;
and
a transmission fiber coupling the first and second ferrule sections.

15. The field repair patch of claim 14 wherein each of the MNS fibers comprises:
a strongly absorbing outer cladding glass;
a non-absorbing inner cladding glass; and
a non-absorbing core glass wherein modal noise is suppressed.

16. The field repair patch of claim 15 wherein the outer cladding glass is silica glass solution doped with cobalt oxide.

17. The field repair patch of claim 16 in which the coupling of the transmission fiber to the MNS fiber comprises cementing the fibers via a photopolymerizing index matching element.

18. The field repair patch of claim 16 in which the coupling of the transmission

3 fiber to the MNS fiber comprises cementing the fibers via fusion splicing.

1 19. A method for providing a modal noise suppression fiber comprising
2 steps
3 of:

- 4 a) providing a strongly absorbing outer cladding glass;
5 b) providing a non-absorbing inner cladding glass; and
6 c) providing a non-absorbing core glass, wherein modal noise is
7 suppressed.

1 20. The method of claim 19 wherein the outer cladding glass comprises a
2 silica glass solution doped with cobalt opide.

Figure 1a

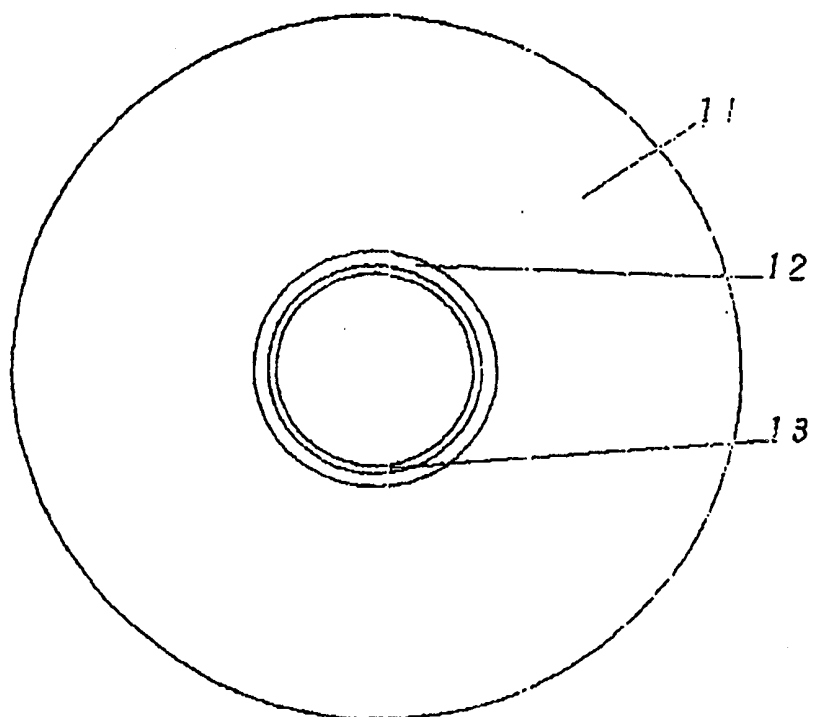


Figure 1b

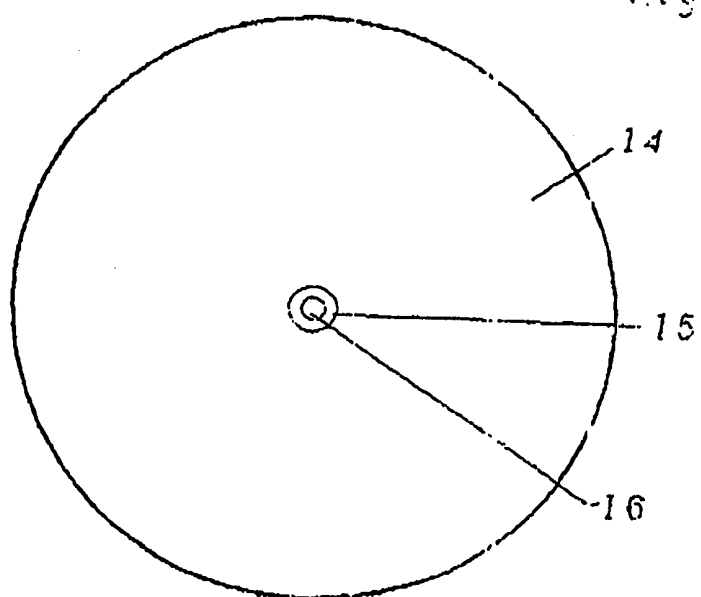


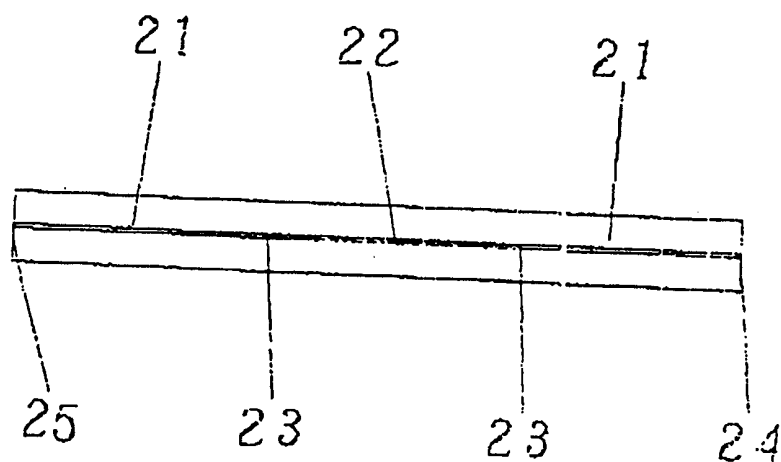
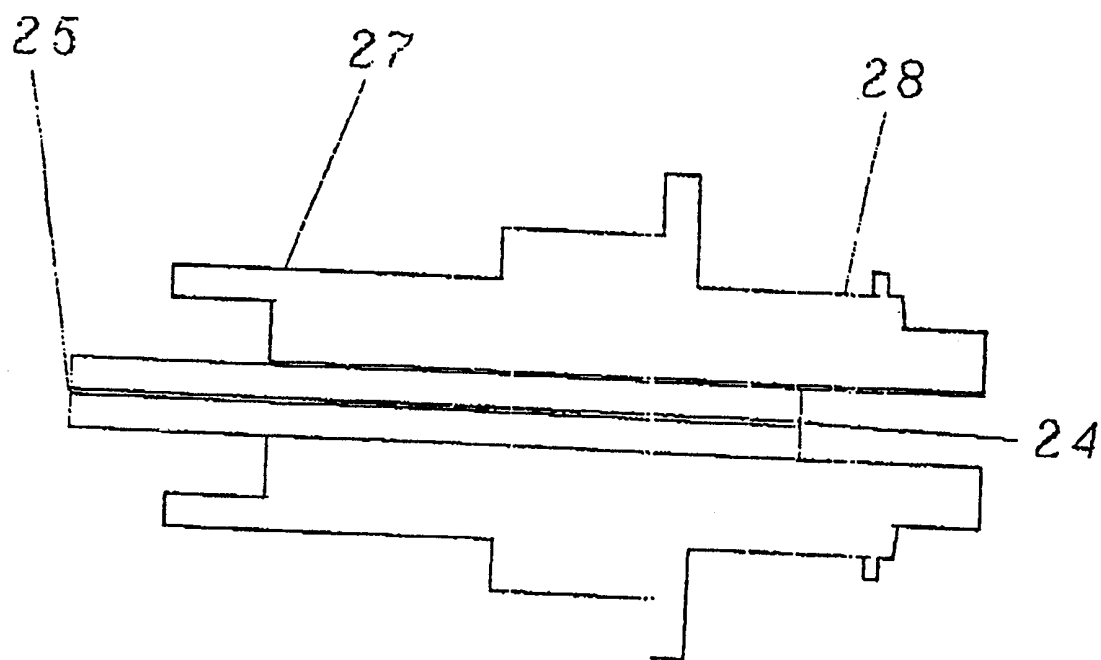
Figure 2a*Figure 2b*

Figure 3

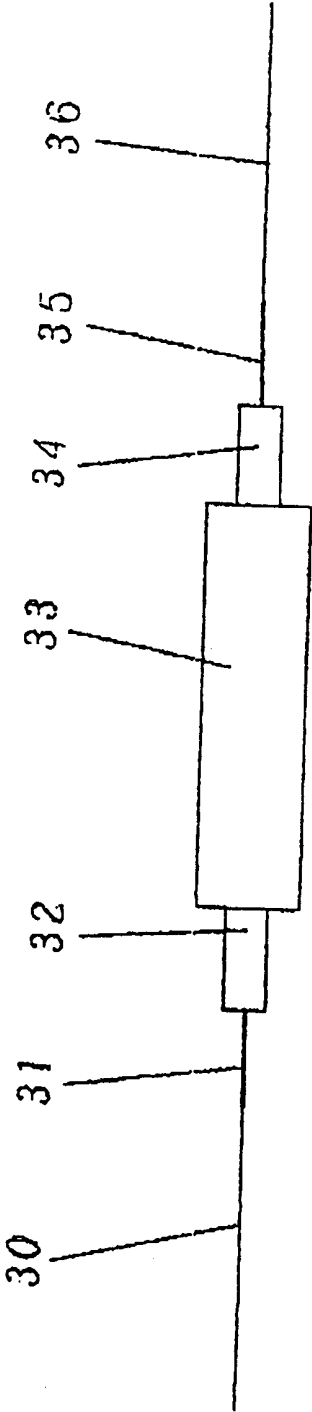


Figure 4

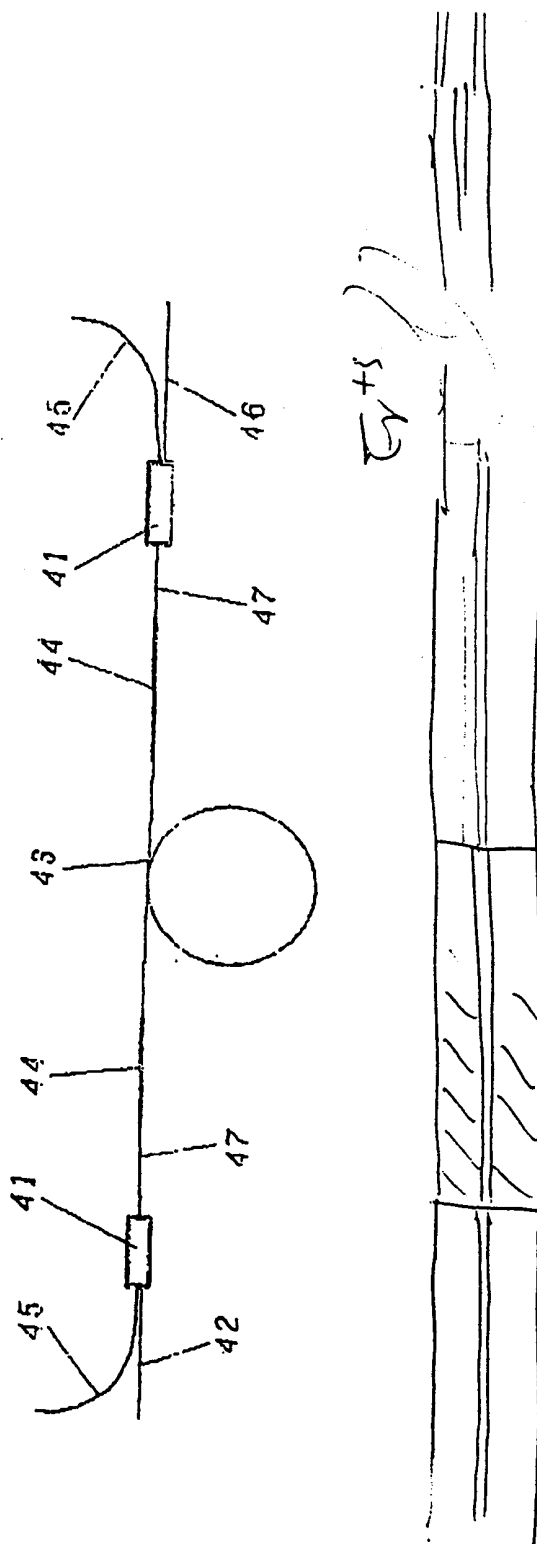


Figure 5

