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[Continued on next page]

(54) Title: HIGH SPEED DISTRIBUTED TEMPERATURE SENSING WITH AUTO CORRECTION

(57) Abstract: A system and method for a higher speed auto-correcting temperature measurement in a system using a fiber optic distributed sensor.

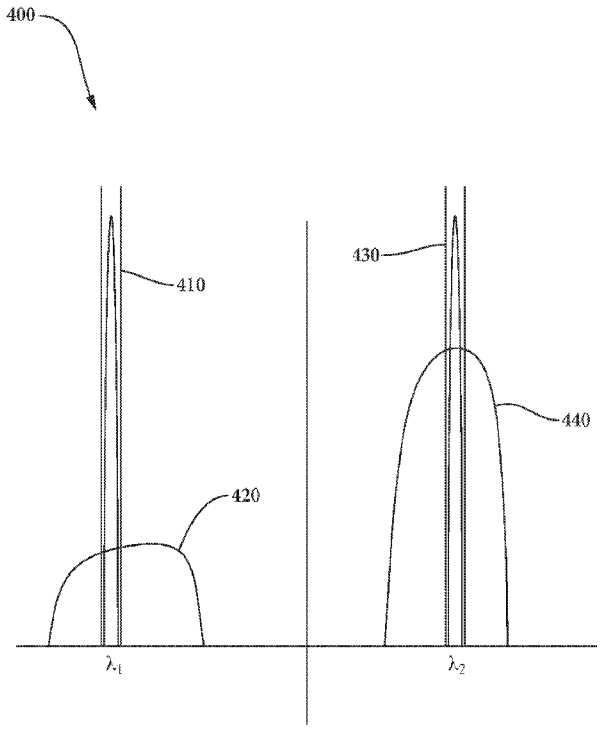


FIG 4

WO 2016/043733 A1

Declarations under Rule 4.17:

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

Published:

— *with international search report (Art. 21(3))*

Title

High Speed Distributed Temperature Sensing with Auto Correction

Background

This disclosure relates generally to temperature sensing, and more particularly, to dual source self-calibration or auto-correction systems and methods for distributed temperature sensing.

Fiber optic Distributed Temperature Sensing (DTS) systems were developed in the 1980s to replace thermocouple and thermistor based temperature measurement systems. DTS technology is often based on Optical Time-Domain Reflectometry (OTDR) and utilizes techniques originally derived from telecommunications cable testing. Today DTS provides a cost-effective way of obtaining hundreds, or even thousands, of highly accurate, high-resolution temperature measurements, DTS systems today find widespread acceptance in industries such as oil and gas, electrical power, and process control.

The underlying principle involved in DTS-based measurements is the detection of spontaneous Raman back-scattering. A DTS system launches a primary light source pulse that gives rise to two back-scattered spectral components. A Stokes component that has a lower frequency and higher wavelength content than the launched light source pulse, and an anti-Stokes component that has a higher frequency and lower wavelength than the launched light source pulse. The anti-Stokes signal is usually an order of magnitude weaker than the Stokes signal (at room temperature) and it is temperature sensitive, whereas the Stokes signal is almost entirely temperature independent. Thus, the ratio of these two signals can be used to determine the temperature of the optical fiber at a particular point. The time of flight between the launch of the primary light source pulse and

the detection of the back-scattered signal may be used to calculate the spatial location of the scattering event within the fiber.

One problem involved in the operation of DTS systems is proper calibration. DTS technology derives temperature information from two back-scattered signals that are in different wavelength bands. The shorter wavelength signal is the Raman anti-Stokes signal, the longer one is usually the Raman Stokes signal. After the light from the primary source at λ_1 is launched in a temperature sensing fiber, the scattered power arising from different locations within the optical fiber contained in the backscattered Stokes and anti-Stokes bands travel back to the launch end and gets detected by single or multiple detectors. As the Stokes and anti-Stokes signals travel, they suffer different attenuation profiles α^{Stokes} (a_S) and $\alpha^{\text{Anti-Stokes}}$ (a_{AS}), respectively, due to the difference in the wavelength band for these two signals. For proper temperature measurement a correction needs to be made so that the two signals exhibit the same attenuation.

One approach that has been used is to assume that the attenuation profile is exponentially decaying as a function of distance. This creates an exponential function with an exponent called the Differential Attenuation Factor (DAF) that is multiplied by the Stokes signal to adjust the attenuation profile to that of the anti-Stokes signal. The ratio of the resulting two signals is then used to derive temperature. The DAF is the difference in attenuation (a_{AS}-a_S) between two different wavelengths.

The assumption of a smooth exponential decay however is not always a reality. A number of factors can cause the actual attenuation to deviate from the exponential form. Localized mechanical stress or strain, fiber crimping, chemical attack (eg. hydrogen ingression) all can induce abnormalities, and some of these can change with time. It has been

recognized in the industry that some form of continuous calibration or auto-correction is needed to reduce all of these irregularities.

One successful approach for such continuous calibration or auto-correction was described in US Patent 8,496,376 using a dual laser system to automatically correct for the differential attenuation that exists between the Raman Stokes and Anti-Stokes backscattered light. This is achieved by having the Rayleigh signal of one laser overlap with the Raman signal of the other laser. This approach can effectively negate the scattering effects that are not temperature dependent, resulting in a signal that only represents temperature effects. Such an approach requires however that the dual lasers must be fired alternately because the backscattered Rayleigh signal of each laser is much larger in size than the backscattered Raman signals, making it impossible to detect the backscattered Raman signals. This alternate firing of the lasers results in a reduced sampling rate for the system.

There is a need then for a much faster and more effective self-calibration or auto correction scheme.

Brief Description of the Drawings

Figure 1 illustrates a prior art dual laser distributed temperature system capable of performing a self-calibration or auto correction method.

Figure 2 illustrates primary and secondary light sources chosen to closely match the Raman anti-Stokes wavelength of the primary with the principle wavelength of the secondary source, resulting in closely matching the Ramen Stokes wavelength of the secondary source with the principle wavelength of the primary source.

Figure 3 illustrates a dual laser distributed temperature sensing system described in this disclosure that can perform a self-calibration or auto correction method and much higher speeds.

Figure 4 illustrates the principle of using notch filters to filter out the much larger Rayleigh signals to enable continuous use of the backscattered Raman Stokes and anti-Stokes signals for self calibration or auto-correction.

Figure 5 illustrates the optical transmission spectra of the notch filters.

Detailed Description

In the following detailed description, reference is made to accompanying drawings that illustrate embodiments of the present disclosure. These embodiments are described in sufficient detail to enable a person of ordinary skill in the art to practice the disclosure without undue experimentation. It should be understood, however, that the embodiments and examples described herein are given by way of illustration only, and not by way of limitation. Various substitutions, modifications, additions, and rearrangements may be made without departing from the spirit of the present disclosure. Therefore, the description that follows is not to be taken in a limited sense, and the scope of the present disclosure will be defined only by the final claims.

Figure 1, shown generally as the numeral **100** shows a block diagram of a prior art dual laser DTS system capable of performing a self-calibration or auto correction method. Primary light source **104** (wavelength λ_1) and secondary light source **106** (wavelength λ_2) may alternatively feed primary and secondary optical signals into sensing fiber **112** and reference fiber coil **116** via optical switch **105**. When optical switch **105** is in a first position, primary source **104** produces primary back-scattered signals from sensing fiber **112**. When optical switch **105** is in a second position, secondary source **106** produces secondary back-scattered signals from sensing fiber **112**. Optical combiner/splitter **108** directs these mixed spectral components to optical filter **120**, which separates the back-scattered components into the bands of interest, which may be the Rayleigh, Raman Stokes and Raman anti-Stokes frequencies of the primary or secondary light sources and then feeds them into photo-detectors **124**. Three photo detectors are shown for illustrative purposes, but more are possible. The signals from photo-detectors are fed to a

programmed signal processor that outputs temperature as a function of location along sensing fiber **112**.

In an example embodiment, the wavelength of the secondary source (λ_2) is chosen to coincide with the anti-Stokes wavelength (λ_{1_AS}) of the primary source. This is shown in Figure 2, shown generally by the numeral **200**. If secondary source wavelength is chosen to match the anti-Stokes of the primary wavelength then the Stokes wavelength of the secondary is a close match to the primary wavelength λ_1. This configuration eliminates the need to use any Rayleigh signal for adjustments, and accurate temperature may be measured using only the Stokes and anti-Stokes signals.

A proven example of this example embodiment is a commercially available measurement light source of primary wavelength of 975 (nm) coupled with a correcting light source of 940 (nm). With Dual Laser Distributed Temperature Sensor (DTS) Systems the main goal is to automatically correct for differential attenuation that exists between the Raman Stokes and Anti-Stokes backscattered light. This is achieved by having the Rayleigh signal of one laser overlap with the Raman signal of the other laser. In this way you can effectively negate the scattering effects that are not temperature dependent, leaving you with a signal that only represents temperature effects.

In addition to this combination presented above three higher end combinations are suited to this application. One would be a commercially available measurement light source of primary wavelength of 1500 (nm) coupled with a correcting light source of 1410 (nm). Another would be a commercially available measurement light source of primary wavelength of 1550 (nm) coupled with a correcting light source of 1450 (nm). The third would be a commercially available measurement light source of primary

wavelength of 1030 (nm) coupled with a correcting light source of 990 (nm).

This approach results in speed limitation issues if one wants to collect the Raman Stokes and Anti-Stokes signals at the same time since the Rayleigh signal is several 10's of dB larger than the Raman signal, and the receiver would be unable to detect the Raman signal. This disclosure proposes a way around this limitation of the dual laser technology and increases the sampling rate of a dual laser system by roughly a factor of 2.

This can be achieved by the addition of notch filters that match the wavelengths of the Rayleigh signals. Since the Raman spectrum is so wide and the Rayleigh spectrum is so narrow, subtracting it in this manner will not negatively impact performance.

Figure 3, shown generally as the numeral **300**, illustrates a system that can do this. Illustrated herein is a two light source system, light sources **310** and **320**. The light sources feed into a wave division multiplexer **330.** The wave division multiplexer then combines the two different wavelengths and feed them into a distributed fiber optic sensor **340** into a region of interest to be measured.

Backscattered light signals from distributed fiber optic sensor **340** then return to wave division multiplexer **330** which separates the signals into the Raman anti-Stokes wavelength (λ_{1_AS}) of the primary source λ_1 and the Raman Stokes signal (λ_{2_S}) of the secondary source λ_2. As is illustrated in Figure 2, each of these Raman backscattered signals from the primary and secondary sources would then be accompanied by the Rayleigh signals from the other source. The Raman backscattered anti-Stokes signal (λ_{1_AS}) from primary source λ_1 then feeds through a notch filter **350** and into a first photo detector **370**. Raman backscattered Stokes

signal (λ_{2_S}) from secondary source λ_2 then feeds through a notch filter **360** and into a second photo detector **380**.

The work of the notch filters can be seen in Figure 4. As described earlier the two Raman spectrums are very wide and the Rayleigh spectrum is very narrow. The backscattered Raman anti- Stokes spectrum **420** from the primary light source is shown along with the very narrow backscattered Rayleigh spectrum from the secondary source λ_2. The notch filter **410** can be designed to filter out just the Rayleigh component. Likewise on the right hand side of the figure the backscattered Stokes spectrum **440** from the secondary light source λ_2 is shown along with the vary narrow backscattered Rayleigh spectrum from the primary source λ_1. Notch filter **430** then filters out just the Rayleigh component. Because the Raman spectrums are so wide and the Rayleigh spectrums so narrow, subtracting out the Rayleigh component still leaves very substantial Raman signals available to be measured by photo detectors **370** and **380**. The two light sources can thus be fired continuously and the photo detectors can continuously measure the backscattered Raman signals.

Some notch filters may be passive and will have to be selected carefully for the light source wavelengths chosen. In other cases the notch filters are tunable by thermal or other means and may be tuned as closely as possible to the center wavelength of the Rayleigh wavelength of each light source. Both of these options are anticipated in this disclosure.

The signals from photo-detectors can then be fed to a programmed signal processor that outputs temperature as a function of location along the distributed fiber optic sensor **340** using art recognized computation methods that calibrate and measure the temperature distribution along the distributed fiber optic sensor based on the ratio of the intensity of the anti-

Stokes band of the primary light source and the Stokes band of the secondary light source.

Figure 5 illustrates the optical transmission spectra of the notch filters. The notch filter is chosen in such a way as to minimize the amount of Rayleigh backscatter that can make it to the detectors.

An aspect of this disclosure is then a system for auto-correcting temperature measurement in a system using a distributed fiber optic sensor including at least: a distributed fiber optic sensor; a primary light source for providing a back-scattered anti-Stokes band from said distributed fiber optic sensor; a secondary light source for providing a back-scattered Stokes band from said distributed fiber optic sensor; wherein the primary and secondary light sources are chosen so that the Rayleigh signal of the primary light source overlaps with the Raman Stokes signal of the secondary light source and the Rayleigh signal of the secondary light source overlaps with the Raman anti-Stokes signal of the primary light source; a wave division multiplexer (WDM) for receiving the primary light signal and the secondary light signal and passing the resulting signal into the distributed fiber optic sensor; wherein the WDM also acts as a de-multiplexer and separates the backscattered light from the fiber optic distributed sensor into an anti-Stokes band from the primary light source and a Stokes band from the secondary light source; two notch filters that that match the wavelengths of the Rayleigh signals of the primary and secondary light sources and receive the anti-Stokes band from the primary light source and a Stokes band from the secondary light source and filter out the Rayleigh signals of the primary and secondary light sources; two photo detectors for receiving the signals from the notch filters and measure the intensity of each; wherein the system for auto-correcting temperature measurement calibrates and measures the temperature distribution along said distributed fiber optic sensor based on

the ratio of the intensity of the anti-Stokes band of the primary light source and the Stokes band of the secondary light source.

Another aspect of this disclosure is then a method of auto-correcting temperature measurement in a system using a fiber optic distributed sensor including at least: feeding a primary light source light pulse energy into a wave division multiplexer; feeding a secondary light source pulse energy into the wave division multiplexer to create a combined primary and secondary light source pulse energy; feeding the combined primary and secondary light source pulse energies into the distributed fiber optic sensor deployed into a region of interest; collecting back-scattered light energy from the distributed fiber optic sensor into the wave division multiplexer and separating the backscattered light energy into a Raman anti-Stokes wavelength of the primary light source and a Raman Stokes wavelength of the secondary light source; wherein the Raman anti-Stokes component will also include the Rayleigh wavelength of the backscattered secondary source and the Raman Stokes component will include the Rayleigh wavelength of the primary light source; feeding the Raman anti-Stokes wavelength of the primary light source through a notch filter that filters out the backscattered Rayleigh component of the secondary light source; feeding the Raman Stokes wavelength of the secondary light source through a notch filter that filters out the backscattered Rayleigh component of the primary light source; feeding the output of the two notch filters to two photo detectors to measure the signal intensities of backscattered anti-Stokes signal of the primary light energy and the back-scattered Stokes signal of the secondary light energy; and calculating a temperature using the backscattered anti-Stokes signal of the primary light energy and the back-scattered Stokes signal of the secondary light energy.

Current approaches to single mode DTS systems require long trace times. The method and apparatus described herein could cut that time by a factor of two.

Although certain embodiments and their advantages have been described herein in detail, it should be understood that various changes, substitutions and alterations could be made without departing from the coverage as defined by the appended claims. Moreover, the potential applications of the disclosed techniques is not intended to be limited to the particular embodiments of the processes, machines, manufactures, means, methods and steps described herein. As a person of ordinary skill in the art will readily appreciate from this disclosure, other processes, machines, manufactures, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufactures, means, methods or steps.

Claims

1. A system for auto-correcting temperature measurement in a system using a distributed fiber optic sensor comprising:

    a. a distributed fiber optic sensor;

    b. a primary light source for providing a back-scattered anti-Stokes band from said distributed fiber optic sensor;

    c. a secondary light source for providing a back-scattered Stokes band from said distributed fiber optic sensor; wherein the primary and secondary light sources are chosen so that the Rayleigh signal of the primary light source overlaps with the Raman Stokes signal of the secondary light source and the Rayleigh signal of the secondary light source overlaps with the Raman anti-Stokes signal of the primary light source;q

    d. a wave division multiplexer (WDM) for receiving the primary light signal and the secondary light signal and passing the resulting signal into the distributed fiber optic sensor; wherein the WDM also acts as a de-multiplexer and separates the backscattered light from the fiber optic distributed sensor into an anti-Stokes band from the primary light source and a Stokes band from the secondary light source;

    e. two notch filters that that match the wavelengths of the Rayleigh signals of the primary and secondary light sources and receive the anti-Stokes band from the primary light source and a Stokes band from the secondary light source and filter out the Rayleigh signals of the primary and secondary light sources;

f. two photo detectors for receiving the signals from the notch filters and measure the intensity of each;

g. wherein the system for auto-correcting temperature measurement calibrates and measures the temperature distribution along said distributed fiber optic sensor based on the ratio of the intensity of the anti-Stokes band of the primary light source and the Stokes band of the secondary light source.

2. The system for auto-correcting temperature measurement in a system using a distributed fiber optic sensor of claim 1 wherein said primary light source has a wavelength of about 975 nanometers and said secondary light source has a wavelength of about 940 nanometers.

3. The system for auto-correcting temperature measurement in a system using a distributed fiber optic sensor of claim 1 wherein said primary light source has a wavelength of about 1500 nanometers and said secondary light source has a wavelength of about 1410 nanometers.

4. The system for auto-correcting temperature measurement in a system using a distributed fiber optic sensor of claim 1 wherein said primary light source has a wavelength of about 1550 nanometers and said secondary light source has a wavelength of about 1450 nanometers.

5. The system for auto-correcting temperature measurement in a system using a distributed fiber optic sensor of claim 1 wherein said primary light source has a wavelength of about 1030 nanometers and said secondary light source has a wavelength of about 990 nanometers.

6. The system for auto-correcting temperature measurement in a system using a distributed fiber optic sensor of claim 1 wherein the

notch filters are tunable by thermal or other means and may be tuned as closely as possible to the center wavelength of the Rayleigh wavelength of each light source.

7. A method of auto-correcting temperature measurement in a system using a fiber optic distributed sensor comprising:

   a. feeding a primary light source light pulse energy into a wave division multiplexer;
   b. feeding a secondary light source pulse energy into the wave division multiplexer to create a combined primary and secondary light source pulse energy;
   c. feeding the combined primary and secondary light source pulse energies into the distributed fiber optic sensor deployed into a region of interest;
   d. collecting back-scattered light energy from the distributed fiber optic sensor into the wave division multiplexer and separating the backscattered light energy into a Raman anti-Stokes wavelength of the primary light source and a Raman Stokes wavelength of the secondary light source; wherein the Raman anti-Stokes component will also include the Rayleigh wavelength of the backscattered secondary source and the Raman Stokes component will include the Rayleigh wavelength of the primary light source;
   e. feeding the Raman anti-Stokes wavelength of the primary light source through a notch filter that filters out the backscattered Rayleigh component of the secondary light source;
   f. feeding the Raman Stokes wavelength of the secondary light source through a notch filter that filters out the backscattered Rayleigh component of the primary light source;
   g. feeding the output of the two notch filters to two photo detectors to measure the signal intensities of backscattered

anti-Stokes signal of the primary light energy and the back-scattered Stokes signal of the secondary light energy; and

h. calculating a temperature using the backscattered anti-Stokes signal of the primary light energy and the back-scattered Stokes signal of the secondary light energy.

8. The method of auto-correcting temperature measurement in a system using a fiber optic distributed sensor of claim 7 wherein said primary light source has a wavelength of about 975 nanometers and said secondary light source has a wavelength of about 940 nanometers.

9. The method of auto-correcting temperature measurement in a system using a fiber optic distributed sensor of claim 7 wherein said primary light source has a wavelength of about 1500 nanometers and said secondary light source has a wavelength of about 1410 nanometers.

10. The method of auto-correcting temperature measurement in a system using a fiber optic distributed sensor of claim 7 wherein said primary light source has a wavelength of about 1550 nanometers and said secondary light source has a wavelength of about 1450 nanometers.

11. The method for auto-correcting temperature measurement in a system using a distributed fiber optic sensor of claim 7 wherein said primary light source has a wavelength of about 1030 nanometers and said secondary light source has a wavelength of about 990 nanometers.

12. The method for auto-correcting temperature measurement in a system using a distributed fiber optic sensor of claim 7 wherein the notch filters are tunable by thermal or other means and are tuned as closely as possible to the center wavelength of the Rayleigh wavelength of each light source.

13. The method of auto-correcting temperature measurement in a system using a fiber optic distributed sensor of claim 7 wherein said calculating step is performed without measuring or using differential attention profiles.

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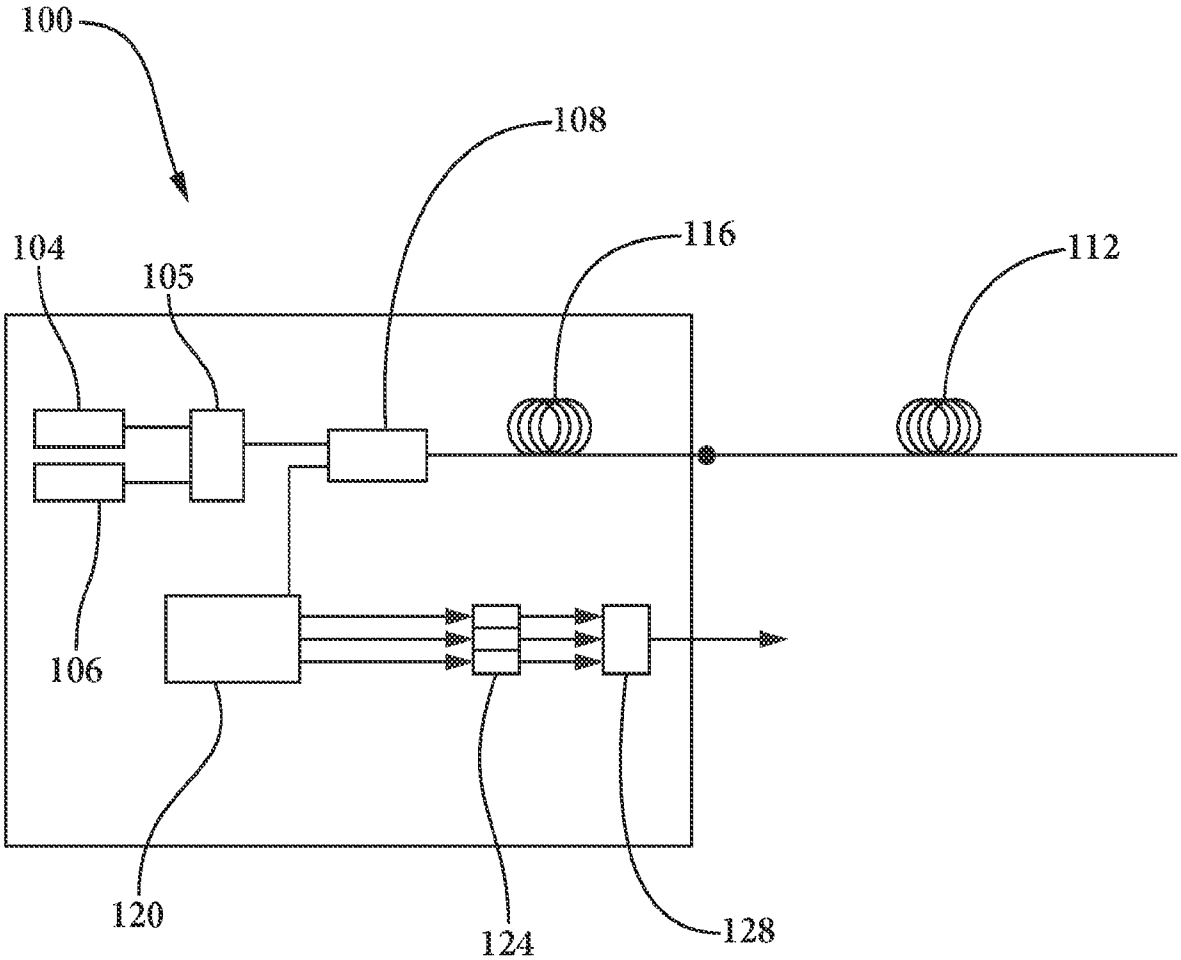


FIG 1

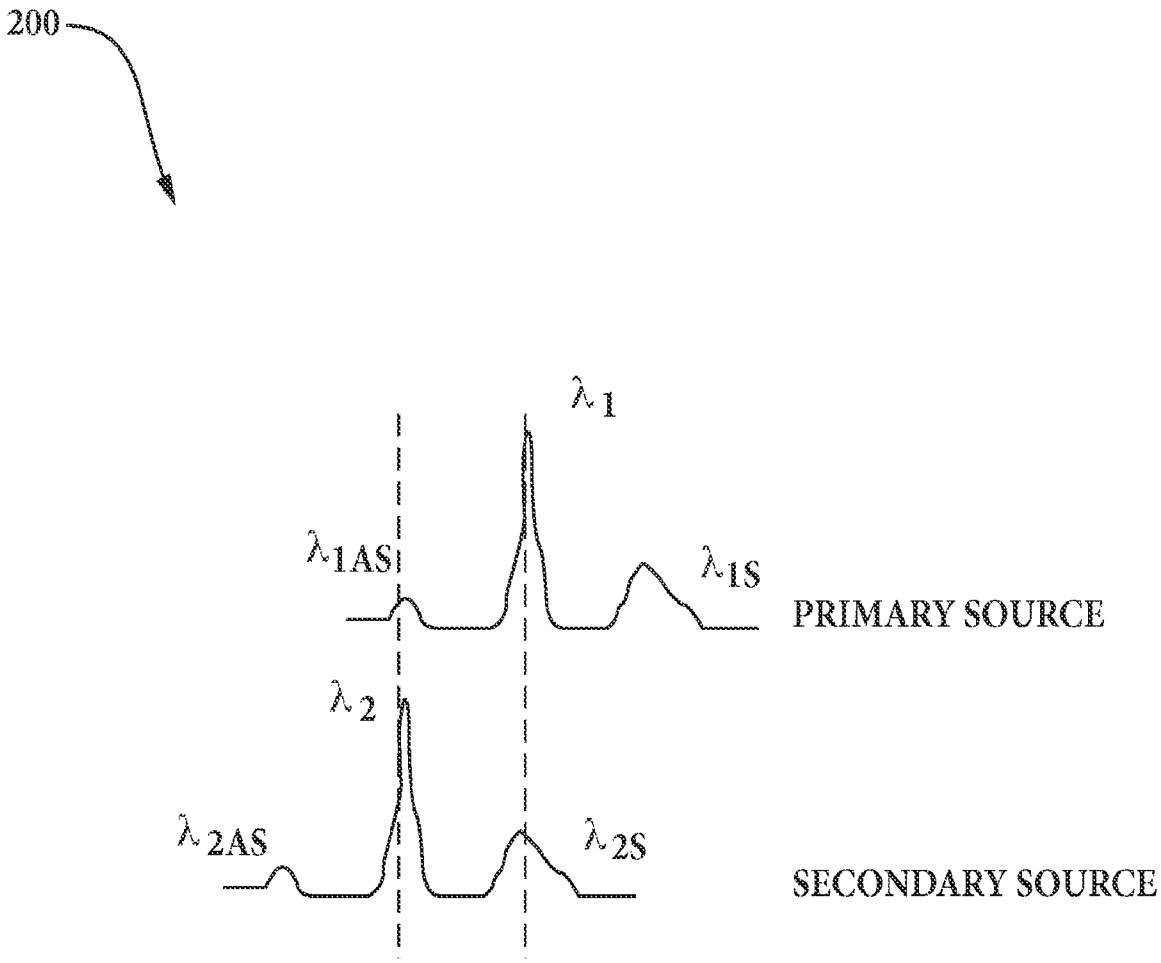


FIG 2

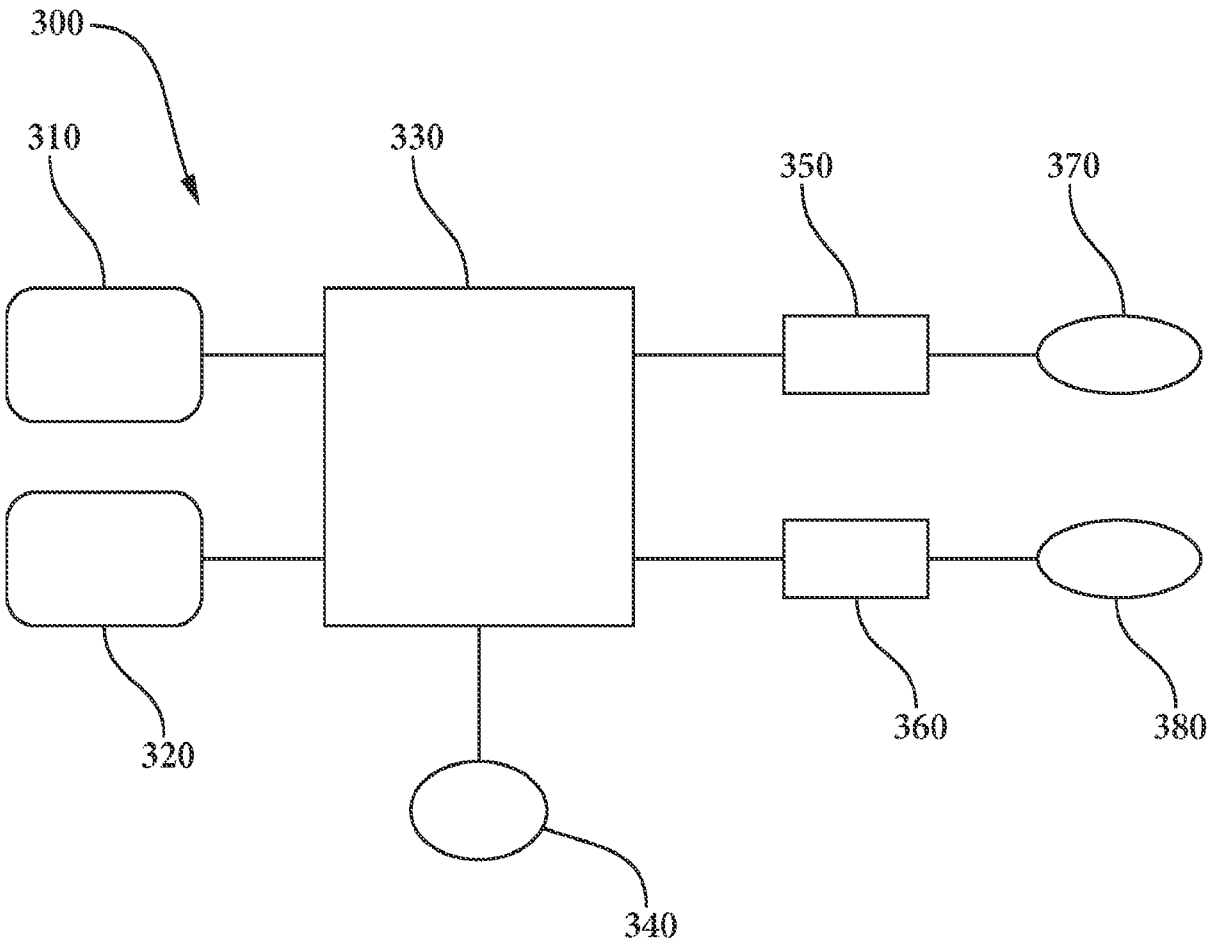


FIG 3

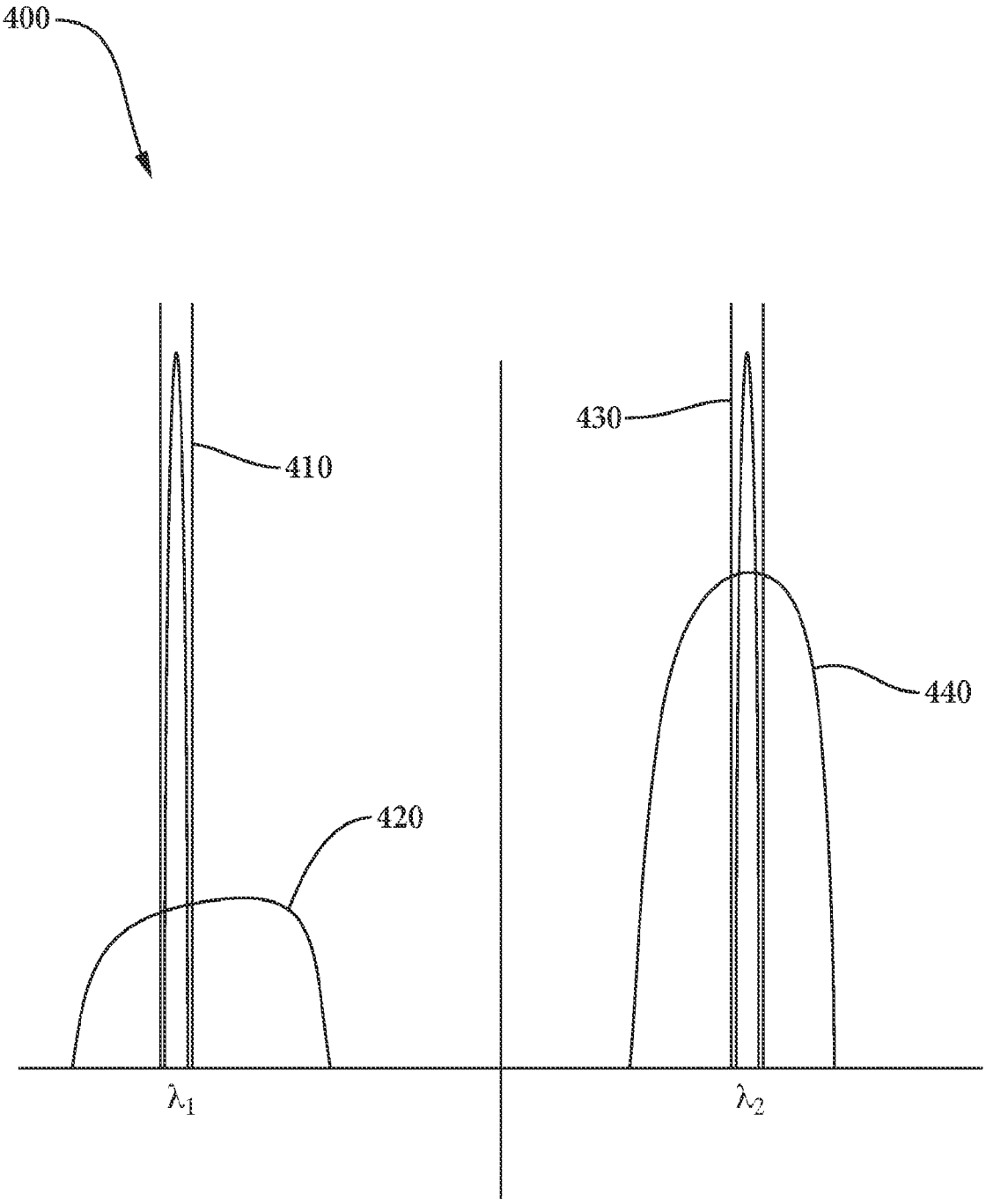


FIG 4

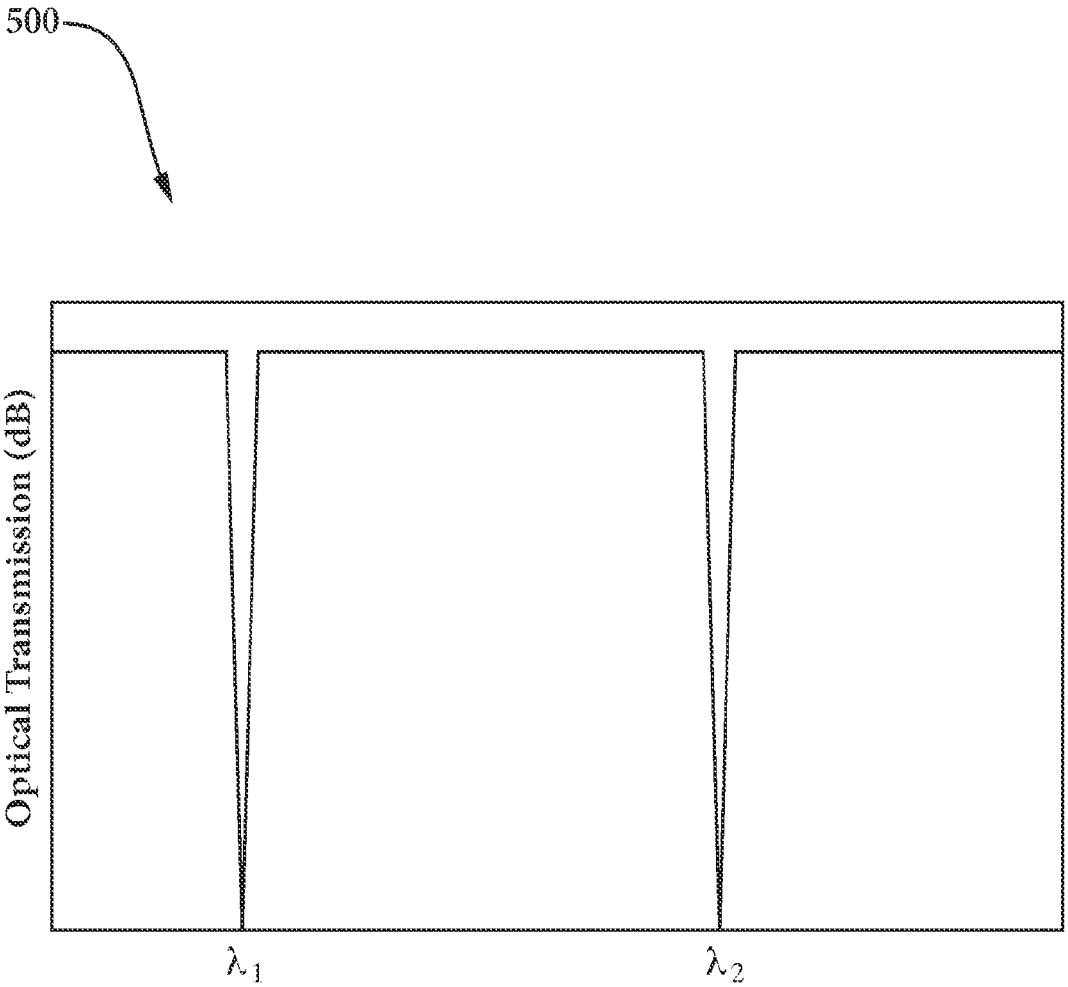


FIG 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/056079

A. CLASSIFICATION OF SUBJECT MATTER

G01K 11/32(2006.01)i, G01J 5/08(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)
G01K 11/32; G01K 15/00; G01K 1/16; G01K 11/00; G01J 5/08

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: anti-stokes, frequency, wavelength, fiber, temperature, rayleigh and raman

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010-0128756 A1 (LEE et al.) 27 May 2010 See abstract, paragraphs [0003]-[0005], [0024]-[0028], [0034], claims 1-4 and figures 2-5.	1-13
A	US 2009-0252193 A1 (HILL et al.) 08 October 2009 See abstract, paragraphs [0033]-[0042], claims 7-11 and figures 1-4.	1-13
A	US 2007-0223556 A1 (LEE et al.) 27 September 2007 See abstract, paragraphs [0037]-[0045], claims 7-10 and figures 1-6.	1-13
A	US 2007-0165691 A1 (TAVERNER et al.) 19 July 2007 See abstract, paragraphs [0032]-[0040], claims 10-15 and figures 3-7.	1-13
A	US 2006-0239330 A1 (YAMATE et al.) 26 October 2006 See abstract, paragraphs [0038]-[0045], claims 1-4 and figures 1-5.	1-13

☐ 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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Date of the actual completion of the international search	Date of mailing of the international search report
16 June 2015 (16.06.2015)	**16 June 2015 (16.06.2015)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/056079

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010-0128756 A1	27/05/2010	CA 2692804 A1	22/01/2009
		CN 101743460 A	16/06/2010
		CN 101743460 B	19/10/2011
		EP 2167928 A1	31/03/2010
		US 8496376 B2	30/07/2013
		WO 2009-011766 A1	22/01/2009
US 2009-0252193 A1	08/10/2009	CA 2661471 A1	07/10/2009
		CN 101556193 A	14/10/2009
		DE 102008017740 A1	15/10/2009
		EP 2108931 A2	14/10/2009
		EP 2108931 A3	17/10/2012
		US 8529123 B2	10/09/2013
US 2007-0223556 A1	27/09/2007	CA 2646312 A1	20/09/2007
		EP 1996911 A1	03/12/2008
		EP 2755004 A2	16/07/2014
		US 2008-0048103 A1	28/02/2008
		US 7628531 B2	08/12/2009
		US 7628533 B2	08/12/2009
		WO 2007-106827 A1	20/09/2007
		WO 2008-112023 A1	18/09/2008
US 2007-0165691 A1	19/07/2007	CA 2571772 A1	17/07/2007
		CA 2571772 C	14/06/2011
		GB 2434641 A	01/08/2007
		GB 2434641 B	13/07/2011
		US 7585107 B2	08/09/2009
US 2006-0239330 A1	26/10/2006	AU 2003-239285 A1	06/01/2004
		AU 2003-261080 A1	06/01/2004
		CA 2490107 A1	31/12/2003
		CA 2490107 C	16/02/2010
		CA 2490113 A1	31/12/2003
		CA 2490113 C	31/07/2007
		CA 2577160 A1	31/12/2003
		CA 2577160 C	11/10/2011
		GB 2406168 A	23/03/2005
		GB 2412432 A	28/09/2005
		GB 2412432 B	20/09/2006
		GB 2426331 A	22/11/2006
		GB 2426331 B	17/01/2007
		JP 2004-069685 A	04/03/2004
		NO 20040755 A	20/04/2004
		US 2003-0234921 A1	25/12/2003
		US 2003-0236626 A1	25/12/2003
		US 2005-0140966 A1	30/06/2005
		US 2006-0209291 A1	21/09/2006
		US 6751556 B2	15/06/2004

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/056079

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		US 7126680 B2	24/10/2006
		US 7215416 B2	08/05/2007
		WO 2004-001356 A2	31/12/2003
		WO 2004-001356 A3	01/07/2004
		WO 2004-001357 A1	31/12/2003