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(54) Title: REMOTE PUMPED DUAL CORE OPTICAL FIBER SYSTEM FOR USE IN SUBTERRANEAN WELLS

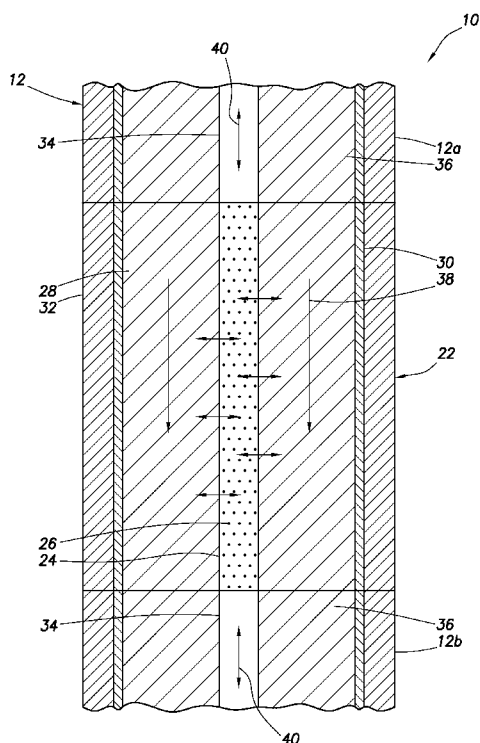


FIG.2

(57) Abstract: A downhole optical system can include an optical fiber disposed in a subterranean well, and an optical fiber amplifier which amplifies optical power in a core of the optical fiber in the well, the amplifier being optically pumped with optical power in another core of the optical fiber in the well. Another downhole optical system can include an optical fiber disposed in a subterranean well, the optical fiber comprising multiple cores, and an optical fiber amplifier comprising multiple cores optically coupled respectively to the optical fiber multiple cores in the well.



TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, **Published:**  
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**Declarations under Rule 4.17:**

— *as to applicant's entitlement to apply for and be granted  
a patent (Rule 4.17(ii))*

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# REMOTE PUMPED DUAL CORE OPTICAL FIBER SYSTEM FOR USE IN SUBTERRANEAN WELLS

## TECHNICAL FIELD

10           This disclosure relates generally to use of optical  
equipment and techniques with subterranean wells and, in an  
example described below, more particularly provides a remote  
pumped multiple core optical fiber system.

## 15 BACKGROUND

Fiber amplifiers have been used for amplifying optical signals in optical fibers. However, optical pumping for a fiber amplifier is typically provided via a separate optical fiber. Thus, to provide direct optical amplification in a well, at least one additional optical fiber needs to be installed in the well.

Therefore, it will be appreciated that improvements are needed in the art of constructing and operating optical systems in wells.

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**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a representative partially cross-sectional view of a well optical system and associated method which can embody principles of this disclosure.

5        FIG. 2 is an enlarged scale representative cross-sectional view of a fiber amplifier and multiple core optical fiber which may be used in the system and method of FIG. 1.

10       FIG. 3 is a representative schematic view of one example of the system and method.

FIG. 4 is a representative schematic view of another example of the system and method.

15       FIG. 5 is an enlarged scale representative cross-sectional view of another fiber amplifier which may be used in the system and method of FIG. 1.

**DETAILED DESCRIPTION**

Representatively illustrated in FIG. 1 is a well optical system 10 and associated method which can embody principles of this disclosure. However, it should be clearly understood that the system 10 and method are merely one example of an application of the principles of this disclosure in practice, and a wide variety of other examples are possible. Therefore, the scope of this disclosure is not limited at all to the details of the system 10 and method described herein and/or depicted in the drawings.

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In the FIG. 1 example, an optical fiber 12 is positioned external to a tubular string 14 installed in a wellbore 16. The wellbore 16 is lined with casing 18 and cement 20. The optical fiber 12 is visible in FIG. 1, but

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preferably in actual practice, the optical fiber would be included in a cable, contained in a small diameter tube, or otherwise protected from well fluids and from damage.

In other examples, the optical fiber 12 could be positioned in an interior or a wall of the tubular string 14, exterior to or in a wall of the casing 18, in the cement 20, etc. In some examples, the optical fiber 12 could be positioned in an uncased or open hole section of the wellbore 16. In some examples, a cable or tube could comprise or contain other types or combinations of lines (such as, electrical and/or hydraulic lines, etc.). Thus, it should be clearly understood that the scope of this disclosure is not limited to the details of the FIG. 1 example of the system 10 and method.

As depicted in FIG. 1, an optical fiber amplifier 22 is optically connected between sections 12a,b of the optical fiber 12. Although only one amplifier 22 is illustrated in FIG. 1, any number of amplifiers may be used, as desired. The amplifier(s) 22 can be spaced apart, positioned and/or distributed along the optical fiber 12 as desired, for example, to enable very long distance optical telemetry of data, commands, optical power, etc.

In an example described more fully below, the amplifier 22 can comprise a dual core optical fiber, in which one of the cores is used for optically pumping the other core, which has been doped with one or more species of rare earth ions, such as erbium or praseodymium. Thus, the doped core essentially becomes a fiber laser pumped via another core of the amplifier 22. Any number or combination of cores may be used in the fiber amplifier 22 in keeping with the scope of this disclosure.

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Referring additionally now to FIG. 2, an enlarged scale cross-sectional view of the amplifier 22 is representatively illustrated. In this view, it may be seen that the amplifier 22 includes an inner core 24 doped with rare earth ions 26. The inner core 24 is surrounded by an outer core (or inner cladding) 28. The outer core 28 is surrounded by an outer cladding 30 and a polymer jacket 32.

Although only two cores 24, 28 are depicted in FIG. 2, any number or combination of cores may be used in other examples. Although the cores 24, 28 and other elements of the amplifier 22 are depicted as being substantially cylindrical or annular in shape, other shapes (such as elliptical, rectangular, D, or off-centered cross-sectional shapes, etc.) may be used, as desired. Thus, the scope of this disclosure is not limited to the details of the amplifier 22 as depicted in the drawings or described herein.

In the FIG. 2 example, the amplifier inner core 24 is optically connected (e.g., via fusion splicing, use of optical connectors, etc.) to an inner core 34 of the optical fiber 12, and the amplifier outer core 28 is optically connected to an outer core 36 of the optical fiber. Thus, the optical fiber 12 comprises a dual core fiber, similar to the amplifier 22, except that the inner core 34 of the optical fiber is not doped with the rare earth ions 26.

Optical power 38 transmitted via the outer cores 28, 36 optically pumps the rare earth ions 26 in the amplifier inner core 24. Optical signals 40 transmitted via the inner cores 24, 34 are thereby amplified, the amplifier inner core serving as an "in-line" fiber laser. Suitable multiple core optical fiber amplifiers are commercially available, and are

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known to those skilled in the art, and so will not be described further herein.

Note that optical signals 40 in the inner cores 24, 34 can be transmitted and amplified in any direction. The amplified signals 40 desirably will have a same wavelength and phase as the pre-amplified signals. The wavelength(s) chosen for the optical signals 40 and optical pump should be appropriate for desired excitation of the rare earth ions 26.

Referring additionally now to FIG. 3, a schematic view of the system 10 is representatively illustrated, with the optical fiber 12 and amplifier 22 shown in cross-section. A remotely positioned (e.g., at the earth's surface, a subsea facility, etc.) pump laser 42 is used to transmit the optical power 38 through the outer cores 28, 36 of the optical fiber 12 and amplifier 22. An interrogator 44 (comprising, for example, an optical source 46, such as a laser, and a photo-detector 48) is used to transmit and detect the optical signals 40 in the inner cores 24, 34.

Because the signal transmission and amplification functions can be accomplished using the single optical fiber 12, fewer penetrations are needed in wellheads, packers, etc., of the well, and existing penetrations can be more effectively utilized. The use of fewer optical fibers also reduces the risk that an optical fiber will become damaged during rig-up, installation, long term use, etc.

For effective transmission of the optical signals 40, the inner cores 24, 34 can be single mode cores. For effective transmission of optical power 38, the outer cores 28, 36 can be multi-mode cores. However, the scope of this disclosure is not limited to use of any particular core for

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any particular purpose, or to use of a single or multiple mode core to effectively accomplish that purpose.

In the FIG. 3 example, a downhole sensor 50 is optically connected to the inner core 34. The sensor 50 may  
5 be any type of sensor used to measure any well parameter (e.g., pressure, temperature, resistivity, pH, electromagnetic radiation, fluid type, conductivity, acoustic energy, etc.). The optical signals 40 transmitted via the inner cores 24, 34 will preferably include data  
10 indicative of the parameter measurements and/or will provide optical power for operation of the sensor 50.

The sensor 50 may be intrinsic or extrinsic relative to the optical fiber 12. An extrinsic sensor 50, such as a pressure sensor, could be optically coupled to the optical  
15 fiber 12. An intrinsic sensor 50, such as a fiber Bragg grating used to detect strain, could be part of the optical fiber 12 itself.

Various types of interferometric sensors may be used for the sensor 50. However, it is not necessary in keeping  
20 with the scope of this disclosure for the sensor 50 to comprise an interferometric or other type of "optical" sensor.

In some examples, the optical fiber 12 can comprise the sensor 50. For example, distributed temperature, strain,  
25 pressure and acoustic energy measurements may be obtained by detecting Raman, coherent Rayleigh, stimulated Brillouin and/or other types of optical back scatter in the inner core 34. Such distributed measurements via detection of optical back scatter are well known to those skilled in the art, and  
30 so will not be described further herein.

Referring additionally now to FIG. 4, another example of the system 10 and method is representatively illustrated.



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In this example, the measurements made by the sensor 50 are modulated onto the inner core 34 using an optical modulator 52.

5 The modulator 52 is supplied with optical power 38 via the outer core 36. The modulator 52 could include, for example, an optical to electrical converter (such as a photodiode, etc.) which converts the optical power 38 to electrical power, the electrical power may be used to condition and/or amplify electrical or other signals from  
10 the sensor 50, and an electrical to optical converter (such as a light emitting diode, etc.) may be used to modulate and transmit the resulting optical signals 40 via the inner cores 24, 34. Of course, the optical power 38 transmitted via the outer core 36 may be used for other purposes  
15 downhole (for example, to provide power to other well tools), in keeping with the scope of this disclosure.

Referring additionally now to FIG. 5, another example of the optical fiber amplifier 22 is representatively illustrated in an enlarged scale cross-sectional view. This  
20 example is similar to that depicted in FIG. 3, except that the FIG. 5 example includes a reflector 54 that reflects the optical power 38 in the outer core 28 of the amplifier 22, so that enhanced excitation of the rare earth ions 26 is obtained.

25 As depicted in FIG. 5, the reflector 54 is in the form of a fiber Bragg grating in the outer core 28. The fiber Bragg grating could, for example, be selected so that it reflects an appropriate wavelength for excitation of the rare earth ions 26.

30 It may now be fully appreciated that the above disclosure provides significant advancements to the art of constructing and utilizing optical systems in wells. By use

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of the multiple core 34, 36 optical fiber 12, fewer penetrations and optical fibers may be used. Fewer optical fibers used can result in cost and time savings in installation and maintenance for well optical systems. The multiple core optical fiber amplifier 22 examples described above are especially well suited for use with the multiple core optical fiber 12.

A downhole optical system 10 is provided to the art by the above disclosure. In one example, the system 10 can include an optical fiber 12 disposed in a subterranean well, and an optical fiber amplifier 22 which amplifies optical power in a first core 34 of the optical fiber 12 in the well, the amplifier 22 being optically pumped with optical power 38 in a second core 36 of the optical fiber 12 in the well.

The fiber amplifier 22 may comprise a rare earth doped core 24. Other types of optical amplifiers may be used, if desired.

The optical fiber first core 34 can comprise a single mode core. The optical fiber second core 36 can comprise a multiple mode (multi-mode) core.

The fiber amplifier 22 may be optically connected between sections 12a,b of the optical fiber 12. The fiber amplifier 22 may comprise first and second cores 24, 28 optically connected respectively to the optical fiber first and second cores 34, 36.

The optical fiber first core 34 may be optically connected to at least one sensor 50 in the well. The optical fiber first core 34 may comprise a sensor in the well.

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The optical power 38 in the optical fiber second core 36 can be used to modulate a sensor 50 indication transmitted optically via the optical fiber first core 34.

5 The fiber amplifier 22 can comprise a reflector 54 which reflects the optical power 38 in the optical fiber second core 36 through the fiber amplifier 22.

Another downhole optical system 10 described above can include an optical fiber 12 disposed in a subterranean well, the optical fiber 12 comprising first and second cores 34, 10 36, and an optical fiber amplifier 22 comprising first and second cores 24, 28 optically coupled respectively to the optical fiber first and second cores 34, 36 in the well. The fiber amplifier 22 may amplify optical power in the optical fiber first core 34, the amplifier 22 being optically pumped 15 with optical power 38 in the optical fiber second core 36.

A downhole optical system 10 described above can comprise: an optical fiber 12 disposed in a subterranean well, and an optical fiber amplifier 22 which amplifies optical power in a single mode core 34 of the optical fiber 20 12 in the well, the amplifier 22 being optically pumped with optical power in a multiple mode core 36 of the optical fiber 12 in the well. The single mode core 34 may be surrounded by the multiple mode core 36.

Although various examples have been described above, 25 with each example having certain features, it should be understood that it is not necessary for a particular feature of one example to be used exclusively with that example. Instead, any of the features described above and/or depicted in the drawings can be combined with any of the examples, in 30 addition to or in substitution for any of the other features of those examples. One example's features are not mutually exclusive to another example's features. Instead, the scope

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of this disclosure encompasses any combination of any of the features.

Although each example described above includes a certain combination of features, it should be understood  
5 that it is not necessary for all features of an example to be used. Instead, any of the features described above can be used, without any other particular feature or features also being used.

It should be understood that the various embodiments  
10 described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of this disclosure. The embodiments are described merely as examples of useful applications of the principles  
15 of the disclosure, which is not limited to any specific details of these embodiments.

The terms "including," "includes," "comprising," "comprises," and similar terms are used in a non-limiting sense in this specification. For example, if a system,  
20 method, apparatus, device, etc., is described as "including" a certain feature or element, the system, method, apparatus, device, etc., can include that feature or element, and can also include other features or elements. Similarly, the term "comprises" is considered to mean "comprises, but is not  
25 limited to."

Of course, a person skilled in the art would, upon a careful consideration of the above description of representative embodiments of the disclosure, readily appreciate that many modifications, additions,  
30 substitutions, deletions, and other changes may be made to the specific embodiments, and such changes are contemplated by the principles of this disclosure. For example,

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structures disclosed as being separately formed can, in other examples, be integrally formed and *vice versa*. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and  
5 example only, the spirit and scope of the invention being limited solely by the appended claims and their equivalents.

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**WHAT IS CLAIMED IS:**

1. A downhole optical system, comprising:  
an optical fiber disposed in a subterranean well; and  
5 an optical fiber amplifier which amplifies optical power in a first core of the optical fiber in the well, the amplifier being optically pumped with optical power in a second core of the optical fiber in the well.
- 10 2. The downhole optical system of claim 1, wherein the fiber amplifier comprises a rare earth doped core.
3. The downhole optical system of claim 1, wherein the first core comprises a single mode core.
- 15 4. The downhole optical system of claim 1, wherein the second core comprises a multiple mode core.
5. The downhole optical system of claim 1, wherein  
20 the fiber amplifier is optically connected between sections of the optical fiber.
6. The downhole optical system of claim 1, wherein the fiber amplifier comprises first and second cores  
25 optically connected respectively to the optical fiber first and second cores.

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7. The downhole optical system of claim 1, wherein the first core is optically connected to at least one sensor in the well.

5 8. The downhole optical system of claim 1, wherein the first core comprises a sensor in the well.

9. The downhole optical system of claim 1, wherein the optical power in the second core is used to modulate a  
10 sensor indication transmitted optically via the first core.

10. The downhole optical system of claim 1, wherein the fiber amplifier comprises a reflector which reflects the optical power in the second core through the fiber  
15 amplifier.

11. The downhole optical system of claim 1, wherein the first core comprises a single mode core, the second core comprises a multiple mode core, and wherein the first core  
20 is surrounded by the second core.

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12. A downhole optical system, comprising:

an optical fiber disposed in a subterranean well, the optical fiber comprising first and second cores; and

5 an optical fiber amplifier comprising first and second cores optically coupled respectively to the optical fiber first and second cores in the well.

13. The downhole optical system of claim 12, wherein  
10 the fiber amplifier first core is rare earth doped.

14. The downhole optical system of claim 12, wherein the optical fiber first core comprises a single mode core.

15 15. The downhole optical system of claim 12, wherein the optical fiber second core comprises a multiple mode core.

16. The downhole optical system of claim 12, wherein  
20 the fiber amplifier is optically connected between sections of the optical fiber.

17. The downhole optical system of claim 12, wherein the optical fiber first core is optically connected to at  
25 least one sensor in the well.

18. The downhole optical system of claim 12, wherein the optical sensor first core comprises a sensor in the well.



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19. The downhole optical system of claim 12, wherein the optical power in the optical fiber second core is used to modulate a sensor indication transmitted optically via  
5 the optical fiber first core.

20. The downhole optical system of claim 12, wherein the fiber amplifier comprises a reflector which reflects optical power through the fiber amplifier second core.  
10

21. The downhole optical system of claim 12, wherein the fiber amplifier amplifies optical power in the optical fiber first core, the amplifier being optically pumped with optical power in the optical fiber second core.  
15

22. The downhole optical system of claim 12, wherein the optical fiber first core comprises a single mode core, the optical fiber second core comprises a multiple mode core, and wherein the single mode core is surrounded by the  
20 multiple mode core.

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23. A downhole optical system, comprising:

an optical fiber disposed in a subterranean well; and

an optical fiber amplifier which amplifies optical  
5 power in a single mode core of the optical fiber in the  
well, the amplifier being optically pumped with optical  
power in a multiple mode core of the optical fiber in the  
well,

wherein the single mode core is surrounded by the  
10 multiple mode core.

24. The downhole optical system of claim 23, wherein  
the fiber amplifier comprises a rare earth doped core.

15 25. The downhole optical system of claim 23, wherein  
the fiber amplifier is optically connected between sections  
of the optical fiber.

26. The downhole optical system of claim 23, wherein  
20 the fiber amplifier comprises first and second cores  
optically connected respectively to the optical fiber single  
mode and multiple mode cores.

27. The downhole optical system of claim 23, wherein  
25 the single mode core is optically connected to at least one  
sensor in the well.

28. The downhole optical system of claim 23, wherein  
the single mode core comprises a sensor in the well.

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29. The downhole optical system of claim 23, wherein the optical power in the multiple mode core is used to modulate a sensor indication transmitted optically via the single mode core.

30. The downhole optical system of claim 23, wherein the fiber amplifier comprises a reflector which reflects the optical power in the multiple mode core through the fiber amplifier.

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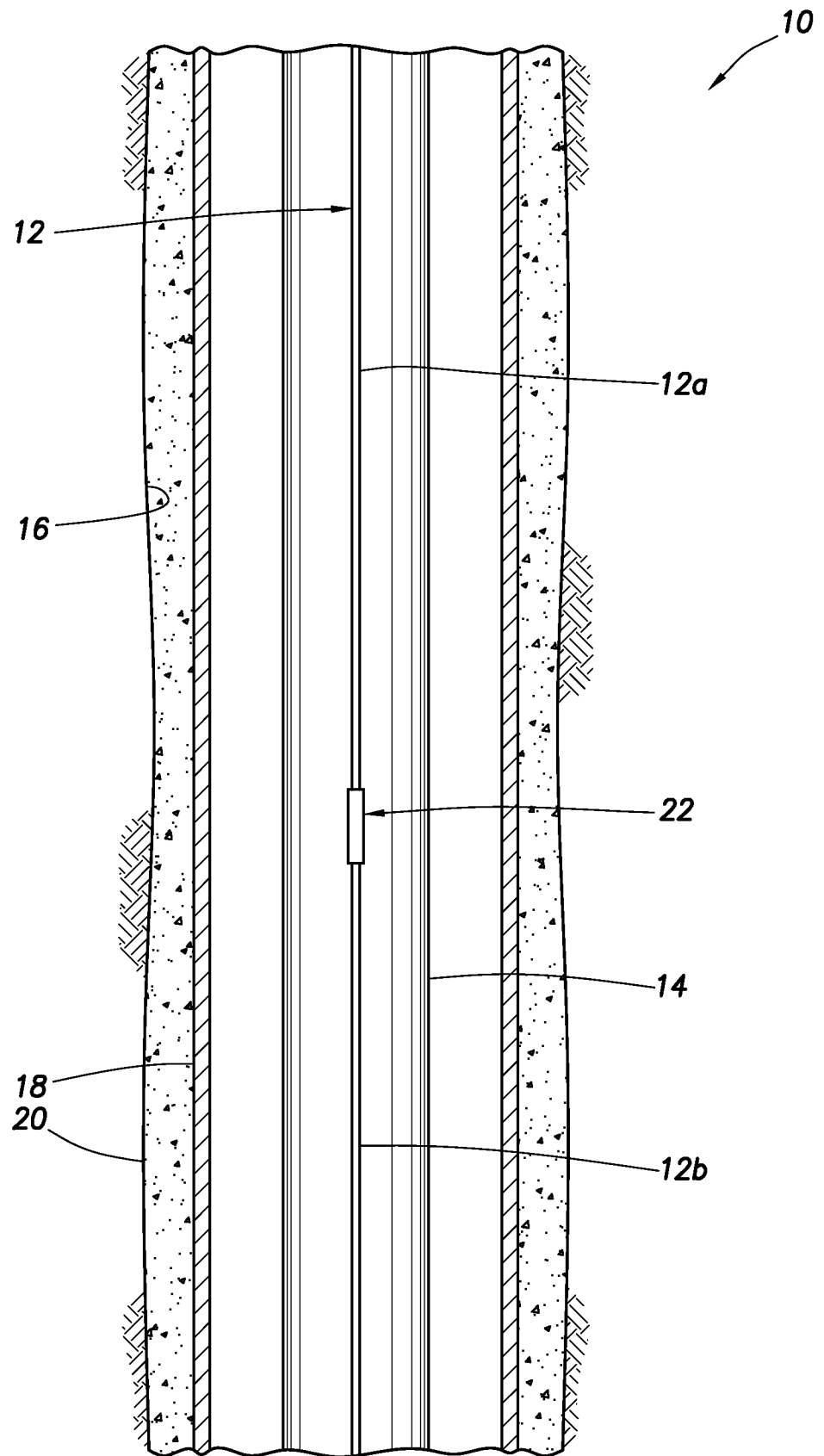


FIG. 1

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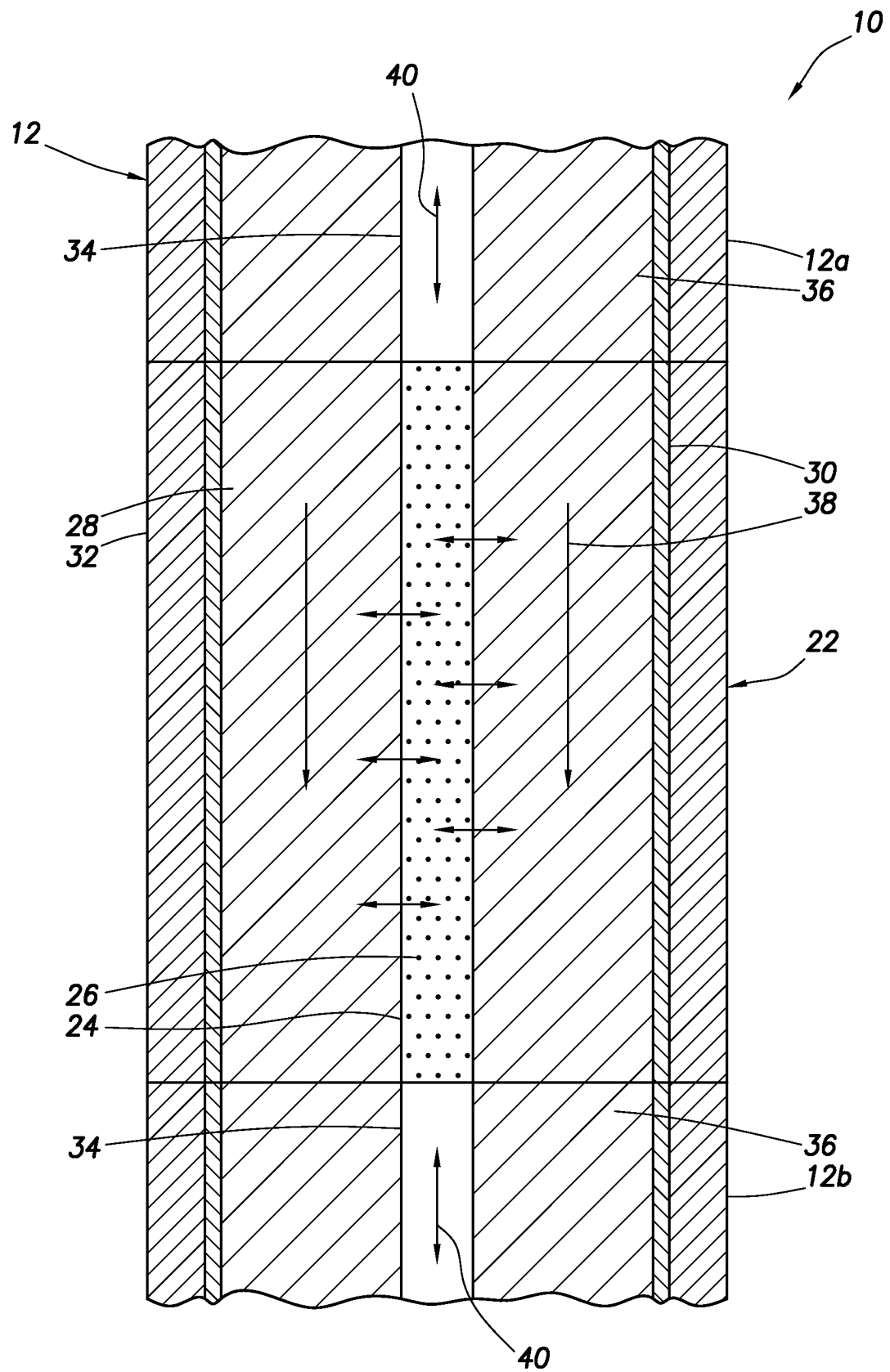


FIG.2

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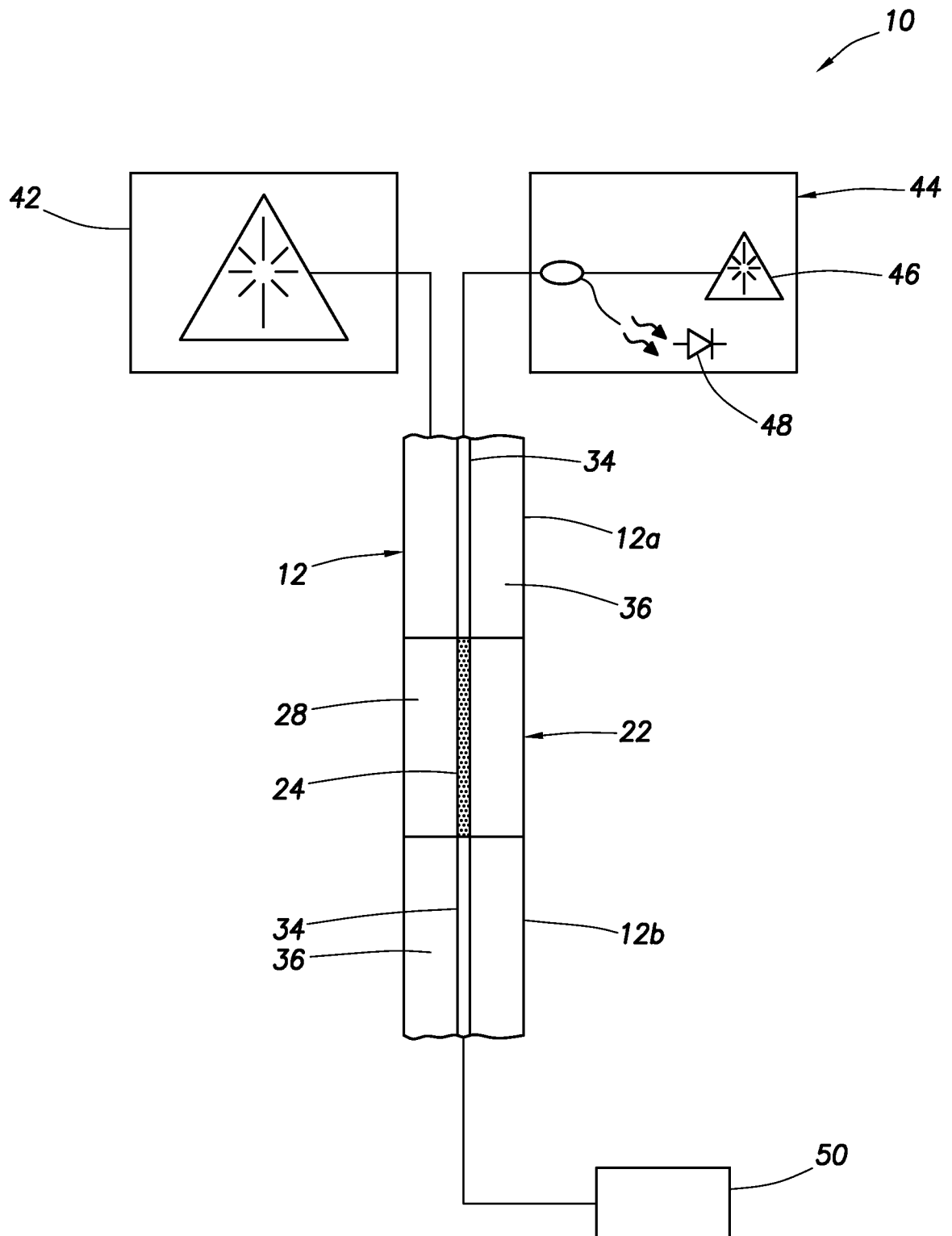


FIG.3

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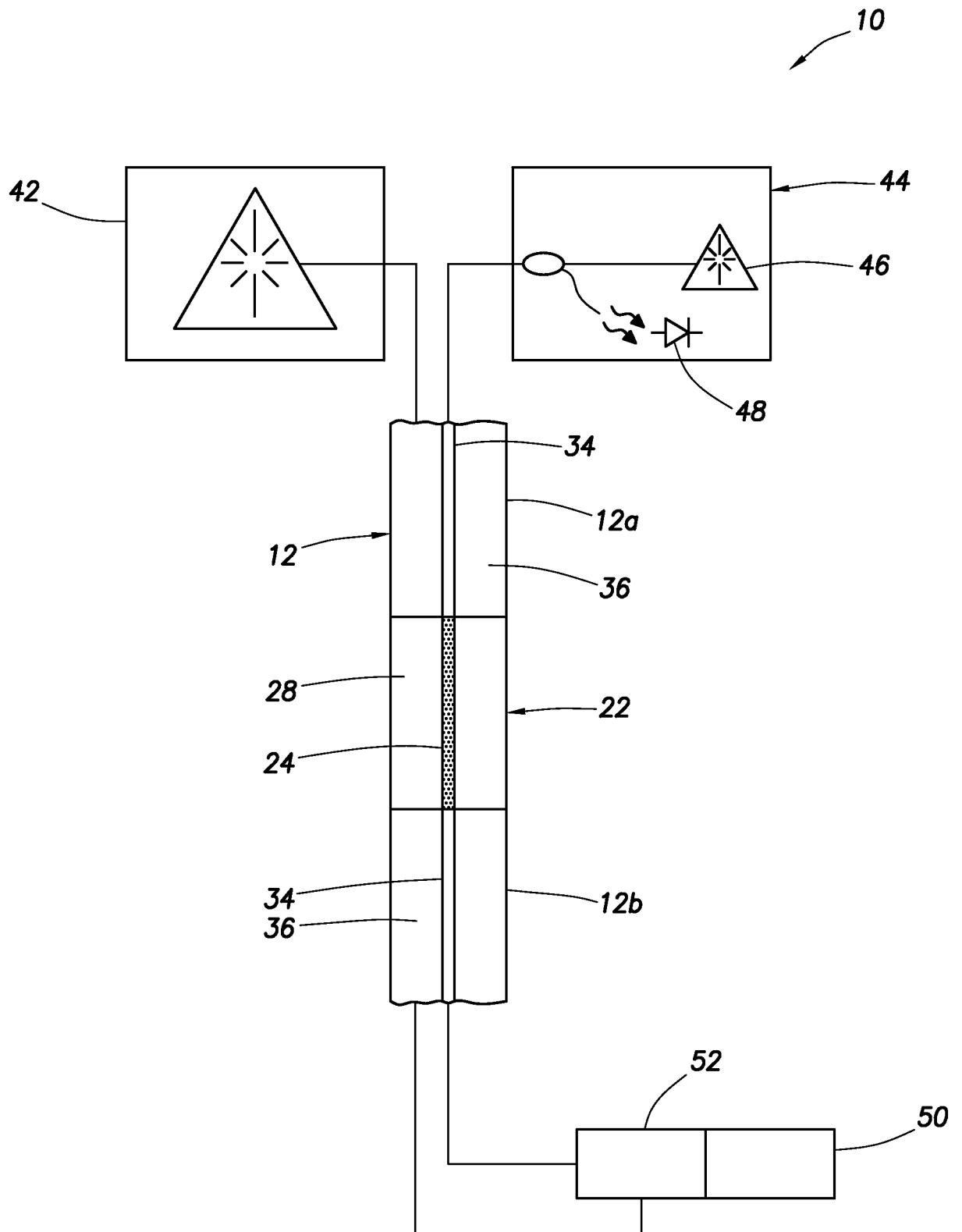
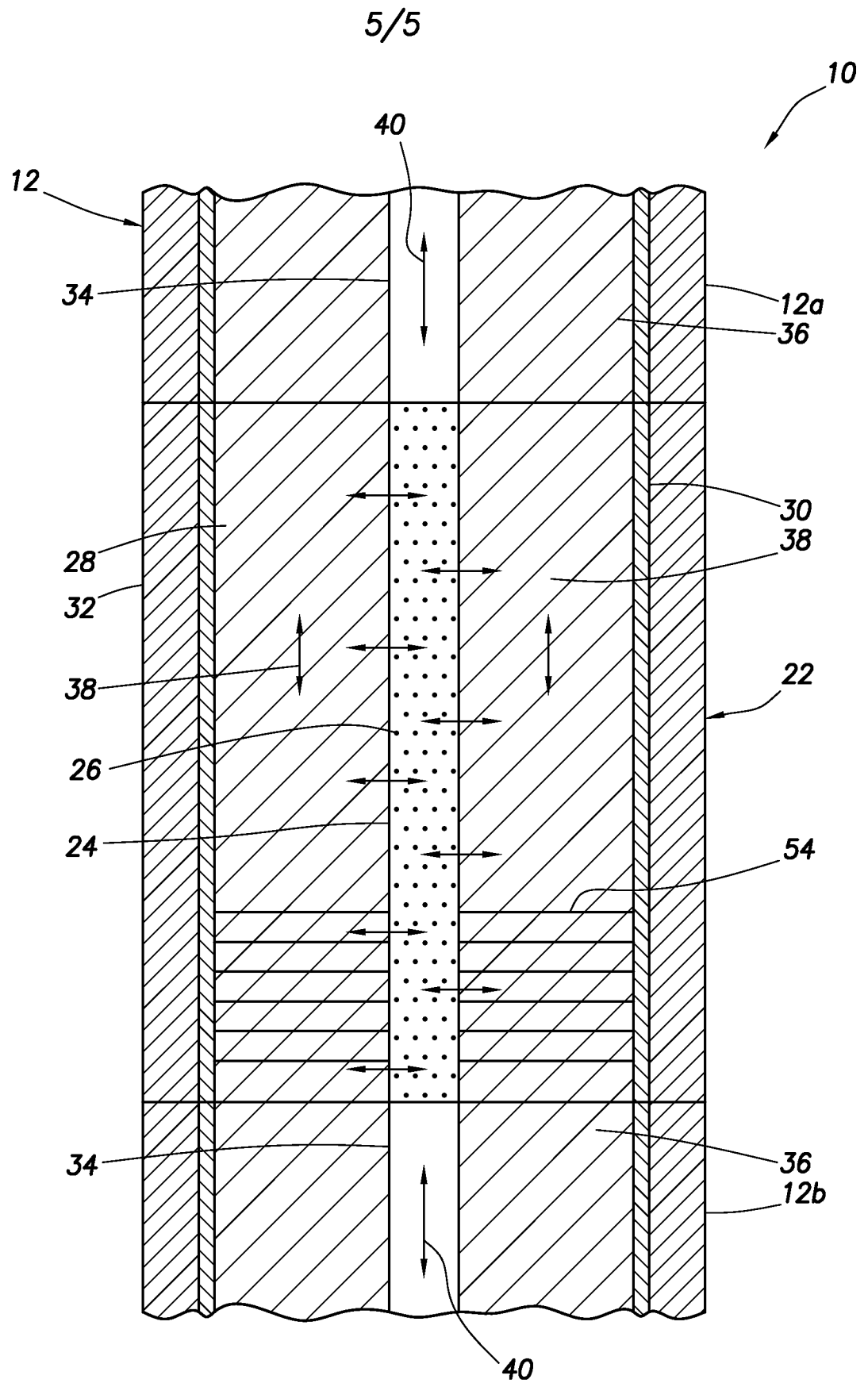


FIG.4



**FIG.5**



## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2014/015482****A. CLASSIFICATION OF SUBJECT MATTER****E21B 49/02(2006.01)i, G01N 21/17(2006.01)i, E21B 47/00(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)

E21B 49/02; H01S 3/067; G01V 5/08; E21B 43/00; H04B 10/08; H04J 14/00; E21B ; E21B 47/12; G01N 21/17; E21B 47/00

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) &amp; keywords: fiber optic, amplifier, single mode, multi mode, light, transmit, and core

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category*   | Citation of document, with indication, where appropriate, of the relevant passages                                                  | Relevant to claim No.                                                         |
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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

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"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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

13 May 2014 (13.05.2014)

Date of mailing of the international search report

**14 May 2014 (14.05.2014)**

Name and mailing address of the ISA/KR

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2014/015482**

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