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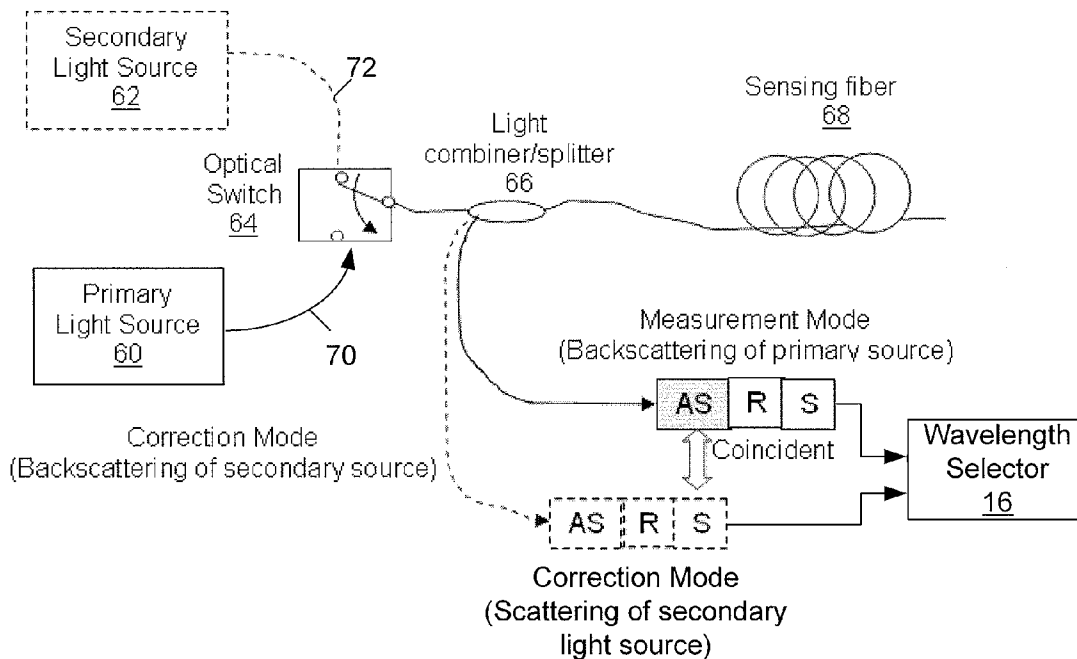
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(54) Title: DUAL SOURCE CALIBRATION FOR DISTRIBUTED TEMPERATURE SYSTEMS



(57) Abstract: Systems and methods for calibrating a temperature sensing system are disclosed. In one respect, a dual light source configuration may be provided. A first light source may illuminate a sensing fiber and an anti-Stokes band may be detected. A second light source may illuminate a sensing fiber and a Stokes band may be detected, where the Stokes band is substantially similar to the anti-Stokes band of the first light source. A ratio between the anti-Stokes and Stokes band may be used to calibrate a temperature sensing system.

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DESCRIPTION

DUAL SOURCE CALIBRATION FOR DISTRIBUTED TEMPERATURE SYSTEMS

This application claims priority to provisional patent applications Serial No. 5 60/781,833 filed on March 13, 2006 and Serial No. 60/787,617 filed March 30, 2006. The entire text of each of the above-referenced disclosures, including figures, is specifically incorporated by reference herein without disclaimer.

BACKGROUND OF THE INVENTION

1. Field of the Invention

10 The present invention relates generally to temperature sensing. More particularly, the present disclosure relates to systems for calibrating temperature profiles in, for example, a distributed line system.

2. Description of Related Art

Optical fibers have been used for optical communication for decades. Recently, 15 optical fiber sensing technologies have grown rapidly due to fiber advantages, which conventional electrical sensors do not have. The advantages of fiber include the ability to handle much higher bandwidth and inherently safe operation (no generation of electric sparks). Also optical fiber is inherently immune to EMI (ElectroMagnetic Interference), and it does not radiate EMI. A prominent feature of the fiber is the capability of true 20 distributed parameter measurement. Utilizing this technology, temperature and strain profiles along significant distances can be monitored over extended lengths. Many temperature data points can be processed along a considerable length, over tens of kilometers. The resultant distributed measurement is equivalent to numerous conventional point temperature sensors which would require more deployment equipment 25 and a higher operational costs.

When an optical fiber is excited with a laser light with a center wavelength λ , most of the light may be transmitted but small portions of incident light λ are scattered backward and forward along the fiber. Scattered light is categorized into three bands: Rayleigh, Raman, and Brillouin scatterings. For the measurement of distributed 30 temperatures, a few components may be used such as a Rayleigh scattering, which is the same as an excitation wavelength λ , and a Stokes and anti-Stokes components which are

longer and shorter than λ , respectively. These three components may be separated by optical filters and received by the photo detectors to convert the light to electrical signals. The ratio of temperature sensitive anti-Stokes intensity to temperature insensitive Rayleigh or Stokes intensities may be used for temperature measurement.

5 To obtain a local temperature profile along a distance, two methods – time domain approach and frequency domain approach have – been applied conventionally. The time domain method uses a pulsed light source and the position of the temperature is identified by the calculation of the pulse round trip time to the distance under test. The frequency method uses a modulated laser source and the position can be calculated by applying the
10 inverse Fourier transformation of a sensing fiber's transfer function or frequency response.

U.S. Patent 5,113,277, which is incorporated by reference, discloses a Fiber Optic DTS (Distributed Temperature Sensing) system, which involves a pulsed light source and a temperature measurement was made by the ratio between Stokes and anti-Stokes
15 intensities at each measured distance determined from the roundtrip time of the pulse. U.S. Patent 7,057,714, which is incorporated by reference, discloses a stepped modulation method to sweep the frequency of the laser source. The time domain profiles of Stokes and anti-Stokes attenuations are obtained by applying the inverse Fourier transformation of amplitude and phase responses of each modulating frequency component. The time
20 domain method is simpler than frequency domain analysis but it requires a costly pulsed light source and higher data acquisition components but has a lower signal to noise characteristics.

The temperature profile along the sensing fiber in DTS is obtained by the ratio of the temperature insensitive Stokes to temperature sensitive anti-Stokes backscattered
25 intensities from a deployed sensing fiber as described above. But both scattering intensities are also dependent on, for example, mechanical and chemical perturbations such as micro bends, tensions, compressions and chemical ingressions such as hydrogen gas, which are common in an oil field environment under high temperatures and high pressures. This kind of ambiguity, *i.e.*, whether the scattering intensities are made by
30 pure local temperature effect or by other effects mentioned above particularly in an anti-Stokes profile, usually introduces some errors in the temperature calculation and needs to be corrected to generate more accurate temperature measurements. This ambiguity may be corrected with the aid of conventional optical reflectometry methods, in which the

backscattered light provides a measure of wavelength dependant attenuations. In order to implement this idea to the DTS system, an extra incident source with the same wavelengths and similar line width of anti-Stokes or Stokes bands is required. Commercial availability and/or the cost have been major obstacles for a practical
5 implementation of this correction technique.

The referenced shortcomings above are not intended to be exhaustive, but rather are among many that tend to impair the effectiveness of previously known techniques for temperature profiling; however, those mentioned here are sufficient to demonstrate that the methodologies appearing in the art have not been altogether satisfactory and that a
10 significant need exists for the techniques described and claimed in this disclosure.

SUMMARY OF THE INVENTION

The present disclosure provides an economic and straightforward solution for determining an accurate temperature profile in a distribution line system, and more particularly for correcting error generated by the ambiguities of a local sensing fiber
15 cable. Embodiments of this disclosure utilize a secondary light source whose Stokes band coincides with the anti-Stokes band of a primary light source of the DTS system.

In one respect, a method is provided. The method may provide a first and second light source. The first light source may be configured to operate in a measurement mode and the second light source may be configured to operate in a correction mode. The
20 second light source may have a Stoke band substantially similar to the anti-Stoke band of the first light source. A ratio between the anti-Stoke band and Stoke band may be used to calibrate a temperature sensing system.

In some respects, a sensing fiber may be illuminated with a first light source and an anti-Stoke band may be detected. Similarly, the sensing fiber may be illuminated with
25 a second light source and a Stokes band may be detected. A ratio between the detected Stokes band and anti-Stokes band may be used to calibrate a temperature sensing system.

The terms “a” and “an” are defined as one or more unless this disclosure explicitly requires otherwise.

The term “substantially,” “about,” and its variations are defined as being largely
30 but not necessarily wholly what is specified as understood by one of ordinary skill in the art, in one non-limiting embodiment substantially and its variations refers to ranges

within 10%, preferably within 5%, more preferably within 1%, and most preferably within 0.5% of what is specified.

The term “coupled” is defined as connected, although not necessarily directly, and not necessarily mechanically.

5 The terms “comprise” (and any form of comprise, such as “comprises” and “comprising”), “have” (and any form of have, such as “has” and “having”), “include” (and any form of include, such as “includes” and “including”) and “contain” (and any form of contain, such as “contains” and “containing”) are open-ended linking verbs. As a result, a method or device that “comprises,” “has,” “includes” or “contains” one or more
10 steps or elements possesses those one or more steps or elements, but is not limited to possessing only those one or more elements. Likewise, a step of a method or an element of a device that “comprises,” “has,” “includes” or “contains” one or more features possesses those one or more features, but is not limited to possessing only those one or more features. Furthermore, a device or structure that is configured in a certain way is
15 configured in at least that way, but may also be configured in ways that are not listed.

Other features and associated advantages will become apparent with reference to the following detailed description of specific embodiments in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

20 The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood by reference to one or more of these drawings in combination with the detailed description of specific embodiments presented herein.

FIG. 1 shows a block diagram of a distributed temperature sensing system.

25 **FIG. 2** shows scattering components from the distributed temperature sensing system of FIG. 1.

FIG. 3 shows a corresponding output of the components of FIG. 2 from an optical wavelength separation assembly.

30 **FIG. 4** shows a wavelength diagram of a distributed temperature sensing system, in accordance with embodiments of the disclosure.

FIG. 5 shows a graph of scattering bands of a primary light source and a secondary light source, in accordance with embodiments of the disclosure.

FIG. 6 shows a block diagram of a calibration system, in accordance with embodiments of the disclosure.

5 **FIGs. 7A and 7B** show a profile of an anti-Stokes band of a primary light source and a Stokes band of a secondary light source, in accordance with embodiments of the disclosure.

FIG. 8 shows a profile of a primary light source and a second light source, in accordance with embodiments of the disclosure.

10 **FIG. 9** shows the difference between the primary light source and the second light source profile of FIG. 8, in accordance with embodiments of the disclosure.

FIG. 10 shows a block diagram of a calibration system, in accordance with embodiments of the disclosure.

15 **FIG. 11** shows a block diagram for detecting corrosion, in accordance with embodiments of the disclosure.

FIGs. 12A-12D show integration of a luminescent layer on a fiber, in accordance with embodiments of the disclosure.

FIG. 13 shows a block diagram of a system, in accordance with embodiments of the disclosure.

20 **FIGs. 14A and 14B** show an output of the system of FIG. 13 indicating where corrosion has occurred, in accordance with embodiments of the disclosure.

DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

The disclosure and the various features and advantageous details are explained more fully with reference to the non-limiting embodiments that are illustrated in the
25 accompanying drawings and detailed in the following description. Descriptions of well known starting materials, processing techniques, components, and equipment are omitted so as not to unnecessarily obscure the invention in detail. It should be understood, however, that the detailed description and the specific examples, while indicating embodiments of the invention, are given by way of illustration only and not by way of
30 limitation. Various substitutions, modifications, additions, and/or rearrangements within

the spirit and/or scope of the underlying inventive concept will become apparent to those skilled in the art from this disclosure.

The present disclosure provides techniques for improving the accuracy of distributed temperature measurements derived from the intensities of back scattered wavelengths along a sensing fiber in a distributed fiber temperature sensing instrument. Optical attenuation along the optical fiber sensing cable may be empirically derived for the light wavelengths of interest and may be used to obtain an improved temperature calculation. An apparatus of the present disclosure integrates fiber with two or more different incident wavelengths. The wavelength values are chosen so the anti-Stokes Raman return of the primary light source is substantially the same value as the Stokes Raman return of the secondary light source. This Raman Stokes backscatter may be used as indicator of fiber attenuation profile for the primary light source's anti-Stokes wavelength.

In one respect, the present disclosure covers both a time domain method which uses optical pulsed light sources (for the first and second light sources) and a frequency domain method, which is based on other types of modulation known in the art of the first and second light sources.

Referring to FIG. 1, a basic configuration of a DTS system based on light scattering is shown. The light source 10 is injected into a lead fiber 11 to reach the sensing fiber 14 through a light splitter/combiner 12, which is coupled to sensing fiber 14. When the light is guided to a sensing fiber, a portion of the light is scattered and travels to a wavelength selector 16 through a splitter/combiner 12 again via lines 13 and 15, respectively. The backscattered light from fiber 16 may include a Raleigh component 17 (same center wavelength as injected light), a Brillouin component 18, 19 and a Raman scattering component 20, 21. The latter two may be shifted from the input wavelength and have mirrored images symmetrical to the two components called Stokes and anti-Stokes.

Among these scatterings, Raleigh component 17 and Raman components 20 (Stokes) and 21 (anti-Stokes) are used for the calculation of temperature profile. The Stokes and anti-Stokes band may be separated by more than tens of nanometers but Brillouin components are more closely spaced- less than about 0.1 nm from the Rayleigh bandwidth. These components are shown in FIG. 2.

To calculate the temperature profile, back scattered light components may be fed to an optical wavelength separation assembly 16, and the light may be separated to three groups, anti-Stokes (AS), Rayleigh (R), and Stokes (S). The output of each group, shown in FIG. 3, may subsequently be guided to three optical converters to convert each group's optical signal to electrical signals to the signal processing unit.

As mentioned before, the temperature profile may be calculated by the ratio of Stokes to anti-Stokes component. But the intensities of both components may be affected by local circumstances and the variation of these intensities may be compensated or calibrated to achieve a more accurate temperature measurement. Particularly, the magnitude of anti-Stokes band may be varied by temperature as well as other physical perturbations other than temperature. Therefore, there is a need for common perturbations to be eliminated. For this purpose, a temperature independent Rayleigh component may be used as a reference. But the separation between Rayleigh and anti-Stoke band is typically more than about 50 nm, hence, a precise compensation is difficult. For accurate correction, another light source with a same band of anti-Stokes is useful.

Referring to FIG. 4, a diagram is shown of a scattering component 23 of a secondary light source, the secondary light source having a very close center wavelength and line-width to the anti-Stokes band 21 of the primary light source. In other embodiments, a secondary light source whose scattered Stoke band 25 coincides with the anti-Stoke band of the primary light source 21 may be used, as shown in FIG. 5. The light source of similar intensity and line-width may improve the accuracy of the compensation.

FIG. 6 illustrates an auto-calibration system, according to embodiments of the present disclosure. The primary light source 60 of the DTS may inject optical energy into the sensing fiber 68 through the optical route 70 via light combiner/splitter 66. Scattering bands Stokes (S), Rayleigh (R), and anti Stokes (AS) may be obtained and may be used to calculate a temperature profile.

The anti-Stokes band generated from primary light source 60 is varied by other physical phenomena and thus, may cause an error in the temperature calculations. According to one embodiment, during a correction mode, optical switch 64 may be changed such that an energy path from secondary light source 62 via optical route 72 may be created. The selected secondary light source may generate a Stokes backscattering

band identical to or substantially similar to the anti-Stokes band of the primary light source 60.

In some embodiments, the primary light source and the secondary light source may be the light source, *i.e.*, a dual wavelength laser source operably configured to provide at least two optical signals to the sensing fiber. One of ordinary skill in the art may recognize that an optical switch may not be needed. The dual wavelength laser source may operate at a first wavelength and at least the anti-Stokes band may be collected. Next, the dual wavelength laser source may operate at a second wavelength and at least the Stokes band may be collected, where the anti-Stokes and Stokes band are substantially similar.

Referring to Table 1, an example of a first light source and second light source are shown. The selection of a secondary light source may be based on its Stokes band in proximity to the anti-Stokes (A-Stokes) band of the primary light source. 980 nm semiconductor laser sources, which can be used as a secondary light source are popularly used as a pumping source of high fiber lasers and are commercially available.

Light Source	Wavelength, λ (nm)	$\Delta\lambda$ (nm)	A-Stokes	Stokes
Primary Light Source	1064	45.3	1018.7	1109.3
Secondary Light Source	980	38.4	941.6	1018.4

$\Delta\lambda$ indicates the Raman Stokes or anti-Stokes separation from the primary light source's center wavelength. Each bandwidth may be extended over, for example, 20 nm although the range may be greater or less than 20 nm. One of ordinary skill in the art can recognize that other primary light sources may be used as long as the secondary light source's Stokes band is substantially similar to the anti-Stokes band of the primary light source.

The secondary light source's Stokes attenuation profile, without or with the minimum temperature effect, may be used to correct the anti-Stokes profile made by the primary light source during a measurement mode. Thus, the generation of an extra wavelength band via a second light source that may be insensitive to temperature effects and corresponds to an anti-Stokes band of the DTS unit (*e.g.*, primary light source) may

be used to correct temperature error induced by anti-Stokes profile in the first primary light source.

Two like bands, one from the anti-Stokes of a primary light source (in measurement mode) and the other from the Stokes band of the secondary light source (in correction mode) may pass through a wavelength selector 16 (FIG. 6) and may be detected with an Optical Spectrum Analyzer. The result is shown in FIGs. 7A and 7B. The wavelength bands under the dotted area may indicate the anti-Stokes band for the primary light source (FIG. 7A) and the Stokes band of the secondary light source (FIG. 7B).

FIGs. 8 show the profile of the primary anti-Stokes band (202) and the secondary Stoke band (200), and FIG. 9 shows the difference between the two profiles, which will be used as a calibration factor, respectively.

Referring to FIG. 10, an alternative calibration system is shown. By selecting the primary and secondary light source 31 and 32 via an optical switch 34, which may be synchronized to optical switches 44 and 45, the Rayleigh and the anti-Stokes bands which are outputs of wavelength selector 35 (38, 39, and 41 respectively) of the primary may be chosen to calculate the temperature profile in measurement mode. In one respect, outputs 38 and 40 may be used during a measurement mode and outputs 39 and 41 may be used during a calibration mode.

During calibration mode, the secondary Rayleigh band and the Stokes band (output 39 and 40 of the optical switches 44 and 45) may be selected to calibrate the primary anti-Stokes and the Rayleigh (*e.g.*, 980 nm and 1015 nm). Unit 37 and 45 may be wavelength reflection devices such as a FBG (Fiber Bragg grating) and edge filter respectively. By implementation of this configuration, the anti-Stokes and the DAF (Differential Attenuation factor) between the sources 1064 and 980 may also be calculated. The DAF may be determined based on the attenuation difference between the primary light source and the secondary light source. In other words, the difference between the anti-Stoke bands of the primary light source and the Stokes band of the secondary source may be used to determine the DAF.

Various advantages of fiber optic sensors make them useful as tools particularly for application in electric power industries. Small size, flexibility, and immunity to EMI (Electromagnetic Interference) are the key benefits. The disclosure provides systems and

methods for the detection, location, and measurement of corrosion along a length of an extended object or objects on which a single line of optical fiber is deployed in close proximity.

In some respect, a distributed sensor system and method for detecting, locating,
5 and measuring corrosion occurring anywhere in the vicinity of an optical fiber containing an appropriate luminescent material are provided. The system and method may provide time rate progress data for the entire length or at discrete points of the line.

In one respect, the sensor of the present disclosure may utilize optical fiber, which contains continuous or discrete luminescent layers. When corrosion occurs, the
10 luminescent material starts to interact with corrosion chemicals and the luminescent material's emissions may change, for example, in intensity and/or peak wavelength. A back scattered emission light from the sensing region may be guided to a detector through the fiber as shown in FIG. 11. By selecting a suitable luminescent material, the corrosion effects may be effectively monitored.

The luminescent material may be integrated onto the entire length of the core
15 (FIG. 12A) or at discrete locations on the core, as shown in FIG. 12B and 12C. Alternatively, a porous protection layer is integrated on luminescent cladding layer as the jacket of the fiber, as shown in FIG. 12D.

In some respect, the flight time of the light pulse may used to determine the
20 location of the corrosion source along the fiber, using for example a sensing system as shown in FIG. 13. The system may include a pulsed laser coupled to a fiber splitter (FS) which may be coupled to an optical connector (OC). It is noted that a pulsed or CW ultra violet laser may be used to find a corrosion location. Alternatively, any electromagnetic radiation source may be used. The intensity variation of the lighting source, connector,
25 and/or sensing fiber may be compensated.

Coupled to the optical connector may be a sensing fiber which may be illuminated by the radiation source and may provide backscattering emission light via the OC and to, for example, the filter or a detector (Det2). Alternatively, the backscattering emission light may be provided to a filter and an optical switch, the optical switch and filter may be
30 coupled a detector (Det 1). Outputs from Det1 and Det2 may be provided to a signal processor for determining, among other things, corrosion location.

By measuring the average signal from backscattered emission light, the magnitude of the corrosion can also be determined. A compensating algorithm may be used to avoid calculation error due to undesired variation of backscattered light intensities and to avoid the calculation error due to undesired variation of backscattered light intensities occurring
5 from the fiber connector, bending of sensing fiber itself and the light source.

When corrosion occurs in proximity to the area where the sensing fiber is deployed, the backscattered light luminescent intensity may be affected at each location, as illustrated in the graphs of FIGs. 14A and FIG. 14B. In FIG. 14A, no corrosion was detected. In FIG. 14B, incidents of corrosion occurred at locations, L1, L2, and L3.

10 It is noted that the present disclosure contemplates using other backscattering bands from at least one light source to calibrate a temperature sensing system. The anti-Stokes and Stokes band from a first light source and a second light source, respectively are examples of the bands that may be used. One of ordinary skill in the art can recognize the advantages of replacing a backscattering band from a first light source due to
15 perturbations or factors with a similar backscattering band from another light source.

* * *

With the benefit of the present disclosure, those having ordinary skill in the art will comprehend that techniques claimed here may be modified and applied to a number of additional, different applications, achieving the same or a similar result. The claims
20 cover all such modifications that fall within the scope and spirit of this disclosure.

CLAIMS

1. A method comprising:
providing a first light source;
providing a second light source, the second light source having a Stokes band substantially similar to an anti-Stokes band of the first light source;
calibrating a temperature sensing system based on the Stokes band and the anti-Stokes band.
2. The method of claim 1, where calibrating comprises selecting a wavelength from the anti-Stokes band and the Stokes band.
3. The method of claim 1, where calibrating comprises determining a difference in anti-Stokes band and the Stokes band.
4. The method of claim 1, where the first light source and second light source are the same light source.
5. The method of claim 1, where the first light source has a wavelength of about 1064 nanometers and the second light source has a wavelength of about 980 nanometers.
6. A method comprising:
providing a first light source and a second light source, the first light source being configured to operate in a measurement mode and the second light source being configured to operate in a correction mode;
illuminating a sensing fiber with the first light source;
detecting an anti-Stokes band using the illumination of the first light source;
illuminating the sensing fiber with the second light source;
detecting a Stokes band using illumination from the illumination of the second light source;
calibrating a temperature sensing system based on a ratio between the Stokes and anti-Stokes band.
7. A system for calibrating a temperature sensing system comprising:
a primary light source for providing an anti-Stokes band;

a secondary light source coupled to the primary light source for providing a Stokes band;

an optical switch for selecting between the primary light source and the secondary light source; and

wherein the system calibrates the temperature sensing system based on a ratio of the anti-Stokes band and Stokes band.

8. The system of claim 7, further comprising a sensing fiber for generating backscattering bands.

9. The system of claim 8, the backscattering bands comprising the anti-Stokes band of the primary light source.

10. The system of claim 8, the backscattering bands comprising the Stokes band of the second light source.

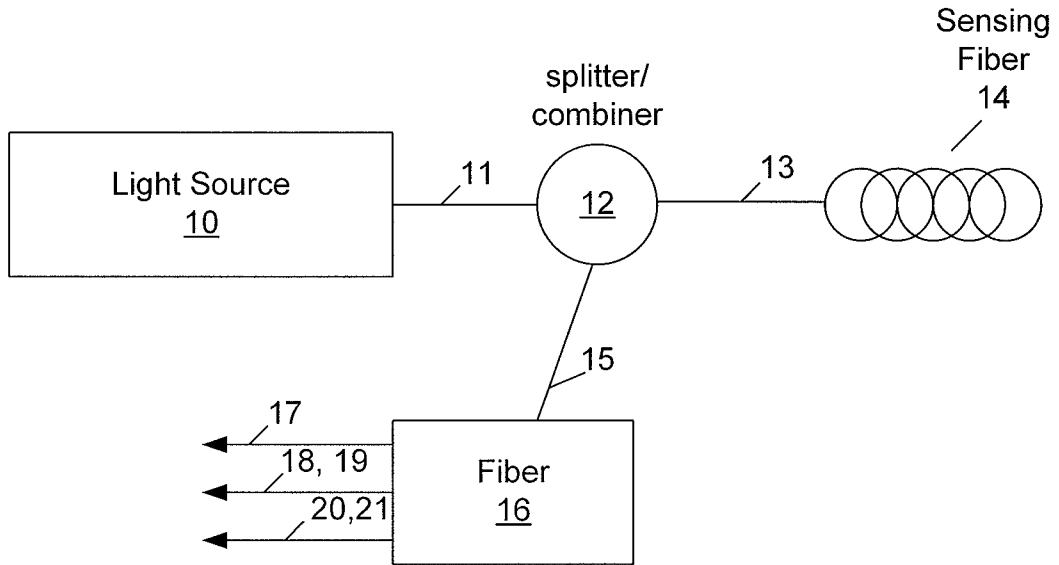


FIG. 1

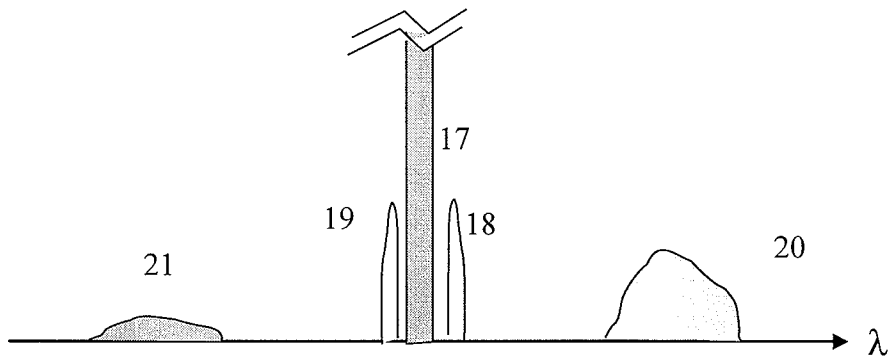


FIG. 2

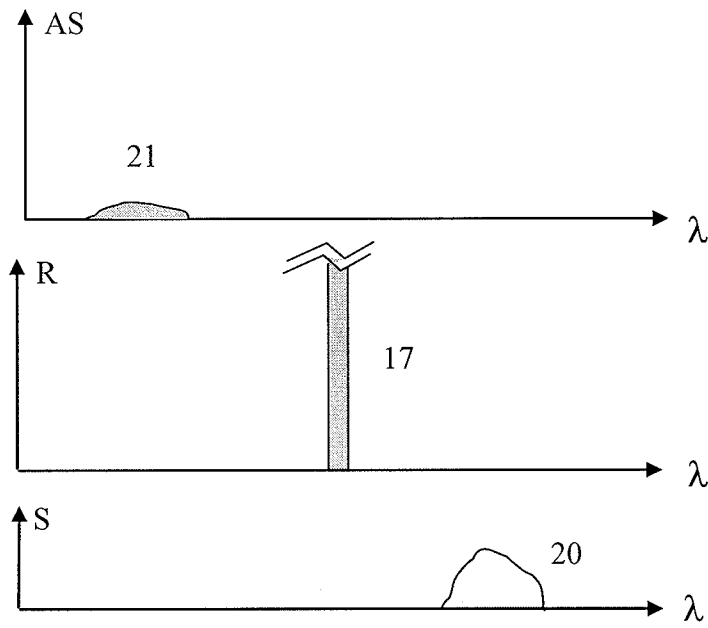


FIG. 3

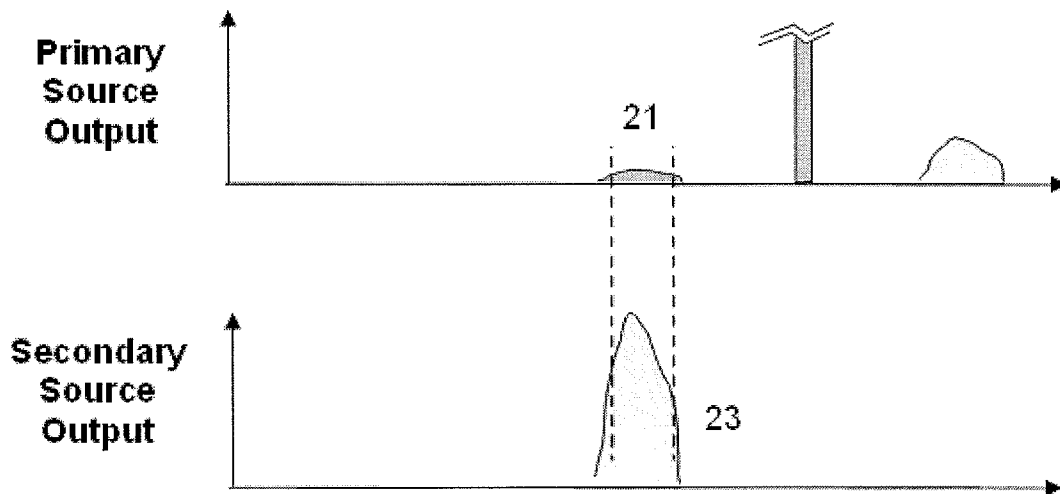


FIG. 4

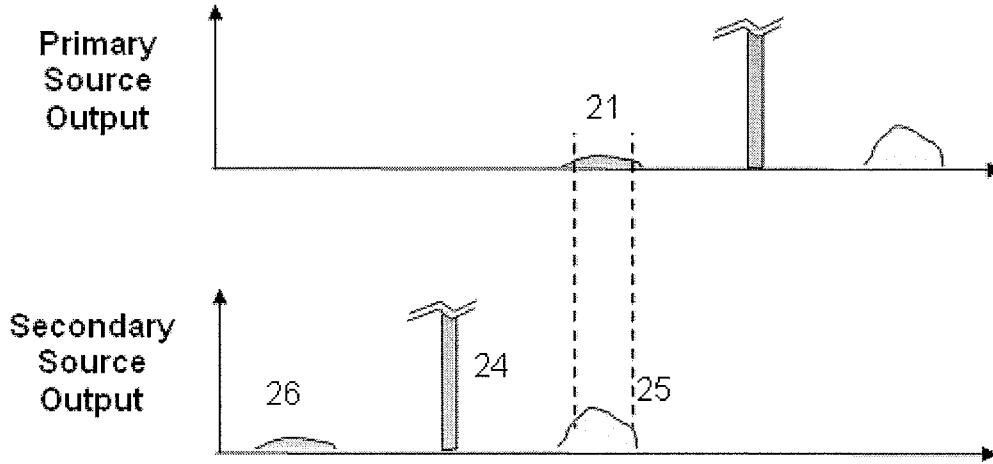


FIG. 5

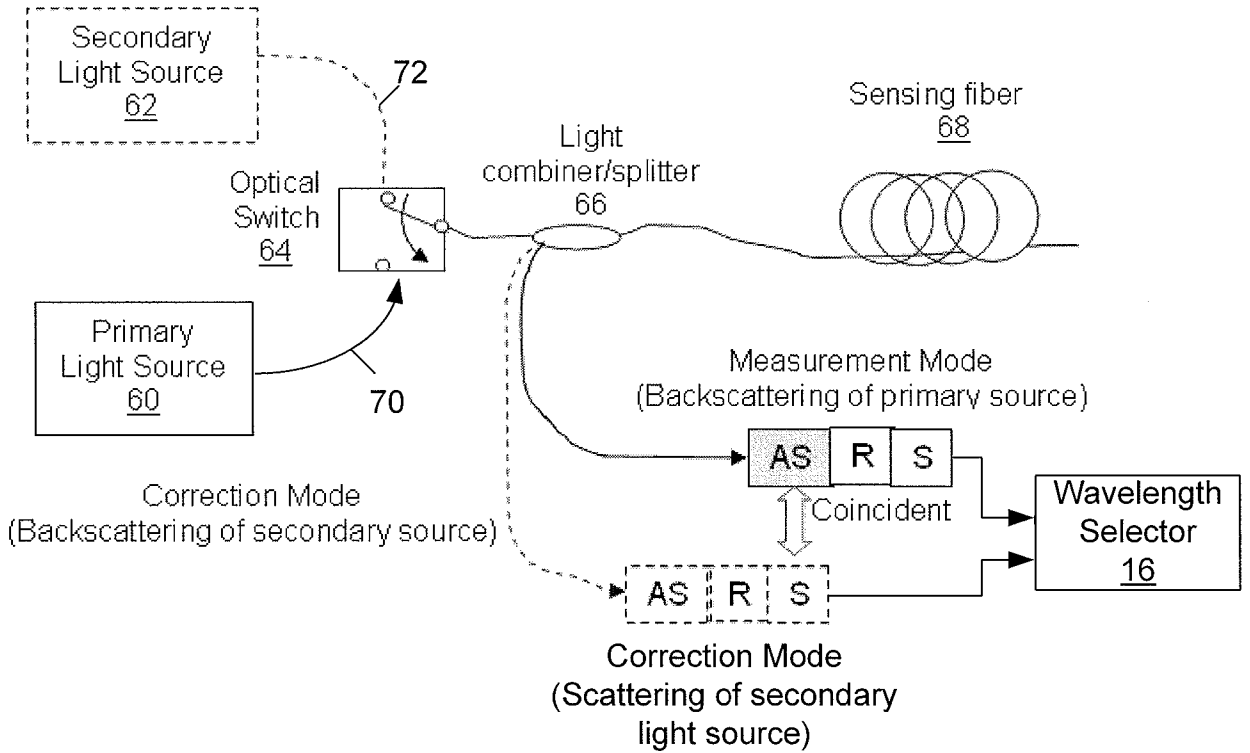


FIG. 7A

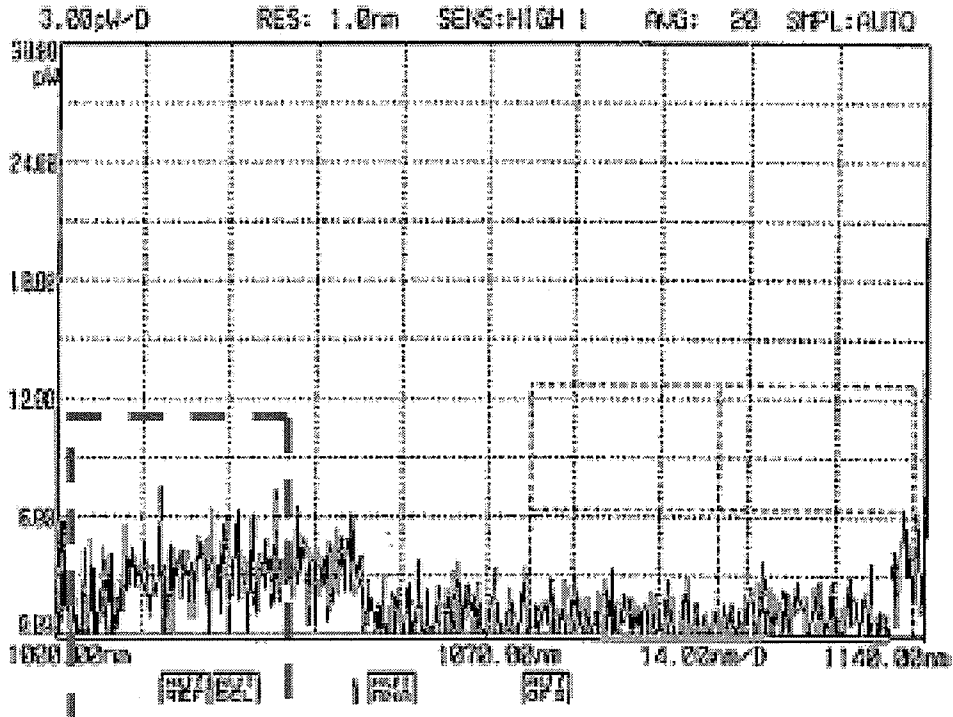
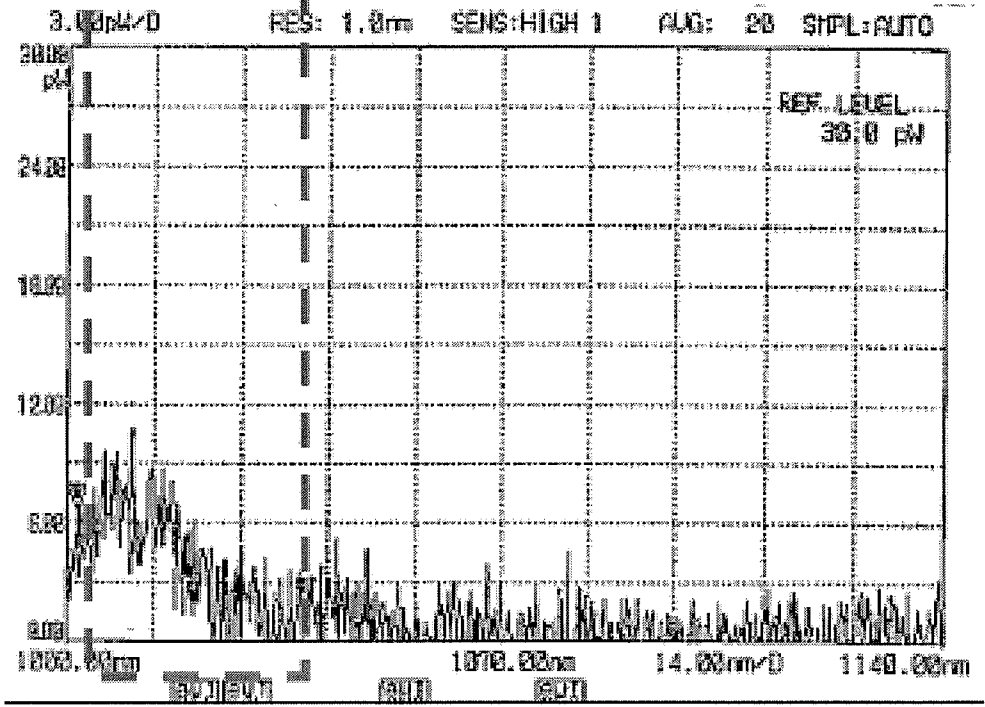


FIG. 7B



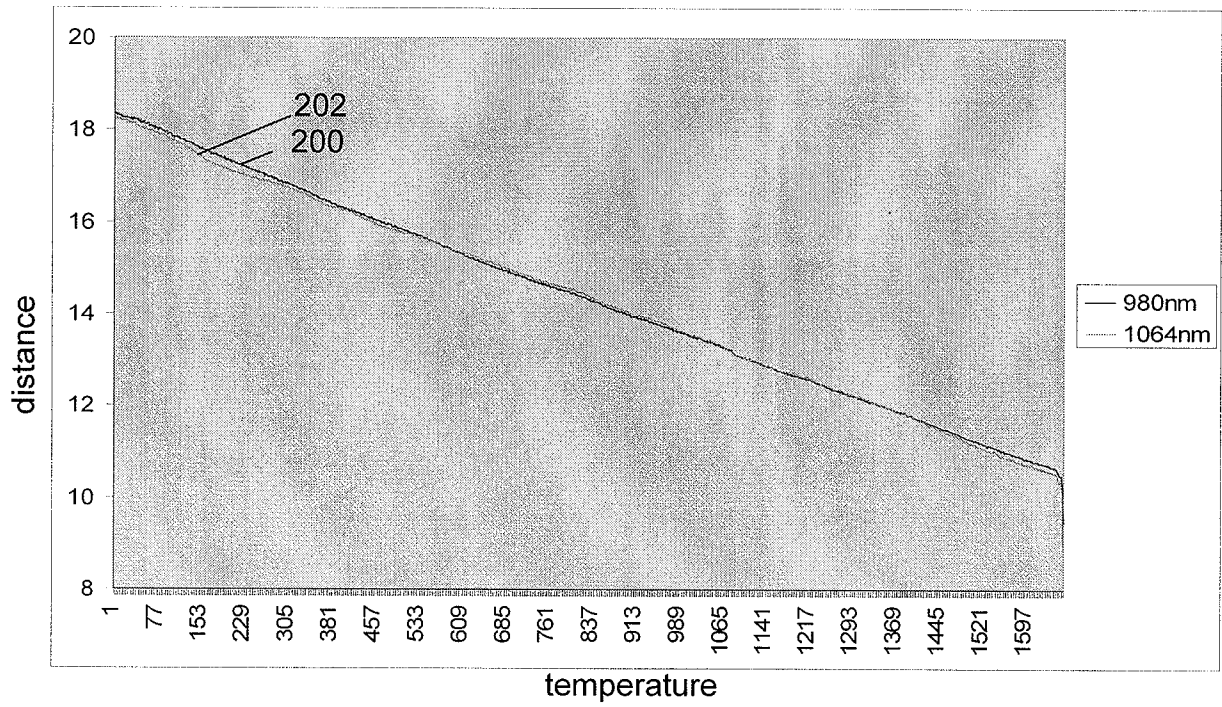


FIG. 8

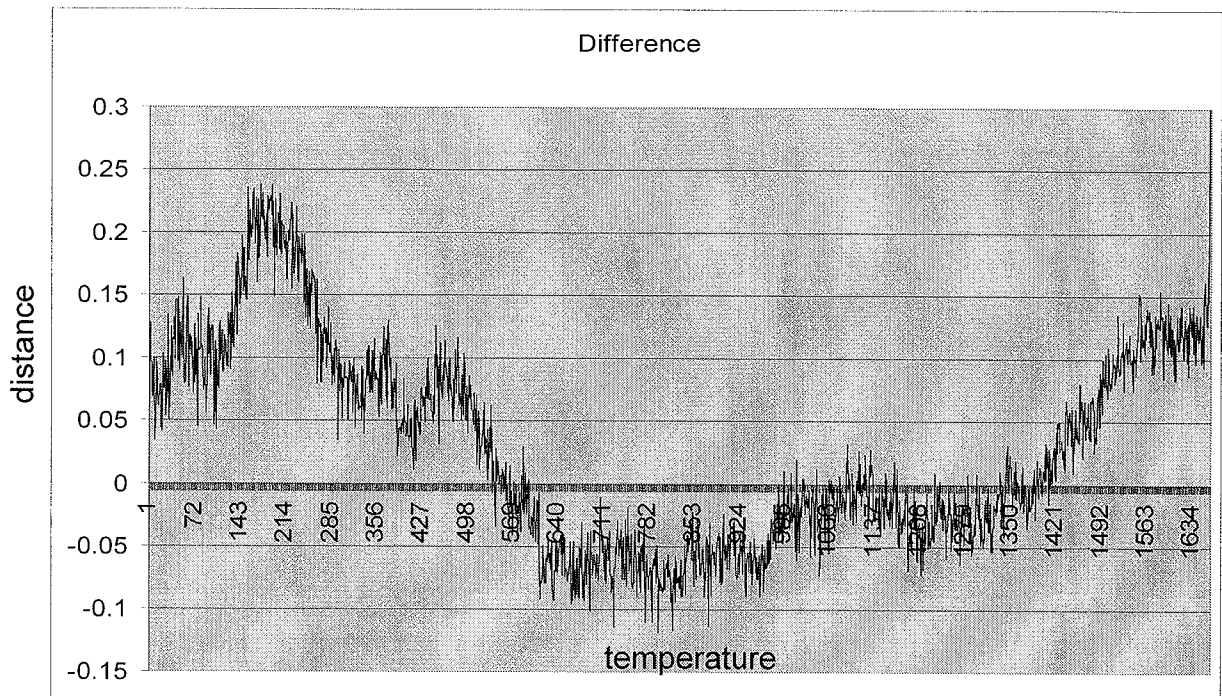
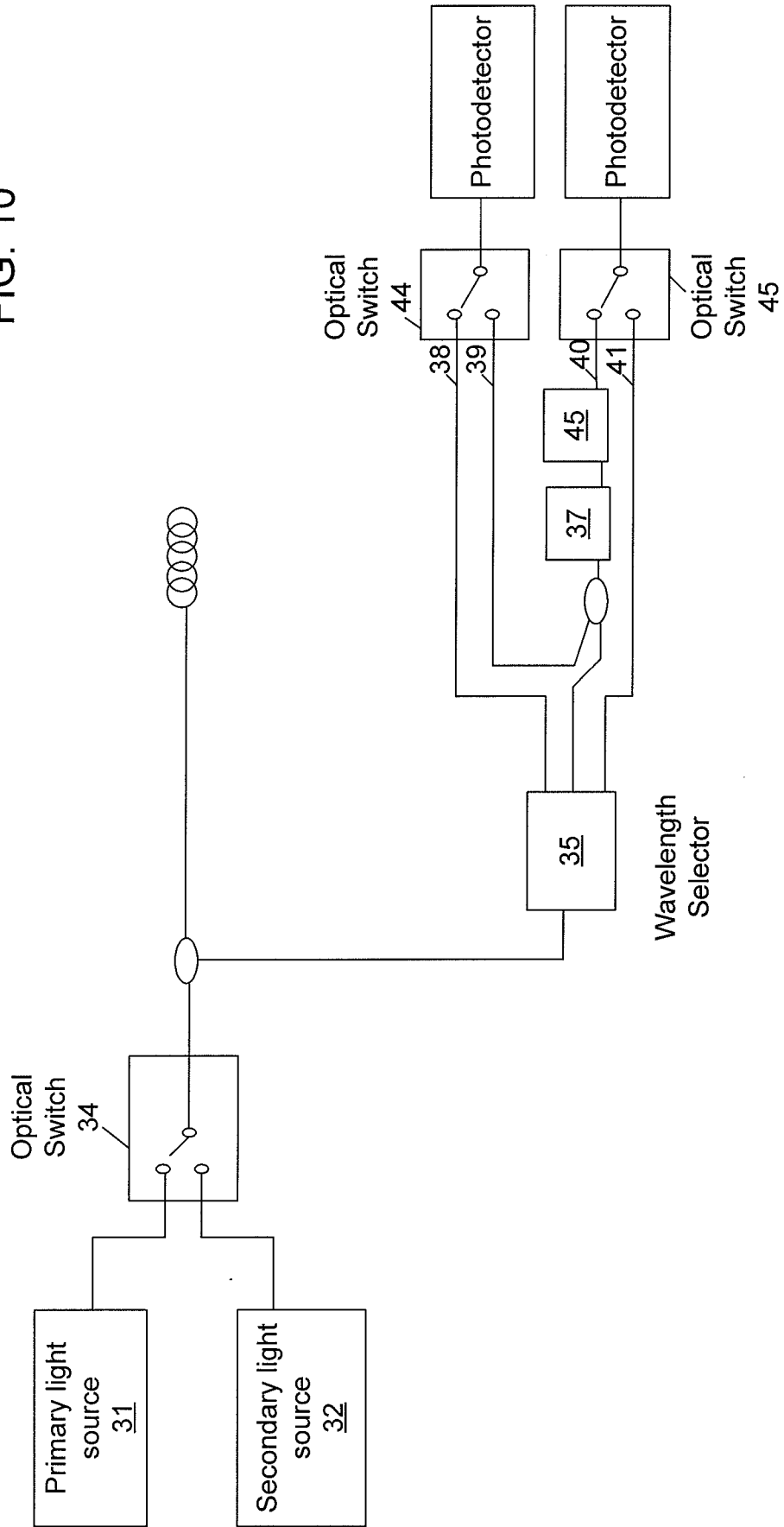


FIG. 9

FIG. 10



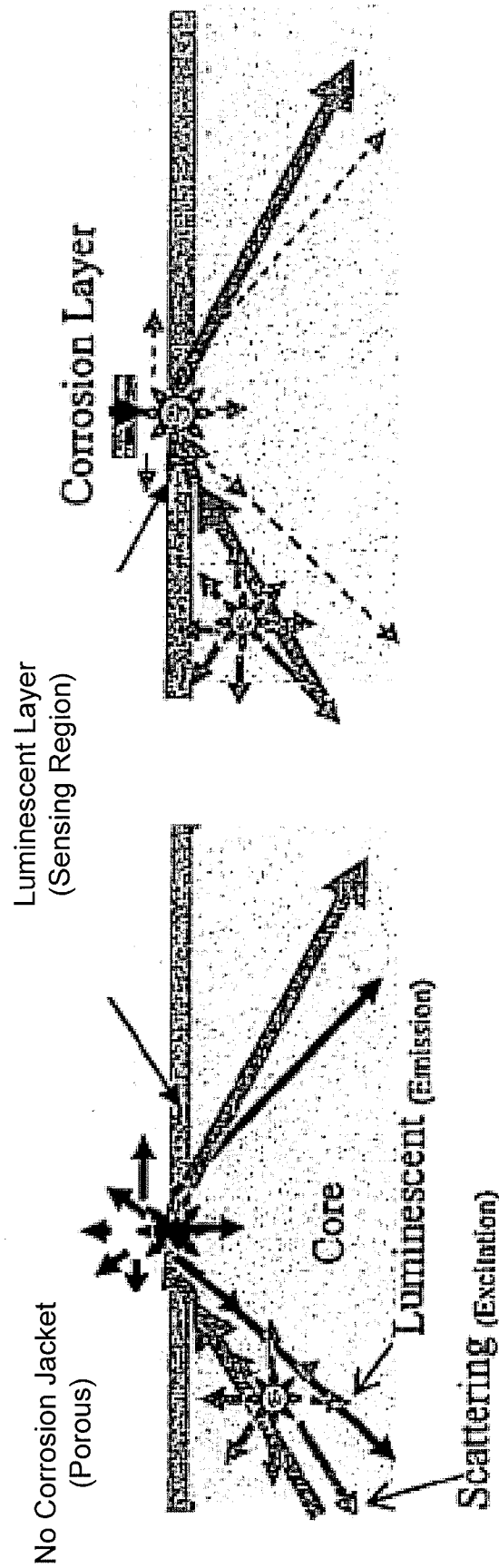


FIG. 11



FIG. 12A

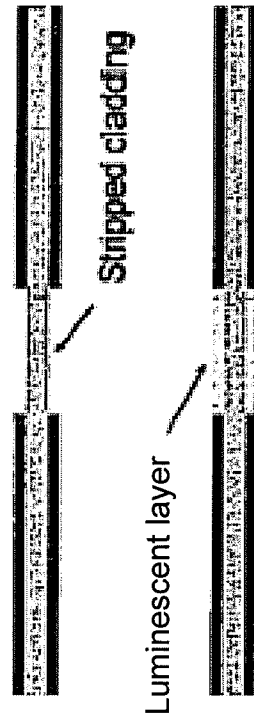


FIG. 12B

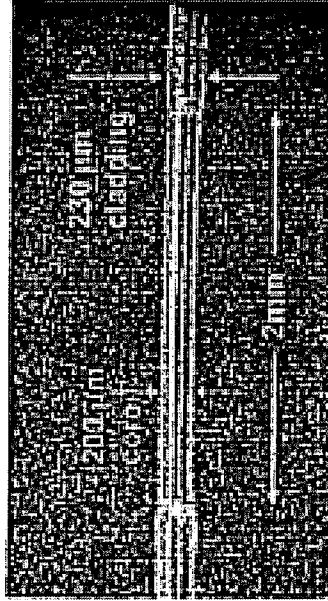


FIG. 12C

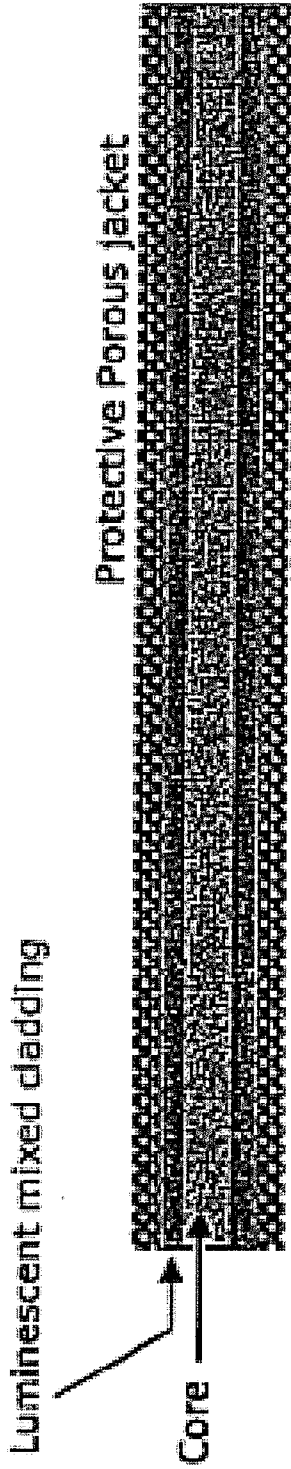


FIG. 12D

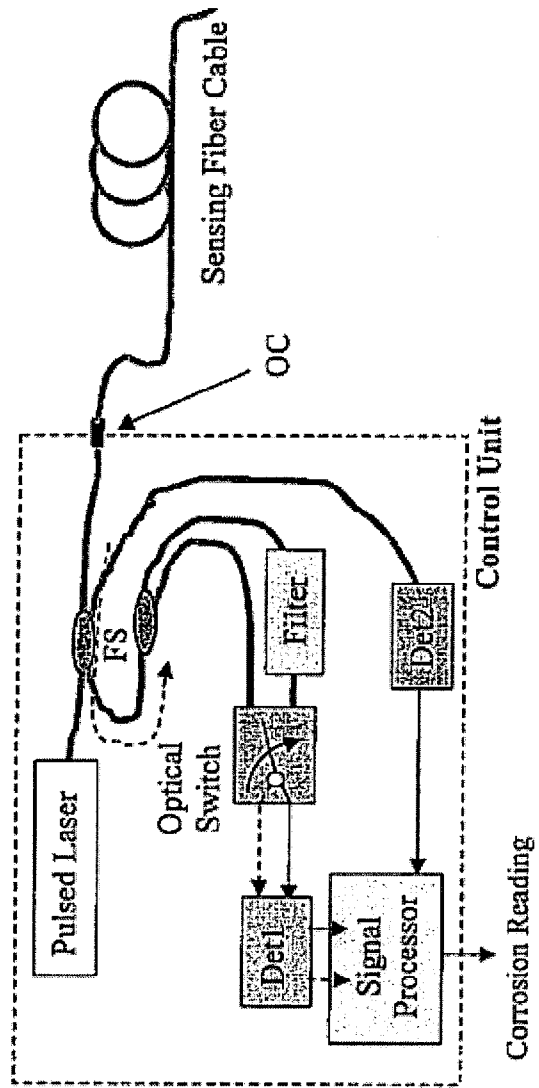


FIG. 13

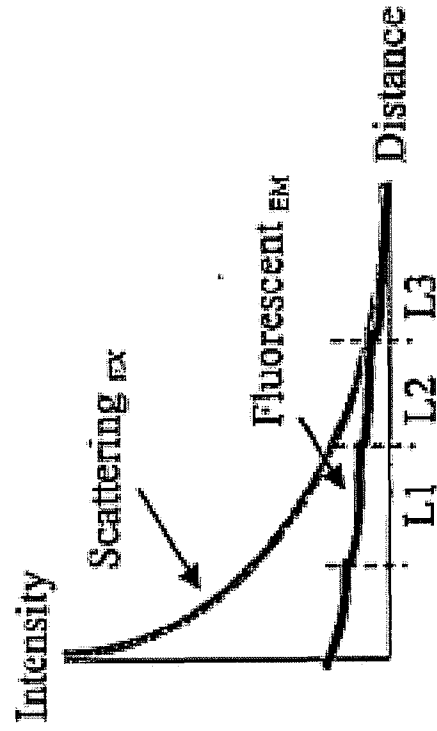


FIG. 14B

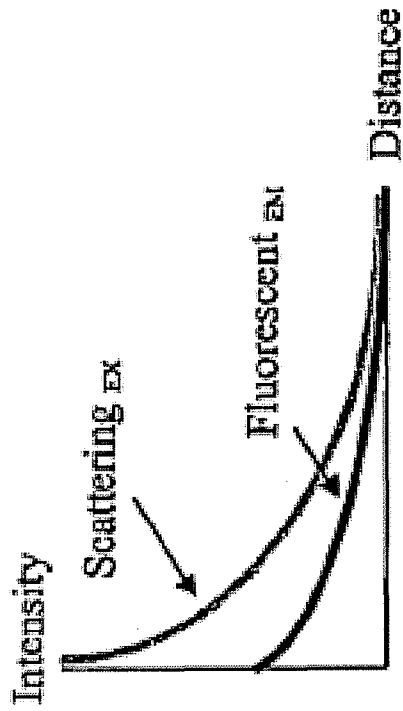


FIG. 14A

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/063913

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01K11/32

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)
G01K

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 170 595 A (CENTRAL ELECTR GENERAT BOARD) 6 August 1986 (1986-08-06) page 1, line 62 - page 2, line 31 figure 1	1-10
X	GB 2 210 451 A (PLESSEY CO PLC [GB] PLESSEY CO PLC [GB]; SIEMENS PLESSEY CONTROLS LTD) 7 June 1989 (1989-06-07) pages 4-6	1-10

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

13 July 2007

Date of mailing of the international search report

25/07/2007

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de Bakker, Michiel

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2007/063913

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2170595	A	06-08-1986	NONE
GB 2210451	A	07-06-1989	NONE