



(51) International Patent Classification:

G01V 8/02 (2006.01) G01K 11/32 (2006.01)
G01V 8/16 (2006.01) G01L 1/24 (2006.01)
G01V 8/24 (2006.01) G01B 9/02 (2006.01)
G01J 3/26 (2006.01) G01B 11/16 (2006.01)

(21) International Application Number:

PCT/US2014/072074

(22) International Filing Date:

23 December 2014 (23.12.2014)

(25) Filing Language:

English

(26) Publication Language:

English

(71) Applicant: HALLIBURTON ENERGY SERVICES, INC. [US/US]; 10200 Bellaire Blvd., Houston, TX 77072 (US).

(72) Inventors: WANG, Yunmiao; 9206 Sandtown Lane, Houston, TX 77064 (US). JAASKELAINEN, Mikko; 4011 Bell Hollow Lane, Katy, TX 77494 (US).

(74) Agent: ERVIN, Michael A.; 8202 Talbot Cove, Austin, TX 78746 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,

BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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

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))

(54) Title: METHODS TO CORRECT THE SPECTRUM DISTORTION OF FFPI SENSORS INDUCED BY DYNAMIC WAVELENGTH DEPENDENT ATTENUATION

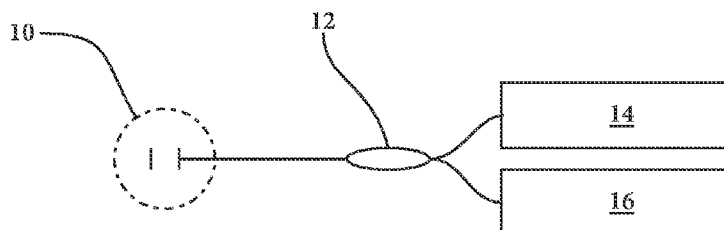


FIG 1

(57) Abstract: Methods are proposed for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells. The methods involve measurement techniques that correct the reflective spectrum from one or more FFPI sensors utilizing a background low frequency spectrum for normalization.

Title

Methods to correct the spectrum distortion of FFPI sensors induced by dynamic wavelength dependent attenuation

5

Background

This disclosure relates methods to compensate dynamic wavelength dependent attenuation induced signal distortion of fiber Fabry-Perot interferometric (FFPI) sensors. More particularly, it relates to using signal processing methods to calculate dynamic wavelength dependent attenuation and further compensate the signal of FFPI sensors. There are several mechanisms that can cause dynamic wavelength dependent attenuation on fibers such as hydrogen darkening, macro bending, water absorption and so on. In this disclosure, hydrogen darkening induced attenuation is used as an example to demonstrate the invented methods.

Fiber optic sensors are attractive for harsh environment applications due to their distinguished advantages including good high-temperature capability, corrosion resistance and electromagnetic insensitivity. Nowadays oil and gas application has increasingly adopted fiber optic sensors to monitor producing zones and take actions to optimize production. Fiber cables with a length from 1km to 10km are deployed in wells. These fiber cables can be sensing elements themselves for some applications like distributed temperature sensing (DTS), distributed acoustic sensing (DAS) and distributed strain sensing (DSS) or serve as waveguide to transmit the signal of some point sensors such as Fiber Bragg grating (FBG) based sensors and FFPI based sensors. It is known that hydrogen diffusion into optical fibers results in the attenuation of the light being transmitted, which is pervasive in oil and gas well environment. This attenuation degrades the sensing performance, so a lot effort has been taken to mitigate the hydrogen darkening by adjusting the dopants in

fibers [1,2] and optimizing the cables designs [3-5]. However all these methods only mitigate the hydrogen darkening but cannot intrinsically exclude the attenuation, especially for long deployment length (up to 10km) and/or high temperature (up to 300C) applications. As a result, it is
5 necessary to compensate the hydrogen darkening in the interrogation system. For example, dual-laser interrogation systems are used to compensate for hydrogen darkening in DTS applications.

There is a need then to compensate for the spectral distortion that occurs
10 in Fiber Fabry-Perot sensing systems due to hydrogen darkening.

Brief Description of the Drawings

5 Figure 1 illustrates an FFPI sensor interrogation system.

Figure 2 illustrates the reflective spectrum of an FFPI sensor.

Figure 3 illustrates an example induced transmission loss of a fiber.

10

Figure 4 illustrates the distorted reflective spectrum of an FFPI sensor with attenuation induced by hydrogen.

15 Figure 5 illustrates a Fourier-transformation of the distorted reflective spectrum of an FFPI sensor.

20 Figure 6 illustrates the signal of Figure 3 after passing through a low-pass filter.

20

Figure 7 illustrates a normalized spectrum of Figure 4.

25 Figure 8 illustrates the interpolated curves from an embodiment of this disclosure.

30 Figure 9 illustrates a calculated background signal from an embodiment of this disclosure.

30

Figure 10 illustrates the normalized spectrum of an FFPI sensor.

35

Detailed Description

5 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
10 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
15 defined only by the final claims.

Many Fiber-Optic Fabry-Perot Interferometer (FFPI) sensors have been proposed to measure variables such as temperature, pressure, strain and acoustic signals. In general, an FFPI sensor consists of two reflective
20 surfaces and the reflective light from these two surfaces interfere with each other. The interference signal is being guided by a fiber and monitored to demodulate the cavity change, which corresponds to the environmental change.

25 Figure 1 illustrates a typical FFPI sensor interrogation system, which includes a Fabry-Perot sensor **10** including a light source **14**, a coupler **12** and a spectrometer **16**. The light source **14** is fed through coupler **12** through a fiber optic cable into a region of interest in a subsurface well and is fed to one or more FFPI sensors **10**. The reflective spectrum from the
30 sensors then returns via coupler **12** and to spectrometer **16** for analysis.

The light source may be a white light source or a swept laser and this disclosure anticipates either could be used.

Figure 2 illustrates a typical reflective spectrum **20** of an FFPI sensor in wavenumber domain without distortion induced by dynamic wavelength dependent attenuation.

The electric field of the reflective light can be expressed as

$$10 \quad \mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 = \eta_1 \mathbf{R}_1 \mathbf{E}_0 + \eta_2 \mathbf{R}_2 \mathbf{E}_0 \exp(j(kL + \phi)) \quad (1)$$

where $\mathbf{E}_0$ is the electric field of the incident light, $\mathbf{R}_1$ and $\mathbf{R}_2$ are the reflective coefficients at two surfaces, $\mathbf{k}$ is the wavenumber, $\mathbf{L}$ is the optical path difference between the two reflective surfaces, η_1 and η_2 are the coefficients of coupling efficiency of the light reflected into the guided fiber and ϕ is the initial phase. The intensity of the reflected light can be given as

$$20 \quad I(k) = |E|^2 = |E_0|^2 [\eta_1^2 R_1^2 + \eta_2^2 R_2^2 + 2\eta_1 \eta_2 R_1 R_2 \cos(kL + \phi)] = I_0 [A + B \cos(kL + \phi)] \quad (2)$$

where I_0 is the intensity of the incident light. A and B are two constants and given as

$$25 \quad A = \eta_1^2 R_1^2 + \eta_2^2 R_2^2 \quad (3)$$

$$B = 2\eta_1 \eta_2 R_1 R_2 \quad (4)$$

30 When an FFPI sensor is deployed in a well with several kilometer fibers, the attenuation induced by hydrogen should be considered. Assuming

$\alpha(k, t)$ is the round-trip attenuation coefficient because of hydrogen in wavenumber domain, the intensity of the reflected light becomes

$$I(k, t) = I_0 \alpha(k, t) [A + B \cos(kL + \phi)] \quad (5)$$

5

The attenuation coefficient $\alpha(k, t)$ is a dynamic variable and is proportional to the molecular concentration of hydrogen in the silica fiber, temperature, fiber length and deployment time. The attenuation is also wavelength dependent. Figure 3 shows the hydrogen induced transmission loss **30** of the fiber prepared as described by Kuwazuru, et al. [Journal of Lightwave Technology, Vol.6, No.2, February 1988], and it is displayed in wavenumber domain corresponding to wavelength range from 1450nm to 1660nm. The spectrum of an FFPI sensor such as the one shown in Figure 2 can be distorted by changes in back ground fiber attenuation because of hydrogen. Figure 4 shows the spectrum **40** of the same FFPI sensor given in Figure 2 but with the attenuation described in Figure 3 applied to it. Since the attenuation changes dynamically with the change of environment, the distorted reflective spectrum changes accordingly. Many published FFPI sensor demodulation methods cannot be applied due to this dynamic distortion. The two methods to be described in this disclosure dynamically calculate the hydrogen induced attenuation and further compensate the spectrum of FFPI sensor.

10

15

20

Embodiment 1

25

In one embodiment a method can be developed as follows. Based on equation 5, the intensity of the reflected light can be expressed as

$$I(k, t) = I_0 \alpha(k, t) [A + B \cos(kL + \phi)] = I_1 + I_2 = I_0 A \alpha(k, t) + I_0 B \alpha(k, t) \cos(kL + \phi)$$

30

(6)

Since the attenuation $\alpha(k, t)$ changes slowly with wavenumber, the spectrum can be considered to contain a background signal $I_1 = I_0 A \alpha(k, t)$ and an amplitude-modulated (AM) signal $I_2 = I_0 B \alpha(k, t) \cos(kL + \phi)$ with a carrier of frequency L in the wavenumber domain. Figure 5 shows the discrete Fourier-transformation result of the spectrum described in equation (6), which is also given in Figure 4. The background signal I_1 falls into the low-frequency region 50 with a spectral range S . The AM signal I_2 , shifts the spectrum of $I_0 B \alpha(k, t)$ to frequency 52, designated as L . If L is selected to be $L > 2S$ during the sensor fabrication, the spectra of I_1 and I_2 will not overlap. A lowpass filter can then be used to select the background signal I_1 . The lowpass filter should be carefully designed to ensure no distortion is introduced to the signal. After filtering with this filter, the analytical signal can be written as

$$I'_1(k, t) = I_0 A' \alpha(k, t) \quad (7)$$

where A' is the amplitude coefficient after filtering. Figure 6 shows the result after a lowpass filter is applied on the distorted spectrum. Assuming the power fluctuation of the light source is negligible compared with the attenuation change, the filtered signal $I'_1(k, t)$ changes with the change of attenuation $\alpha(k, t)$. Before the fiber cable is deployed in the well, there is no attenuation induced by hydrogen $\alpha_{t=0}(k)=1$. The filtered signal at $t=0$ can be used as a reference, the dynamic hydrogen induced attenuation can be calculated as

$$\alpha(k, t) = \frac{I'_1(t, k)}{I'_1(t=0, k)} = \frac{I_0 A' \alpha(k, t)}{I_0 A'} \quad (8)$$

Dividing the filtered signal can normalize the distorted spectrum:

$$I_{nor}(k, t) = \frac{I(k, t)}{I_1'(k, t)} = \frac{A}{A'} + \frac{B}{A'} \cos(kL + \phi) \quad (9)$$

After the normalization, the distortion induced by the attenuation $\alpha(k, t)$ is compensated out. The developed FFPI demodulation methods can be used to calculate the cavity length. Figure 7 shows the normalized spectrum **70** of an FFPI sensor based on this first method despite the severe hydrogen induced transmission loss exhibited earlier in Figure 3.

By comparing the filtered reflective spectrum acquired before and after installation of the one or more FFPI sensors the wavelength dependent loss of the cable can be estimated.

Embodiment 2

Based on equation 5, the peak locations of the spectrum in wavenumber domain meet

$$I(k_{pi}, t) = I_0 \alpha(k_{pi}, t) [A + B], i = 1 \dots N \quad (10)$$

The valley locations of the spectrum in the wavenumber domain meet

$$I(k_{vj}, t) = I_0 \alpha(k_{vj}, t) [A - B], j = 1 \dots M \quad (11)$$

Where i is the index of peak, N is the total number of peaks in the spectrum, j is the index of valley, M is the total number of valleys in the spectrum. With proper interpolation on the peak locations, we can obtain

$$I_p(k, t) = I_0 \alpha(k, t) (A + B), k_{1p} < k < k_{pN} \quad (12)$$

With proper interpolation on the valley locations, we can obtain

$$I_v(k, t) = I_0 \alpha(k, t) (A - B), k_{1v} < k < k_{vM} \quad (13)$$

Figure 8 shows the interpolated curves $I_p(k, t)$ and $I_v(k, t)$. Based on
 5 equation (12) and (13), we can obtain

$$I_1(k, t) = \frac{I_p(k, t) + I_v(k, t)}{2} = I_0 A \alpha(k, t), \max(k_{1p}, k_{1v}) < k < \min(k_{pN}, k_{vM}) \quad (14)$$

10 This is the background signal as described in equation (6). Figure 9 shows the calculated background signal $I_1(k, t)$ 90. The wavenumber range of this calculated background signal is narrower than the original spectrum, which is determined by the first peak/valley locations and last peak/valley locations. Curve-fitting and other signal processing techniques can then be
 15 used to smooth the interpolated curves $I_p(k, t)$ and $I_v(k, t)$ and further to increase the calculation accuracy of background signal $I_1(k, t)$.

Assuming the power fluctuation of the light source is negligible compared with the attenuation change, the background signal $I_1(k, t)$ changes with
 20 the change of attenuation $\alpha(k, t)$. Before the fiber cable is deployed in the well, there is no attenuation induced by hydrogen $\alpha_{t=0}(k)=1$. The background signal at $t=0$ can be used as a reference, the dynamic hydrogen induced attenuation can be calculated as

$$25 \quad \alpha(k, t) = \frac{I_1(k, t)}{I_1(t=0, k)} = \frac{I_0 A \alpha(k, t)}{I_0 A}, \max(k_{1p}, k_{1v}) < k < \min(k_{pN}, k_{vM}) \quad (15)$$

The distorted spectrum can be normalized by dividing the background signal:

$$I_{nor}(k, t) = \frac{I(k, t)}{I_1(k, t)} = 1 + \frac{B}{A} \cos(kL + \phi), \max(k_{1p}, k_{1v}) < k < \min(k_{pN}, k_{vM})$$

(16)

After the normalization, the distortion induced by the attenuation $\alpha(k, t)$ is compensated out. The developed FFPI demodulation methods can be used to calculate the cavity length. Figure 10 shows the normalized spectrum **100** of an EFPI sensor. However the normalized spectrum has a narrower wavenumber range than the original spectrum, which is limited by the first peak/valley locations and last peak/valley locations.

10

With above two embodiments, we can compensate the spectrum distortion of FFPI sensors caused by the attenuation induced by hydrogen. At the same time, it provides solutions to dynamically monitor the attenuation induced by hydrogen, which can be used to compensate other fiber optics sensors deployed in the same well.

15

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.

20

25

30

Claims

5

1. A method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells comprising:
 - a. installing one or more FFPI sensors into a region of interest
 - 10 in a subsurface well;
 - b. feeding a light source through a fiber optic cable into the one or more FFPI sensors;
 - c. returning an original reflective spectrum from the one or more FFPI sensors to a spectrometer for analysis;
 - 15 d. filtering the original reflective spectrum through a low-pass filter;
 - e. dividing the original filtered reflective spectrum by a filtered reflected spectrum obtained from the one or more FFPI sensors before installation into the region of interest in the
 - 20 subsurface well to obtain a normalized spectrum;
 - f. using the normalized spectrum to calculate changes in cavity length.
2. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength
- 25 dependent attenuation in subsurface wells of claim 1 wherein the light source is a white light source.
3. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells of claim 1 wherein the
- 30 light source is a swept laser.

4. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells of claim 1 further comprising comparing the filtered reflective spectrum acquired before and after installation of the one or more FFPI sensors to estimate the wavelength dependent loss of the cable.
5. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells of claim 1 further comprising performing a discrete Fourier-transformation on the reflective spectrum acquired before installation of the one or more FFPI sensors to divide the signal into a low frequency region representing a background signal and a higher frequency region representing an amplitude modulated signal.
6. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells of claim 5 wherein the low-pass filter is chosen to select the lower frequency background signal.
7. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells of claim 1 wherein the FFPI sensors are used to measure temperature changes.
8. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells of claim 1 wherein the FFPI sensors are used to measure pressure changes.
9. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells of claim 1 wherein the FFPI sensors are used to measure strain effects.

10. A method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells comprising:
- a. installing one or more FFPI sensors into a region of interest in a subsurface well;
 - b. feeding a light source through a fiber optic cable into the one or more FFPI sensors;
 - c. returning an original reflective spectrum from the one or more FFPI sensors to a spectrometer for analysis;
 - d. interpolate a curve of the peaks in the reflective spectrum;
 - e. interpolate a curve of the valleys in the reflective spectrum;
 - f. average the curves of the peaks and the valleys to determine an average background signal curve for the reflected signal;
 - g. dividing the original filtered reflective spectrum by the average background signal curve for the reflected signal well to obtain a normalized spectrum;
 - h. using the normalized spectrum to calculate changes in cavity length.
11. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells of claim 10 wherein the light source is a white light source.
12. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells of claim 10 wherein the light source is a swept laser.
13. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength dependent attenuation in subsurface wells of claim 10 wherein the FFPI sensors are used to measure temperature changes.
14. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength

dependent attenuation in subsurface wells of claim 10 wherein the FFPI sensors are used to measure pressure changes.

15. The method for compensation of distortion in fiber Fabry-Perot interferometric (FFPI) sensors induced by dynamic wavelength
5 dependent attenuation in subsurface wells of claim 10 wherein the FFPI sensors are used to measure strain effects.

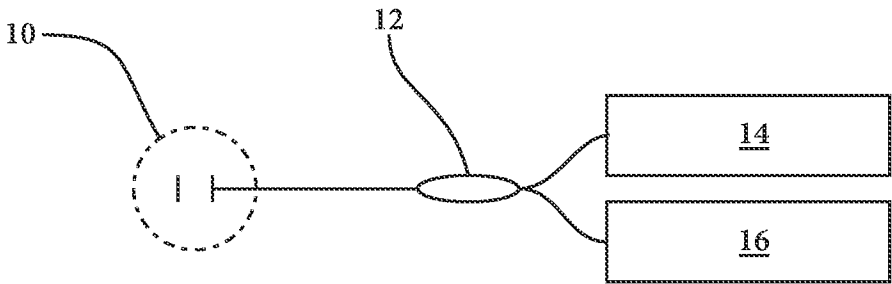
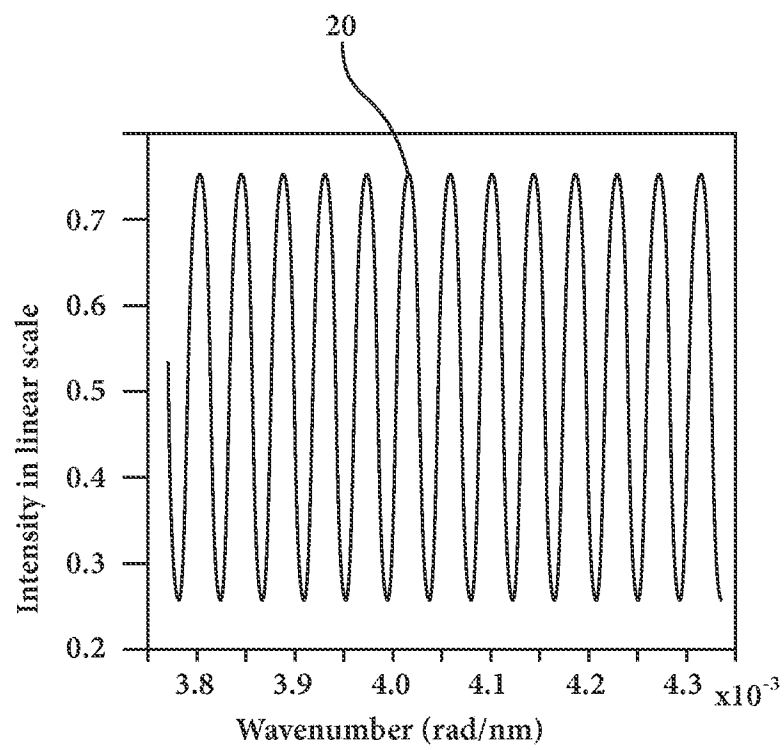


FIG 1

2 of 10**FIG 2**

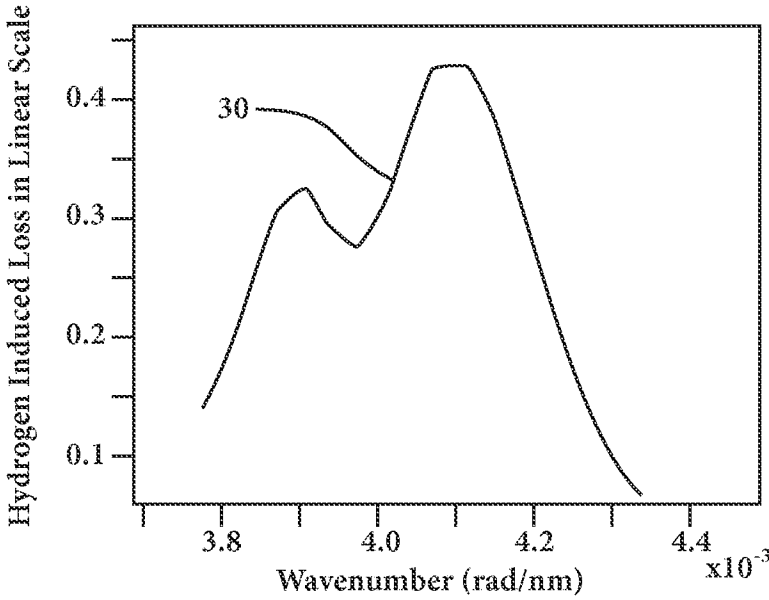
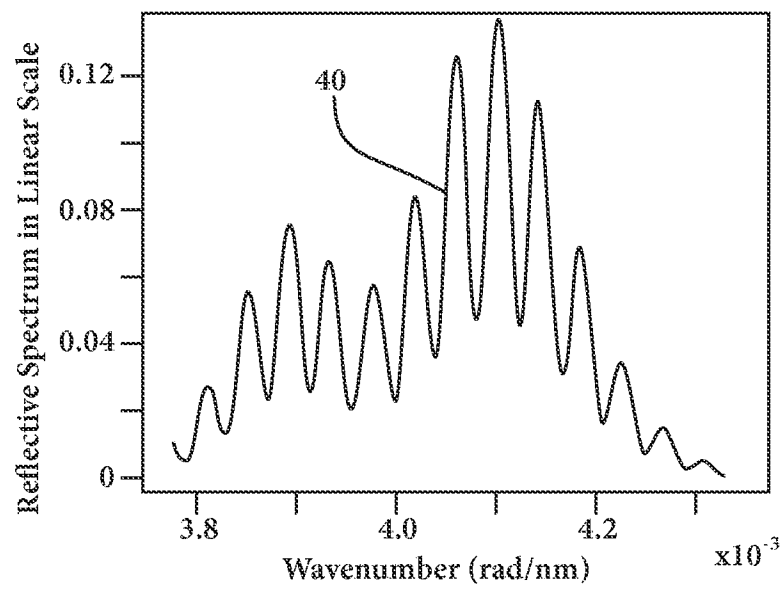
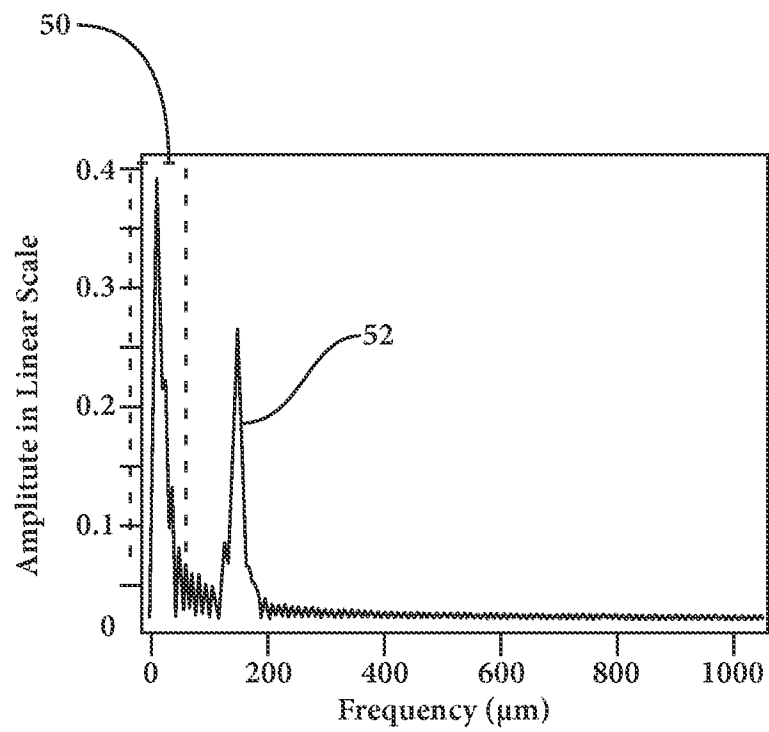


FIG 3

4 of 10**FIG 4**

5 of 10**FIG 5**

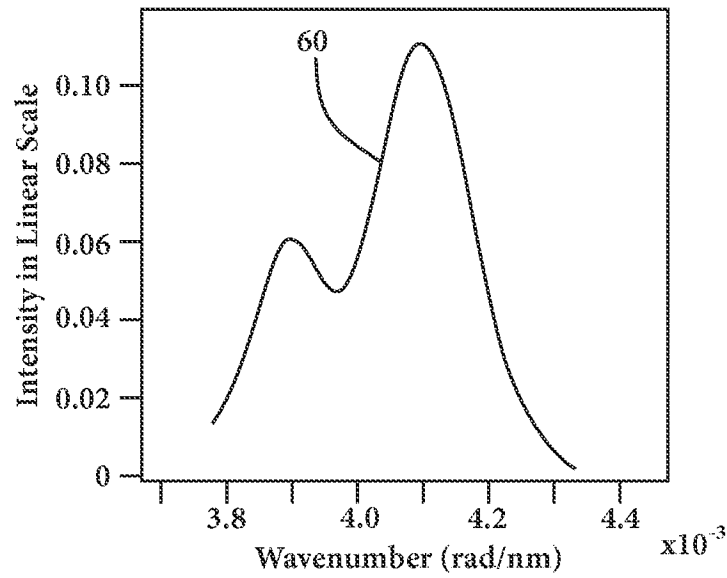
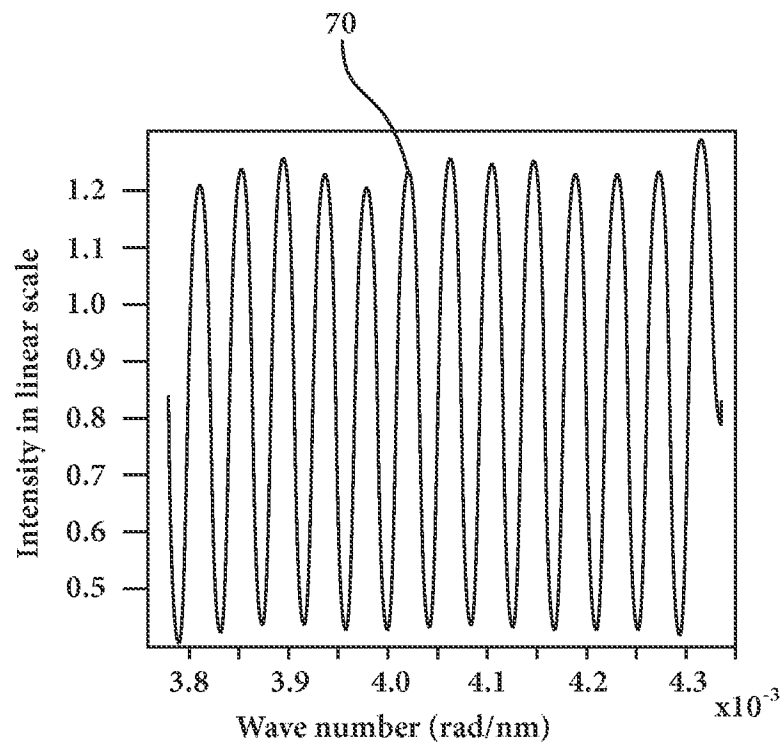


FIG 6

7 of 10**FIG 7**

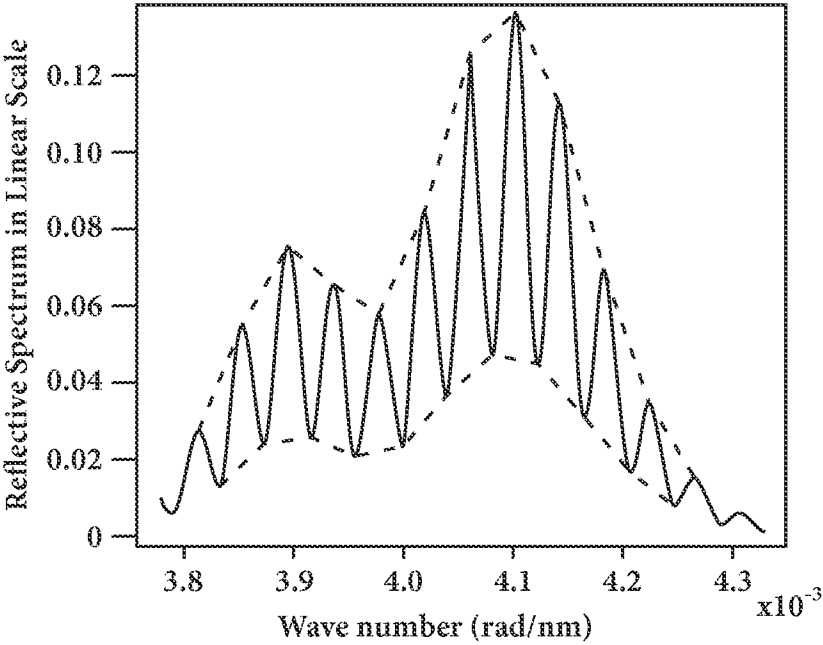


FIG 8

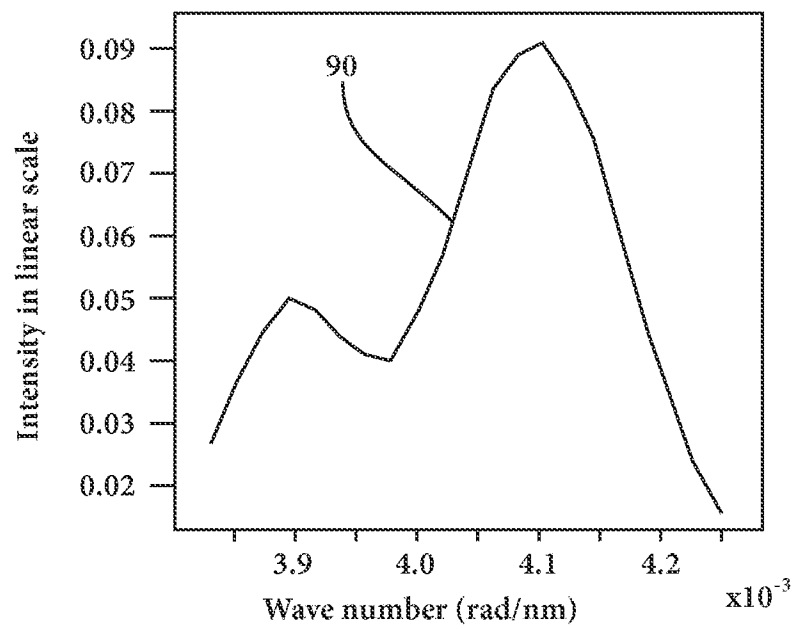
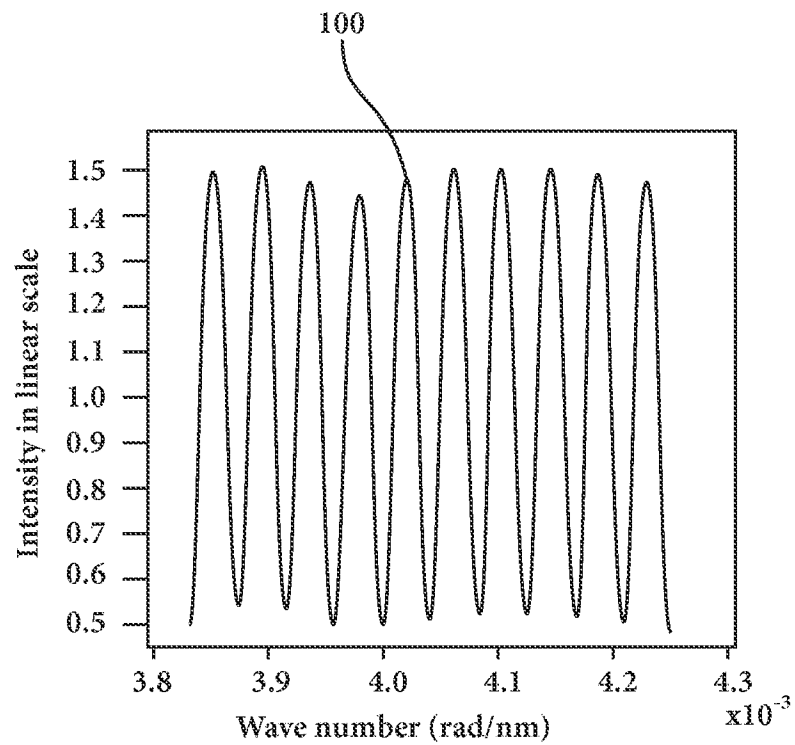


FIG 9

10 of 10*FIG 10*

A. CLASSIFICATION OF SUBJECT MATTER

G01V 8/02(2006.01)i, G01V 8/16(2006.01)i, G01V 8/24(2006.01)i, G01J 3/26(2006.01)i, G01K 11/32(2006.01)i, G01L 1/24(2006.01)i, G01B 9/02(2006.01)i, G01B 11/16(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)

G01V 8/02; G01D 5/353; G01N 21/41; G01N 21/00; G01D 5/26; G01B 11/00; G01B 9/02; G01P 15/093; G01V 8/16; G01V 8/24; G01J 3/26; G01K 11/32; G01L 1/24; G01B 11/16

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: sensor, Fabry-Perot interferometric, light source, fiber optic cable, spectrometer, normalized spectrum, filter

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005-0099618 A1 (DIFOGGIO et al.) 12 May 2005 See paragraphs [0057]-[0060], claims 10, 19, 28, and figures 1-5.	1-15
A	US 2005-0046862 A1 (MELNYK, IVAN) 03 March 2005 See paragraphs [0035]-[0037], claims 1-11, and figure 1.	1-15
A	CN 101509789 A (ZHEJIANG UNIVERSITY) 19 August 2009 See abstract, claims 1, 2, and figure 2.	1-15
A	WO 2013-166407 A1 (US SEISMIC SYSTEMS, INC.) 07 November 2013 See abstract, claims 1-17, and figure 1.	1-15
A	WO 2014-179073 A1 (HALLIBURTON ENERGY SERVICES, INC.) 06 November 2014 See claims 1-16 and figures 1, 2, 7.	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 August 2015 (24.08.2015)

Date of mailing of the international search report

25 August 2015 (25.08.2015)

Name and mailing address of the ISA/KR

 International Application Division
Korean Intellectual Property Office
189 Cheongsu-ro, Seo-gu, Daejeon Metropolitan City, 302-701,
Republic of Korea

Facsimile No. +82-42-472-7140

Authorized officer

KIM, Jin Ho

Telephone No. +82-42-481-8699



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/072074

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005-0099618 A1	12/05/2005	CA 2643154 A1 CN 101427114 A EP 1987345 A2 US 2006-0139646 A1 US 2007-0013911 A1 US 7362422 B2 US 7408645 B2 US 7511819 B2 WO 2005-047647 A1 WO 2007-100564 A2 WO 2007-100564 A3	07/09/2007 06/05/2009 05/11/2008 29/06/2006 18/01/2007 22/04/2008 05/08/2008 31/03/2009 26/05/2005 07/09/2007 24/12/2008
US 2005-0046862 A1	03/03/2005	US 7099015 B2	29/08/2006
CN 101509789 A	19/08/2009	None	
WO 2013-166407 A1	07/11/2013	CA 2880396 A1 CN 104541151 A GB 201421587 D0 GB 2517859 A NO 20141469 A US 2015-0086206 A1	07/11/2013 22/04/2015 21/01/2015 04/03/2015 04/12/2014 26/03/2015
WO 2014-179073 A1	06/11/2014	US 2014-0326860 A1	06/11/2014