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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 September 2016 (22.09.2016)

(10) International Publication Number
WO 2016/149435 A1

(51) International Patent Classification:
G02B 6/06 (2006.01) *G02B 6/46* (2006.01)
G02B 6/14 (2006.01)

(21) International Application Number:
PCT/US2016/022736

(22) International Filing Date:
17 March 2016 (17.03.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/135,641 19 March 2015 (19.03.2015) US
15/071,296 16 March 2016 (16.03.2016) US

(71) Applicant: **II-VI INCORPORATED** [US/US]; 375 Saxonburg Boulevard, Saxonburg, PA 16056 (US).

(72) Inventor: **FILIPOWICZ, Mark**; 355 Martin Drive, Scotts Valley, CA 95066 (US).

(74) Agent: **KOBA, Wendy, W.**; PO Box 556, Springtown, PA 18071 (US).

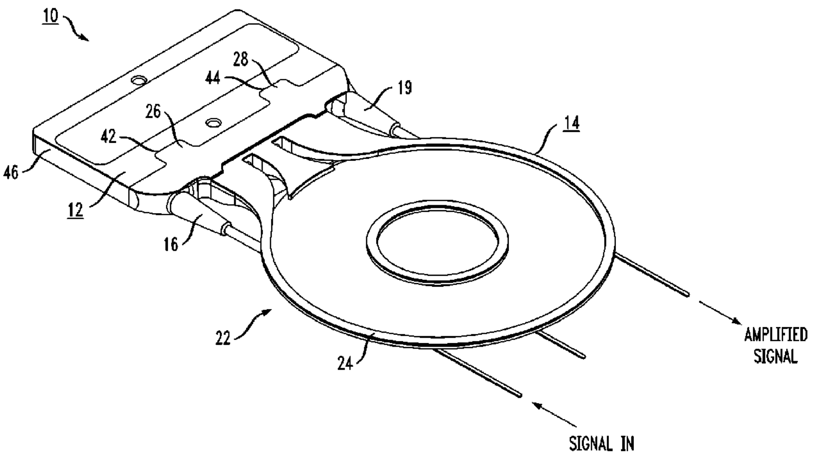
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) Title: COMPACT OPTICAL FIBER AMPLIFIER

FIG. 1



(57) **Abstract**: A fiber-based optical amplifier is assembled in a compact configuration by utilizing a flexible substrate to support the amplifying fiber as flat coils that are "spun" onto the substrate. The supporting structure for the amplifying fiber is configured to define the minimal acceptable bend radius for the fiber, as well as the maximum diameter that fits within the overall dimensions of the amplifier package. A pressure-sensitive adhesive coating is applied to the flexible substrate to hold the fiber in place. By using a flexible material with an acceptable insulative quality (such as a polyimide), further compactness in the final assembly is achieved by 1 ocating the electronics in a space underneath the fiber enclosure.

WO 2016/149435 A1

COMPACT OPTICAL FIBER AMPLIFIER

Cross-Reference to Related Applications

This application claims the benefit of U.S. Provisional Application Serial No. 62/135,641, filed March 19, 2015 and herein incorporated by reference.

Technical Field

The present invention relates to a fiber-based optical amplifier and, more particularly, to a compact configuration for the amplifying fiber portion of the optical amplifier.

Background

Various types of fiber-based optical amplifiers, such as erbium-doped fiber amplifiers (EDFAs) and distributed Raman amplifiers (DRAs), are ubiquitous components of optical communication systems, eliminating the need to perform optical-electrical-optical signal transformations when regeneration of a fading optical signal is required.

In the case of EDFAs, an optical pump laser (typically operating at 980nm) is coupled into a section of Er-doped optical fiber, and the incoming optical signal is propagated through the doped fiber with the pump light. The presence of the pump light with the erbium dopant generates amplification of the propagating optical signal by the transitions of the optically-excited erbium ions. Distributed Raman amplifiers (DRAs) operate by injecting short, high-power pulses along a section of transmission fiber that is supporting the propagation of an optical signal. The presence of these pulses (either co-propagating or counter-propagating with respect to the optical signal) excites the photons to higher energy levels, where the photons create stimulated emission as they return to their ground state.

The various components forming an optical amplifier module are typically made as fiber-coupled elements, and in some cases integrated (or hybridized) to form, for example, a combined isolator and WDM filter, or a combined isolator and GFF filter, or the like. Of course, lower cost and smaller-sized modules lower the overall system costs. Thus, the trend to smaller components, more hybridization and smaller modules has been taking place for some time. Indeed, the pressure for smaller form factors and lower costs continues to be exerted on the industry.

One path to assuage these demands is to continually reduce the size of the various components and, perhaps, increase their degree of integration. However, this is not easily accomplished in an environment where the cost of the amplifier module is also a concern. Indeed, the size of these components has decreased to the point where they cannot be readily assembled by low-cost labor (i.e., the size of some of these components can be on the order of 1mm x 1mm x 1mm).

Furthermore, even with reduction in size of an optical amplifier module, such as from increasing the level of integration within the hybrid components, the different hybrids must be coupled to each other via fiber splicing and routing. As a consequence of the minimum bend radius of the optical fiber as well as the relatively large number of fiber splices and splice protectors mandating the same, the ability to further hybridize current configurations is quickly reaching its technical limits, size limits and economical possibilities of implementation. The "bend radius" is a determinative factor associated with defining an acceptable amount of signal loss. In particular, the loss exhibited by an optical signal increases with a smaller bend radius of the fiber in which the signal is propagating. At exceptionally small bend radius values, there may also be a physical failure of the fiber itself.

Thus, for a fiber-based optical amplifier to continue to meet the expectations of cost and size reduction, while maintaining performance requirements, a different approach to incorporating the amplifying fiber within the optical amplifier module appears to be required.

Summary of the Invention

The needs remaining in the prior art are addressed by the present invention, which relates to a fiber-based optical amplifier and, more particularly, to a compact configuration for the amplifying fiber portion of the amplifier.

In accordance with one embodiment of the present invention, an exemplary optical amplifier is configured as comprising an optics module and a fiber module. The optics module is used to house the various optical devices utilized to process the amplified signal into an acceptable output form, and the fiber module is used to house the actual fiber within which the amplification is created. The inventive fiber module consists of a flexible substrate of insulative material (for example, a polyimide) with a pressure-sensitive adhesive top coating. The fiber itself is wound in a coil configuration on the insulative material and held in place by the adhesive coating. A support tray of a stiffer material is used to impart mechanical strength to the flexible material, and may be formed to include guides to ensure that the radius of the coil does not go below a defined minimum fiber bend radius.

A particular embodiment of the present invention may be configured as a rare earth-doped optical fiber amplifier, providing pump light of a specific wavelength to propagate along a coil of rare-earth (e.g., erbium) doped optical fiber at the same time as the input optical signal. Another embodiment of the present invention takes the form of a distributed Raman amplifier (DRA), where high-power laser pulses are injected into a signal path along which the input optical signal is propagating.

An exemplary embodiment of the present invention takes the form of an optical fiber amplifier comprising an optics module housing optical elements utilized in creating an output optical signal from an amplified version and a fiber module optically coupled to the optics module. The fiber module is used to house a section of amplifying fiber for creating gain in a propagating optical signal in the presence of pump light, where the fiber module specifically includes a flexible substrate for supporting the section of amplifying fiber in a configuration of flat coils and a support structure disposed underneath the flexible substrate, the support structure including an end termination for mechanically attaching the fiber module to the optics module.

Other and further aspects of the present invention will become apparent during the course of the following discussion and by reference to the accompanying drawings.

Brief Description of the Drawings

Referring now to the drawings, where like numerals represent like parts in several views:

FIG. 1 is an isometric diagram of an exemplary optical fiber amplifier, formed in accordance with the present invention;

FIG. 2 is an exploded view of the optical fiber amplifier of FIG. 1;

FIG. 3 depicts a section of amplifying fiber, presented as a flat coil for use within the fiber module of the amplifier;

FIG. 4 illustrates the coil of amplifying fiber of FIG. 3 as disposed on an exemplary fiber module;

FIG. 5 is a diagram of the support structure portion of the fiber module, illustrating the parameters that control the bend radius experienced by the amplifying fiber as it is coiled;

FIG. 6 illustrates an alternative configuration for attaching the fiber module to the optics module of the inventive optical amplifier; and

FIG. 7 shows a compact configuration where the electrical isolation provided by the material of the fiber module allows for an electronic circuit board to be positioned in close proximity to the optical amplifier.

Detailed Description

FIG. 1 is an isometric diagram of an exemplary compact optical amplifier 10, formed in accordance with the present invention. Optical amplifier 10 comprises both an optics module 12 and an amplifying fiber module 14. Optics module 12 is of conventional form perhaps, and includes various optical elements, hybrids, etc. utilized to create an amplified output signal that meets defined system requirements (in terms of, for example, noise floor, isolation, gain profile, insertion loss, etc.). Fiber module 14 houses a (relatively long) section of amplifying fiber that is used to perform the actual amplification function on the incoming optical signal. There exist many different configurations that may be used to provide the optical functions as required within optics module 12, where co-pending US Application Serial No. ____, describes some preferred embodiments and is herein incorporated by reference.

For the sake of clarity, fiber module 14 is shown in FIG. 1 without having the amplifying fiber in place. It is to be understood that when designing a rare-earth doped fiber amplifier, a section of doped fiber (e.g., erbium-doped fiber) would be placed within fiber module 14. For the case of a distributed Raman amplifier, a section of conventional single-mode fiber is typically disposed within fiber module

14. An exemplary process of loading the amplifying fiber into module 14 will be described below in association with FIGs. 3-5.

FIG. 2 is another view of exemplary compact optical amplifier 10, in this case an exploded view with optics module 12 shown as separated from fiber module 14, and a set of exemplary components forming fiber module 14 also shown. Referring to both FIGs. 1 and 2, an incoming optical signal is introduced in optics module 12 via a fiber pigtail connection16. The incoming optical signal and pump light (which may be supplied from a separate external source or co-packaged within optics module 12) are combined within optics module 12 and coupled into fiber module 14 via a pigtail fiber connection 17. The optical signal and pump light then propagate through the length of amplifying fiber 20 housed with fiber module 14, with an amplified version of the optical signal ultimately exiting fiber module 14. The amplified signal is then coupled back into optics module 12 at an optical fiber pigtail 18. Various post-amplification optical functions (gain flattening, power adjustments, etc., as dictated by specific system requirements) are performed on the signal, which then exits optics module 12 from optical fiber pigtail 19 as the amplified output signal from optical amplifier 10.

In the specific embodiment of FIG. 2, fiber module 14 is shown as comprising a stiff support member 22 configured to have a relatively circular distal portion 24 and an opposing pair of end terminations 26 and 28 that are used to attach fiber module 14 to optics module 12. A flexible substrate 30 of a suitable insulative material (e.g., a polyimide-based material) is disposed within support member 22, and a coating 31 of a pressure-sensitive adhesive is applied to flexible substrate 30. The adhesive coating is used to ensure the integrity of the attachment of amplifying fiber 20 to flexible substrate 30. Also shown in FIG. 2 is a top cover plate 32 and a bottom cover plate 34, used to encase amplifying fiber 20 within fiber module 14 (as shown in final form in FIG. 1).

Variations of this specific configuration are contemplated, including the use of fewer or more end terminations to mechanically attach fiber module 14 to optics module 12. Additionally, while it may be preferred to include an adhesive coating 31 on flexible material 30, there may be some types of flexible material that exhibit an adhesive nature without the need for the additional coating.

One aspect of the present invention is the particular configuration of the amplifying fiber as a flat coil (as compared with bundling the fiber as is common in the prior art). In the particular illustration of FIG. 3, amplifying fiber 20 is shown as being coiled in a manner that creates a "stack" of two flat coils shown as 20-1 and 20-1. FIG. 4 illustrates a coil of amplifying fiber 20 as in place within circular portion 24 of support structure 22. In the process of fabricating this portion of the compact optical amplifier, the amplifying fiber is literally spun onto flexible material 30, using a pressure sufficient to allow for adhesive coating 31 to hold the coiled fiber in place.

In the implementation of an EDFA, amplifying fiber 20 comprises a section of rare-earth doped fiber about one meter in length (at times, more than a meter may be required). DRAs may utilize conventional signal mode optical fibers of lengths of several meters in the formation of amplifying fiber 20. In attempting to incorporate these relatively long lengths of amplifying fiber within packages of relatively small dimensions, it is necessary to understand the impact of bend loss on the propagating signal. That is, if a fiber is bent into a curve (in this case, when forming a coil) with a very tight bend radius, a large fraction of the propagating signal will be scattered out of the core region; the loss increases as the fiber radius decreases. A very small fiber bend radius may also cause breakage of the fiber itself. On the other hand, if the bend radius is maintained at a large value (i.e., such that only a relatively "gentle" bend is imparted on the fiber), the size of a package required to accommodate a meter or two of amplifying fiber would be too large for many of the CFP requirements.

FIG. 5 is a diagram of an exemplary support structure 22 formed in accordance with these aspects of the present invention to control the curvature introduced into the coil configuration of amplifying fiber 20. In particular, circular portion 24 of support structure 22 is shown as including a central opening 36, where the diameter **d** of opening 36 is chosen to prevent amplifying fiber 20 from being coiled with a very tight bend radius. The outer diameter D of circular portion 24 is chosen to ensure that the final dimensions of optical amplifier 10 are well within the limitations imposed by the particular package design. Opening 36 may include a rim 38 to prevent the amplifying fiber from entering this central area. Similarly, the outer periphery of support structure 22 may include a rim 40 to maintain the fiber confined within its designated boundary.

In one exemplary assembly process, amplifying fiber 20 is spun onto the surface flexible substrate 30 of support structure 22, using opening 36 (with rim 38) and outer rim 40 as guides for the process. That is, amplifying fiber 20 is spooled in a flat configuration, rather than bundled as in the prior art, with miniature splice protectors inserted in place for connection to fiber pigtails 17 and 18. As such, this portion of the optical amplifier may be assembled with automated methods, making a highly repeatable process with high yield and low cost, as well as a small footprint.

It is to be understood that there are a variety of different configurations that may be used to mechanically attach fiber module 14 to optics module 12 (the optical connection provided via fiber pigtails 17and 18, as explained above). The exemplary configuration as shown in FIGs. 1 and 2 utilizes a straightforward snap-fit friction fitting between end terminations 26, 28 of fiber module 14 and associated attachment elements 42, 44 formed within the housing 46 of optics module 12 (best shown in FIG. 2).

FIG. 6 is an isometric view of an alternative attachment configuration, in this case using a set of screws 48 to attach end terminations 26, 28 of fiber module 14 to housing 46 of optics module 12. The specifics of rims 38 and 40 are also specifically shown in this view of the inventive compact optical amplifier module. from underneath optical amplifier 10, showing the attachment of fiber module 14 to optics module 12. In this view, both end terminations 26 and 28 are visible, with stiffening elements 42 and 42' disposed as shown. Attachment screws 50 and 52 are shown as attaching end termination 26 to optics module 12, with similar attachment screws 50' and 52' used to attach end termination 28.

As mentioned above, another advantage of the compact amplifier module configuration of the present invention is that support structure 22 of fiber module 14 is formed of an insulative material. As such, it is possible to locate associated electric circuits in close proximity to fiber module 14 without affecting its performance. FIG. 7 is an exemplary illustration of the inventive compact optical amplifier that illustrates this aspect. For the sake of clarity, the covering layer enclosing amplifying fiber 20 is not shown. In this case, an electronics circuit board 100 is illustrated as being disposed directly underneath compact optical amplifier 10, extending beneath both optics module 12 and fiber module 14.

It is to be understood that the inventive fiber module for use with a fiber-based optical amplifier may be used in the formation of a doped fiber amplifier (such as an EDFA) or a distributed Raman amplifier, with the only change in assembly being the type of fiber that is spooled onto the flexible substrate of the module. With that said, the particular dimensions of support structure 22 (particularly central opening 32) may differ as a function of a minimum bend radius associated with a particular amplifier's design criteria.

It will be appreciated by those skilled in the art that changes may be made to the embodiment described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiment disclosed, but it is intended to cover modification s within the spirit and scope of the inventive concept as defined by the appended claims.

What is claimed is:

1. An optical fiber amplifier comprising:

an optics module housing optical elements utilized in creating an output optical signal from an amplified version; and

a fiber module optically coupled to the optics module, the fiber module housing a section of amplifying fiber for creating gain in a propagating optical signal in the presence of pump light, the fiber module including

a flexible substrate for supporting the section of amplifying fiber in a configuration of flat coils; and

a support structure disposed underneath the flexible substrate, the support structure including an end termination for mechanically attaching the fiber module to the optics module.

2. The optical fiber amplifier as defined in claim 1 wherein the fiber module further comprises a coating layer of a pressure-sensitive adhesive disposed over the flexible substrate for affixing the section of amplifying fiber to the flexible substrate.

3. The optical fiber amplifier as defined in claim 1 wherein the support structure includes a central opening having a diameter defined by a minimum acceptable fiber bend radius, the minimum acceptable fiber bend radius dictated by the type of fiber utilized as the amplifying fiber.

4. The optical fiber amplifier as defined in claim 1 wherein the support structure further comprises a stiffening element disposed to cover the end termination.

5. The optical fiber amplifier as defined in claim 1 wherein the end termination of the support structure comprises a pair of separate end terminations.

6. The optical fiber amplifier as defined in claim 5 wherein the support structure further comprises a stiffening element disposed over each end termination.

7. The optical fiber amplifier as defined in claim 1 wherein the flexible substrate is formed of an insulative material.

8. The optical fiber amplifier as defined in claim 7 wherein the flexible substrate is formed of a polyimide.

9. The optical fiber amplifier as defined in claim 1 wherein the optical fiber amplifier is a doped fiber amplifier and the section of amplifying fiber comprises a length of rare-earth doped optical fiber.

10. The fiber-based optical amplifier as defined in claim 9 wherein the section of amplifying fiber comprises a length of erbium-doped fiber.

11. The fiber-based optical amplifier as defined in claim 1 wherein the fiber-based optical amplifier is a distributed Raman amplifier and the section of amplifying fiber comprises a length of transmission fiber.

12. The fiber-based optical amplifier as defined in claim 11 wherein the section of amplifying fiber comprises a length of single mode fiber.

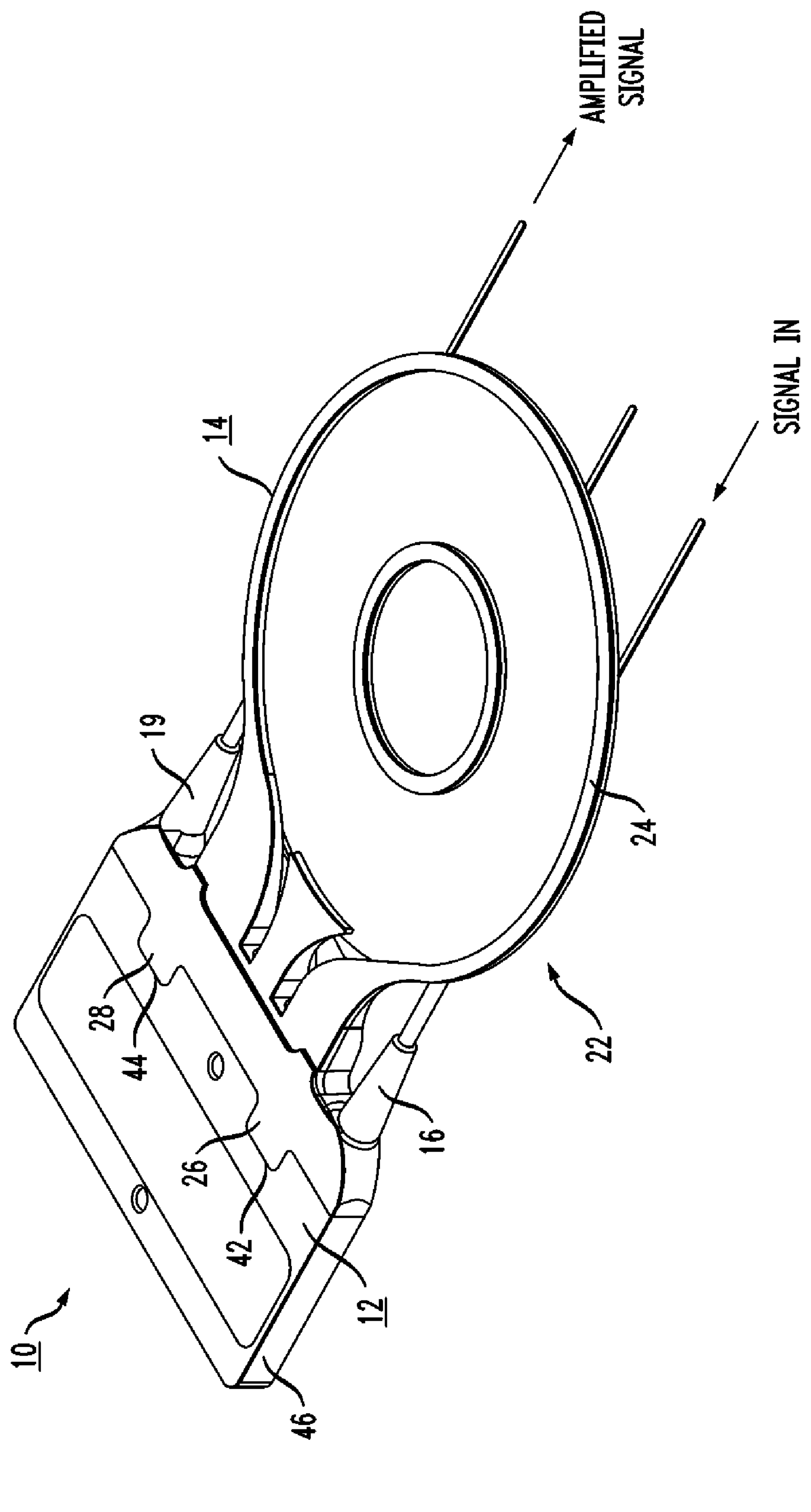


FIG. 1

FIG. 2

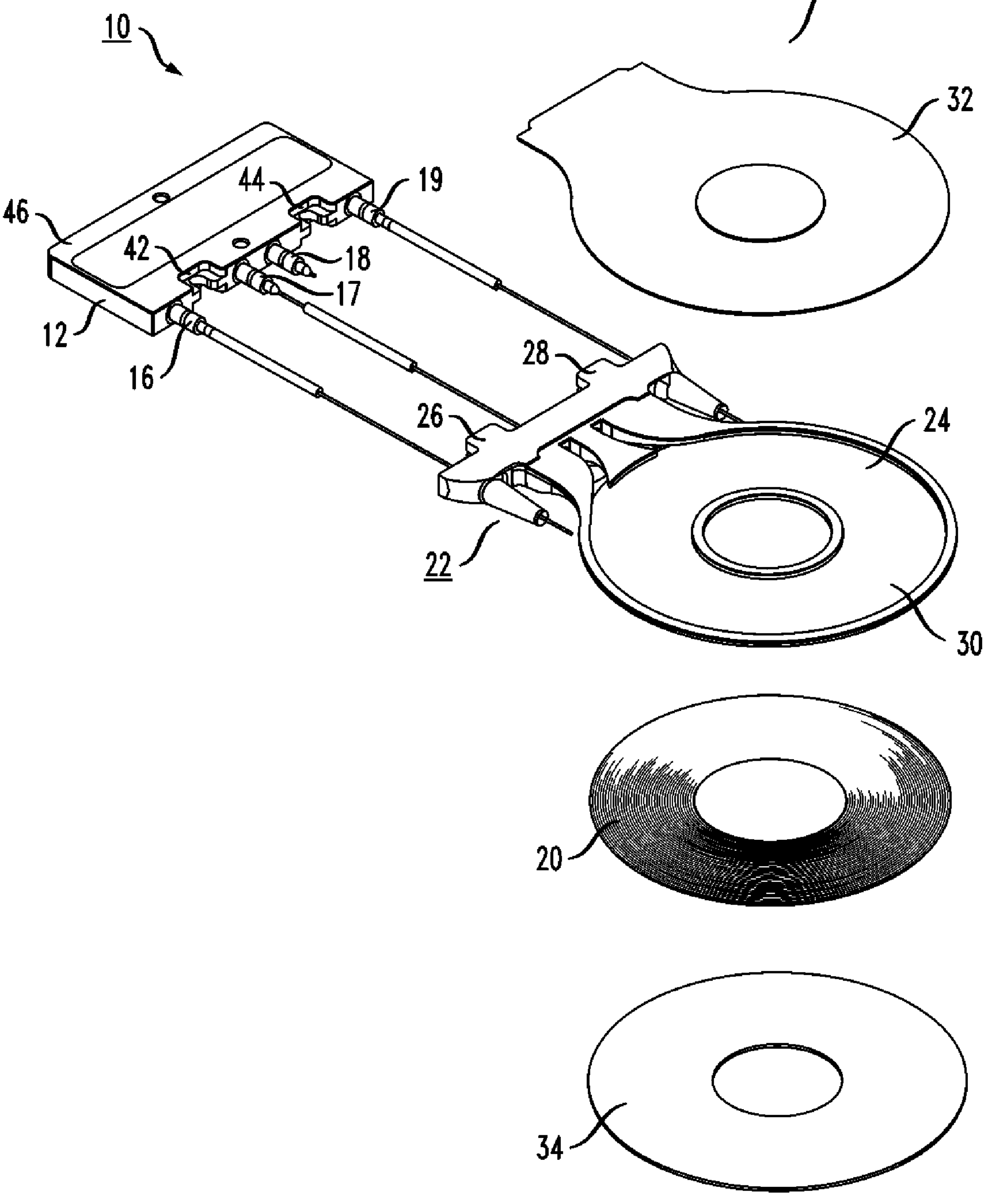


FIG. 3

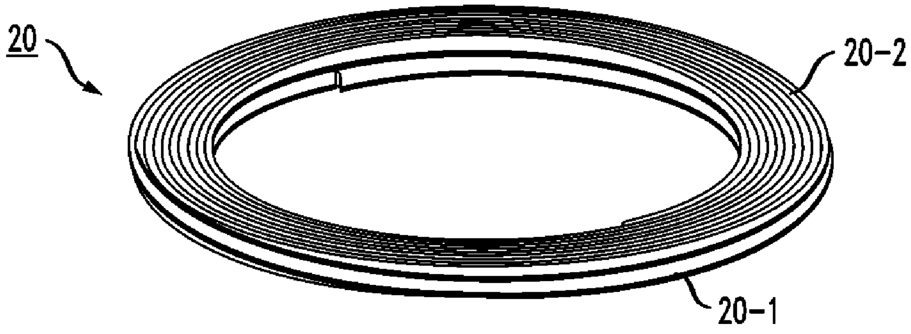
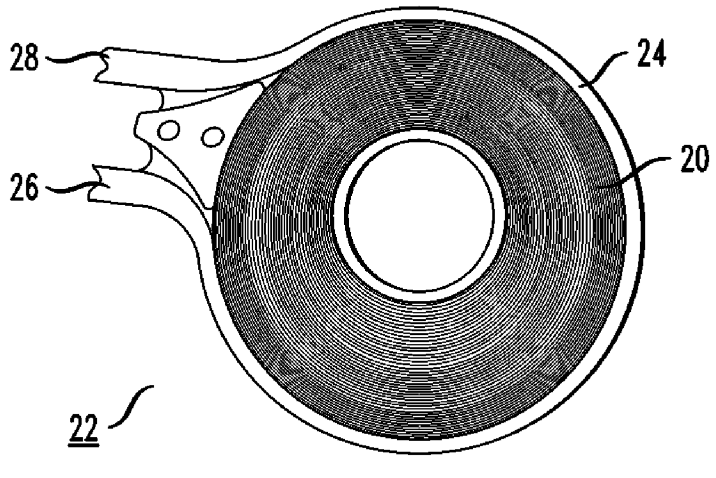


FIG. 4



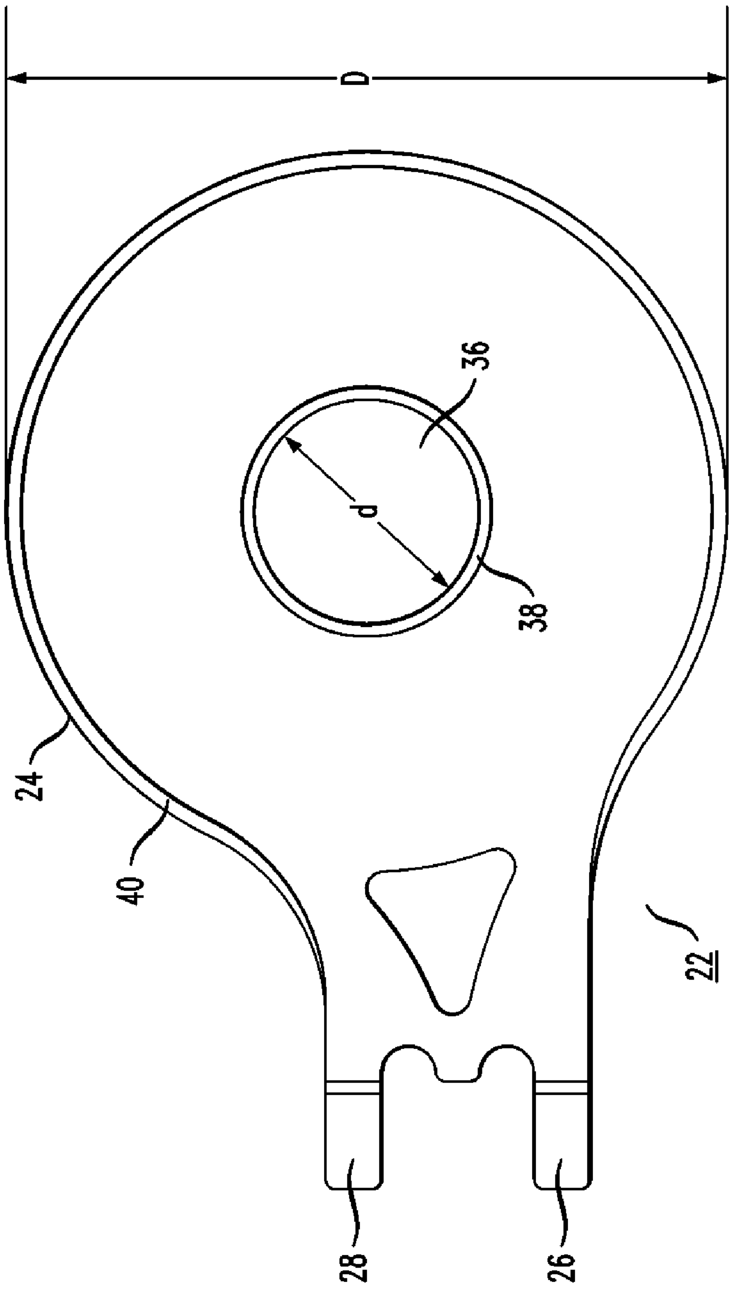


FIG. 5

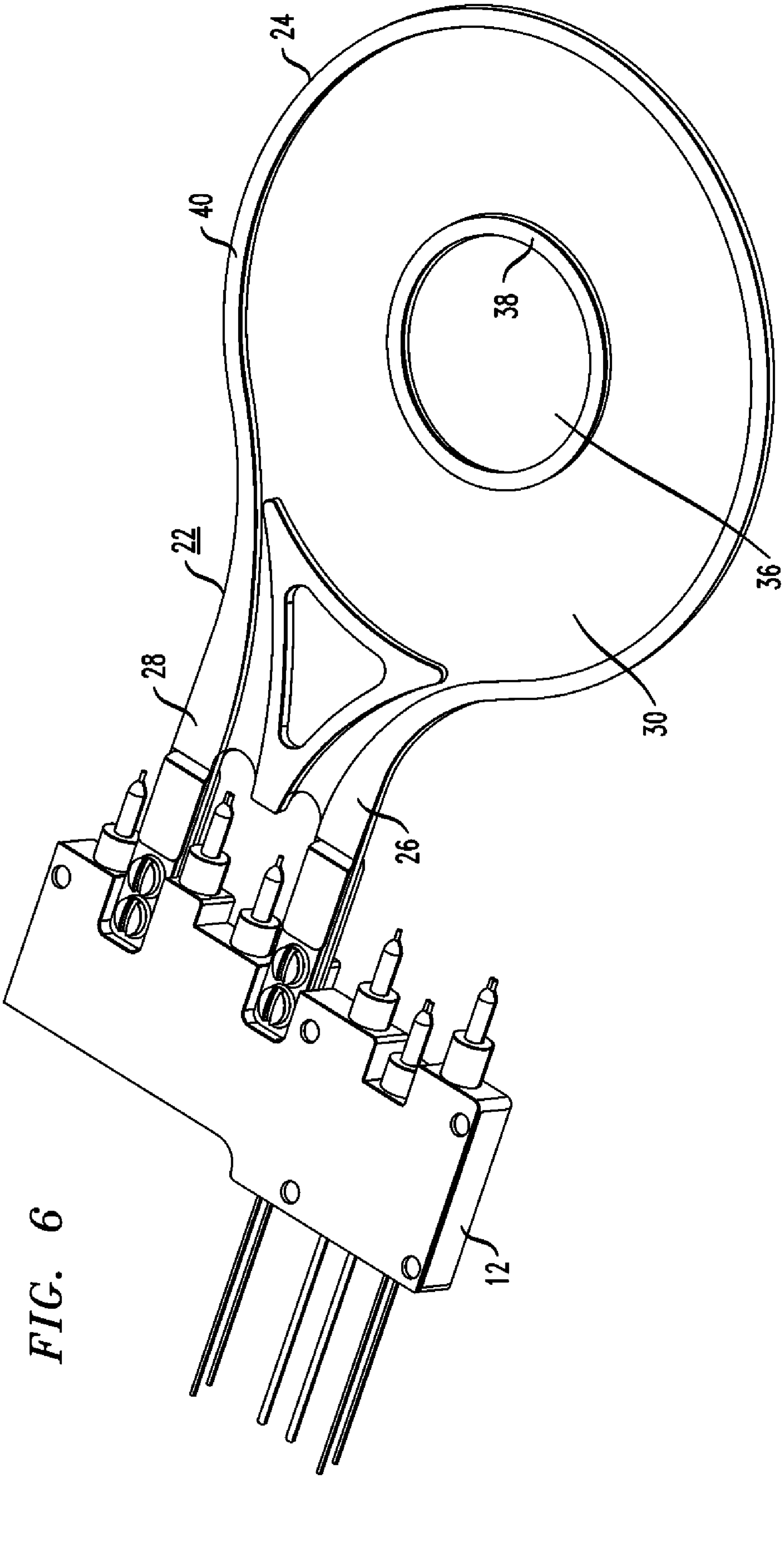


FIG. 6

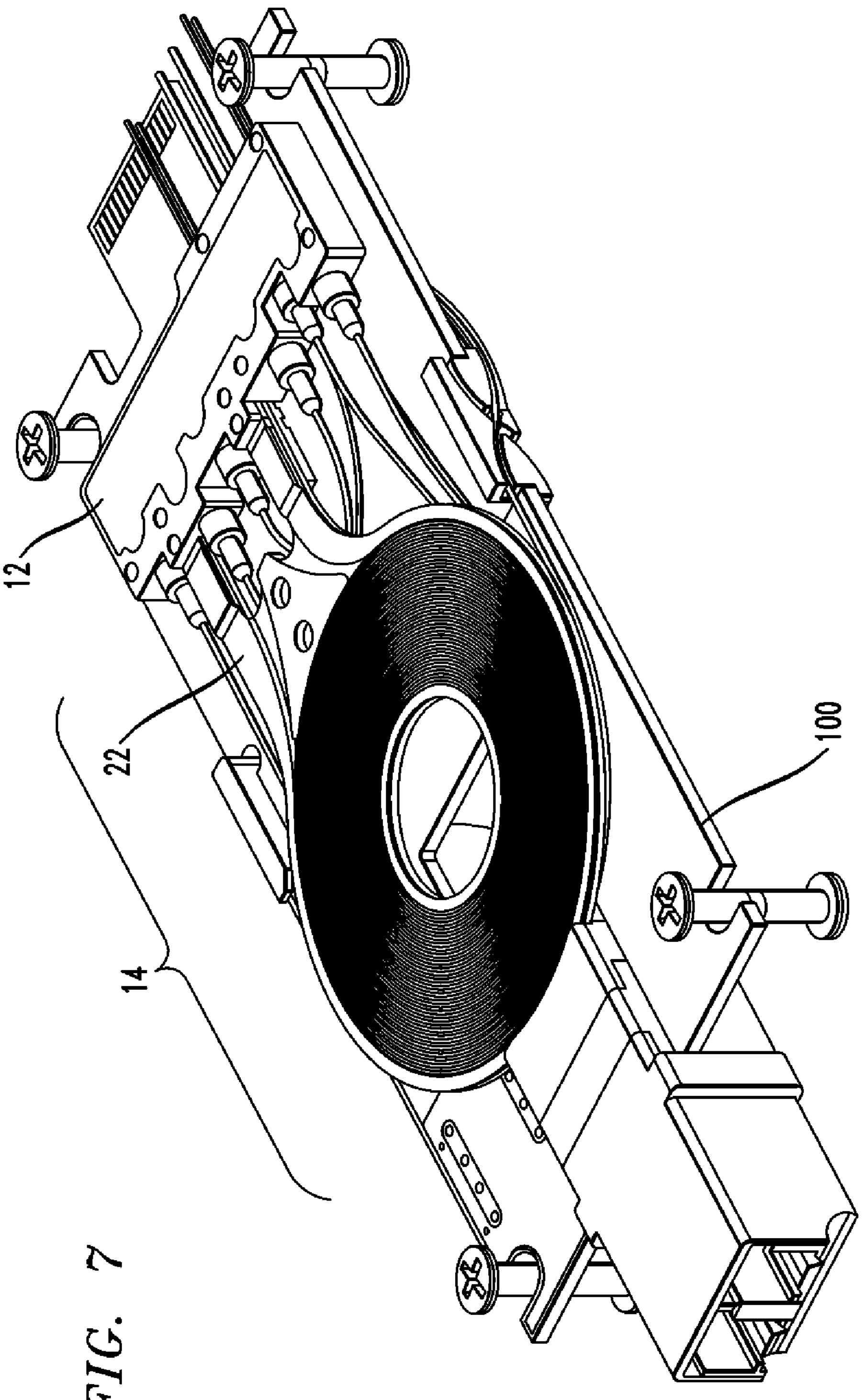


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/022736

A. CLASSIFICATION OF SUBJECT MATTER

G02B 6/06(2006.01)i, G02B 6/14(2006.01)i, G02B 6/46(2006.01)i

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)
G02B 6/06; H01S 3/10; H01S 3/067; H01S ; H01S 3/19; G02B 6/12; G02B 6/30; G02B 6/00; G02B 6/14; G02B 6/46

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: optical fiber amplifier, flexible substrate, support structure

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5726796 A (REGENER et al.) 10 March 1998 See column 1, line 66 - column 2, line 67, claim 1 and figure 1.	1-12
Y	US 2005-0018950 A1 (ARELLANO) 27 January 2005 See paragraphs [0028]-[0033] and figures 4A-5.	1-12
A	EP 1569308 A1 (CENTRAL GLASS COMPANY, LIMITED) 31 August 2005 See paragraphs [0014]-[0031] and figures 1-5.	1-12
A	WO 01-76022 A2 (CORONA OPTICAL SYSTEMS, INC.) 11 October 2001 See page 12, line 7 - page 14, line 5 and figure 1.	1-12
A	KR 10-1998-0032033 A (SAMSUNG ELECTRONICS CO., LTD.) 25 July 1998 See claims 1-3 and figures 1-8.	1-12

☐ 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
10 August 2016 (10.08.2016)

Date of mailing of the international search report
16 August 2016 (16.08.2016)

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-481-8578

Authorized officer
LEE, EUN KYU
Telephone No. +82-42-481-3580

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/022736

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5726796 A	10/03/1998	EP 0743721 A1	20/11/1996
		EP 0743721 B1	02/09/1998
		JP 09-107142 A	22/04/1997
US 2005-0018950 A1	27/01/2005	US 6829426 B1	07/12/2004
		US 7233712 B2	19/06/2007
		WO 2005-057246 A2	23/06/2005
		WO 2005-057246 A3	18/08/2005
EP 1569308 A1	31/08/2005	CN 1720647 A	11/01/2006
		JP 2004-186609 A	02/07/2004
		KR 10-2005-0062661 A	23/06/2005
		US 2006-0001949 A1	05/01/2006
		WO 2004-054051 A1	24/06/2004
WO 01-76022 A2	11/10/2001	AU 2001-45563 A1	15/10/2001
		WO 01-76022 A3	07/03/2002
KR 10-1998-0032033 A	25/07/1998	CN 1107879 C	07/05/2003
		CN 1181512 A	13/05/1998
		JP 10-133035 A	22/05/1998
		JP 3138244 B2	26/02/2001
		US 6144792 A	07/11/2000