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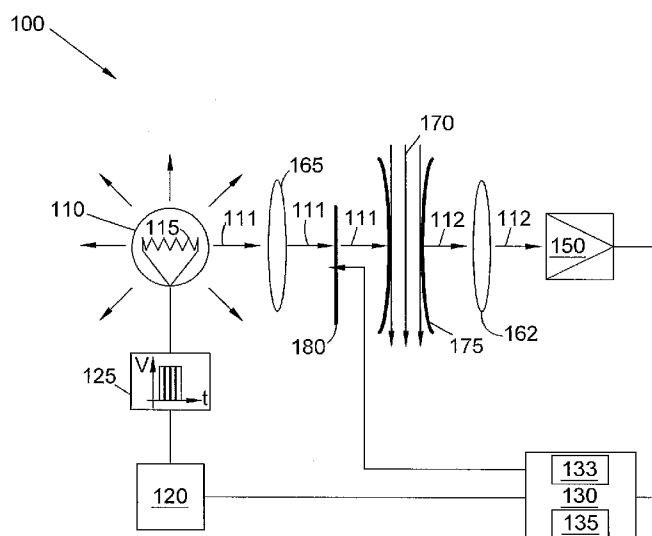
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(54) Title: PULSE WIDTH MODULATION OF CONTINUUM SOURCES FOR DETERMINATION OF CHEMICAL COMPOSITION

FIG. 1



(57) Abstract: A light source and a method for its use in an optical sensor are provided, the light source including a resistively heated element. The light source includes a power circuit configured to provide a pulse width modulated voltage to the resistively heated element, the pulse width modulated voltage including: a duty cycle with a first voltage; and a pulse period including a period with a second voltage, wherein: the duty cycle, the first voltage, and the pulse period are selected so that the resistively heated element is heated to a first temperature; and the first temperature is selected to emit black body radiation in a continuum spectral range. Also provided is an optical sensor for determining a chemical composition including a light source as above.



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5 Pulse Width Modulation of Continuum Sources for Determination of Chemical Composition

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Background

1.- Technical Field

[0001] Embodiments disclosed herein relate to the field of optical sensors. More particularly, embodiments disclosed herein are related to the field of
15 modulated sources for optical sensors to measure the chemical composition in fluids.

2.- Description of Related Art

20 [0002] Optical sensors typically use a light source to provide the excitation of atoms or molecules for prediction or detection of chemical constituents contained in the liquid, solid, or gases under examination. The light source is provided as part of the system or sensor used to study these materials and generally cover a portion, or portions, of the electromagnetic spectral region
25 from the ultraviolet (UV) to the far infrared (FIR). Different types of light sources used may provide a continuum emission, line emission, and continuum plus line and quasi-continuum emission, according to the spectral distribution of the light provided. Examples of these types of sources are incandescent lamps, hollow cathode discharge lamps, xenon-mercury arc lamps, light emitting diodes
30 (LEDs) and lasers, respectively.

[0003] Typically, continuum sources like tungsten lamps are operated at a fixed, continuous voltage, or current. In typical systems, the detected signal is derived from modulating the light beam with the use of an optical chopper or
35 similar device. Light beam modulation improves the measurements made with these devices by moving the detected signal from a direct current (DC) domain to the alternating current (AC) domain, improving signal drift over time.

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[0004] An alternative approach is to utilize modulation of the light source itself, without the use of external elements such as optical choppers or modulators. Current systems that modulate light sources typically include semiconductor light sources. In some applications, a modulated current is applied to a semiconductor light source having an emitter. The current modulation produces a temperature modulation in a gain region of the emitter, thus changing the emitted center wavelength. This method has been used to measure properties of a downhole fluid in oil exploration and extraction applications. However, light source modulation methods such as used in state-of-the-art applications include light sources providing a limited bandwidth such as lasers and semiconductor light sources, typically emitting light within a narrow wavelength band.

[0005] What is needed is an optical source and a method for using the optical source providing measurement stability and high signal-to-noise (SNR) ratio in a broad spectral band, to determine the chemical composition of fluids including hydrocarbons (e.g., crude oils, natural gas, or the like) and/or other fluids present in a downhole environment.

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Brief Summary

[0006] A light source for use in an optical sensor according to some embodiments may include a resistively heated element; and a power circuit configured to provide a pulse width modulated voltage to the resistively heated element, the pulse width modulated voltage including: a duty cycle with a first voltage; and a pulse period including a period with a second voltage, wherein: the duty cycle, the first voltage, and the pulse period are selected so that the resistively heated element is heated to a first temperature; and the first temperature is selected to emit black body radiation in a continuum spectral range.

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[0007] According to some embodiments an optical sensor for determining a chemical composition of a sample may include: a light source including a

5 resistively heated element; a power circuit configured to provide a pulse width modulated voltage signal to the resistively heated element; an optical delivery system to direct an illumination light to a sample; a sample cavity containing the sample and configured to receive the illumination light; an optical collection system to collect a sample light from the sample; and a detector synchronized
10 to the pulse width modulated voltage signal, the detector configured to measure the sample light from the optical collection system.

[0008] According to embodiments disclosed herein a method of determining a chemical composition of a sample using an optical sensor may include:
15 generating an illumination light using a pulse width modulated voltage; collecting a sample light; measuring the sample light with a detector; and determining a chemical component in the sample; wherein the pulse width modulated voltage includes a plurality of pulses having a first frequency, and a duty cycle.

20 **[0009]** These and other embodiments will be described in further detail below, with reference to the following drawings.

Brief Description of the Drawings

25 **[00010]** FIG. 1 shows an optical sensor including a modulated optical source, according to some embodiments.

[00011] FIG. 2 shows a chart including a pulse modulated signal provided to
30 an optical source, according to some embodiments.

[00012] FIG. 3A shows a chart including non-normalized spectral radiance curves at two different temperatures.

35 **[00013]** FIG. 3B shows a differential spectrum response from an optical source, according to some embodiments.

5 **[00014]** FIG. 4 shows an optical sensor including a modulated optical source and an integrated computational element (ICE), according to some embodiments.

10 **[00015]** FIG. 5 shows a flow chart for a method to determine chemical composition of a sample using an optical sensor, according to some embodiments.

15 **[00016]** FIG. 6 shows an optical sensor using a modulated optical source in a wireline logging application, according to some embodiments.

20 **[00017]** FIG. 7 shows a drill bore including a sensor using a modulated optical source in a logging-while-drilling (LWD) application, according to some embodiments.

25 **[00018]** Wherever possible, the same reference numbers are used throughout the drawings to refer to the same or like elements.

Detailed Description

30 **[00019]** Optical sensors consistent with this disclosure are used to determine the chemical composition of a sample of interest. Embodiments of an optical sensor as described herein include a high frequency pulsed-width modulation of a continuum source, to improve sensor performance. For determination of the chemical composition of a sample, use of a continuum light source having a broad spectral band is desirable. A broad spectral band may include visible (VIS) wavelengths from close to the UV region (380-400 nm to about 750 nm), to the near infrared region (NIR, from 750 nm to about 2500 nm), and the mid-infrared region (MIR, from about 2500 nm up to 10 μ m and beyond).

35 **[00020]** Many chemical substances have characteristic optical responses across these three spectral regions (UV-VIS, NIR, and MIR). An optical response from a chemical substance may be obtained by scattering phenomena such as Raman, Brillouin, or Rayleigh scattering, absorption

5 phenomena such as VIS or NIR absorption, or an absorption/emission phenomenon such as fluorescence. Using a broad band light source allows the measurement of many different chemical components, even when they are combined in the same sample. Furthermore, use of a broad band light source may enable the combination of a plurality of phenomena for measurements in
10 different spectral regions. For example, fluorescence spectroscopy may be used in the VIS, Raman spectroscopy may be used in the NIR, and absorption spectroscopy may be used in the MIR. Thus, according to some embodiments, all the above measurement techniques may be applied using the same broadband light source.

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[00021] Some embodiments of optical sensors as disclosed herein provide a pulse width modulation to a voltage signal, i.e. a pulse width modulated voltage, generating a current in an electrically resistive element of a continuum light source. The pulse width modulation may be provided at a relatively high
20 frequency of several kilo-Hertz (kHz), such as 10 kHz, or more. A continuum light source using a resistive element may be a tungsten filament lamp. In addition to a high frequency modulation of the light source, some embodiments include a lower frequency modulation to the optical beam generated by the lamp. For example, a low frequency modulation may be obtained by using an
25 optical chopper placed in the optical path of a light beam from the lamp, producing a beam modulation of a few hundred Hz, or less.

[00022] FIG. 1 shows an optical sensor 100 including a modulated light source 110, according to some embodiments. Optical sensor 100 includes a
30 power circuit 120 providing a voltage signal 125 to light source 110. According to some embodiments, voltage signal 125 is a pulse width modulated voltage signal. Light source 110 provides an illumination light 111 upon receiving voltage signal 125. In some embodiments, light source 110 includes a resistively heated element 115. Resistively heated element 115 may be a
35 filament which, upon receiving voltage signal 125, allows a current flow that resistively heats filament 115 up to a temperature T_0 . The heated filament 115 has a black body emissivity, ϵ , desirably close to 1. In some embodiments,

5 filament 115 is made of an electrically conductive material such as tungsten, and has an emissivity between 0.03 and up to 0.35. The spectral band of the electromagnetic radiation emitted by filament 115 may be selected according to the Planck distribution for a black body at temperature T_0 . Thus, by selecting the temperature T_0 , a continuum spectral range including the VIS, NIR, and
10 MIR regions may be obtained at desired emission intensity.

[00023] Optical sensor 100 also includes an optical delivery system 165 to collect a portion of the radiation emitted by filament 115 in light source 110 and to form a collimated beam for delivery of illumination light 111 to a sample 170.
15 Sample 170 may be flowing continuously through a sample cavity 175, or may be extracted and stored within sample cavity 175. While the arrows in sample 170 indicate a flow, in some embodiments sample 170 may be stationary within an enclosed cavity 175. In some embodiments, sample cavity 175 may have at least one portion or window transparent to illumination light 111. Thus, sample
20 cavity 175 may include at least one portion or window transparent to wavelengths of interest for the measurement. An optical modulator 180 may be placed in the path of the collimated beam, before illumination light 111 interacts with sample 170. After illumination light 111 interacts with sample 170, optical collection system 162 collects a sample light 112. Optical collection system
25 162 provides sample light 112 to detector 150 which produces a signal. Optical sensor 100 may also include controller 130 having a processor circuit 133 and a memory circuit 135. Controller 130 performs signal processing, data analysis and data storage using the signal provided by detector 150, processing circuit 133, and memory circuit 135.

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[00024] In some embodiments, light source 110 in optical sensor 100 may be a tungsten light source. More generally, light source 110 may be a blackbody continuum source using an electrically resistive element emitting light in a broad spectral band. Light source 110 in optical sensor 100 using pulse width
35 modulated signal 125 may operate at an increased temperature relative to a light source operating at a constant voltage, since the stress induced by a high current in filament 115 is reduced by pulsed width modulated signal 125. An increased operation temperature is desirable to increase output intensity of an

5 optical source, according to Planck's law. Intensity increase at longer wavelengths is particularly desirable, since traditional sources have low intensity in the spectral region beyond 2000 nm. Because of the lower stress to filament 115 under pulse width modulated signal 125, light source 110 has an improved performance in terms of stability. Due to the increased optical
10 intensity at any given wavelength, light source 110 improves SNR in detector 150. Improved stability of light source 110 and higher SNR at detector 150 enhance accuracy and precision of a sample chemical composition determined by optical sensor 100.

15 **[00025]** In some embodiments the signal from detector 150 is demodulated in controller 130 at a frequency approximately equal to a sum or a difference frequency of the voltage modulation frequency provided to filament 115 (f_1) and the modulation frequency of the optical modulator, or second frequency f_2 . In cases where detector 150 is a cascaded voltage detector, the detector may be
20 synchronized to a combination frequency including a sum or a difference of the first frequency (f_1) and the second frequency (f_2).

[00026] In addition, embodiments of optical sensor 100 powered with a battery provide a longer battery lifetime, due to low current usage by pulse
25 width modulated signal 125. For measurement stations using optical sensor 100 in field applications, low current usage results in longer time on station and more measurements between battery charging and/or replacement.

[00027] FIG. 2 shows a chart 200 including pulse width modulated signal 125
30 provided to an optical source, according to some embodiments. The abscissa in chart 200 corresponds to time, the ordinate in the left hand axis is voltage, and the ordinate in the right hand axis is temperature. Chart 200 includes pulse width modulated signal 125, plotted in relation to the voltage axis (ordinate to the left), and a filament temperature curve 225 (ordinate to the right). According
35 to some embodiments, pulse width modulated signal 125 has a period 210 and a duty cycle 215. Duty cycle 215 includes the time during which lamp filament 115 is turned 'on' at a voltage $223 V_1$. Outside of duty cycle 215, filament 115

5 may be turned 'off' completely (0 voltage), or may be turned 'on' at a low voltage 221 (V_2).

[00028] Filament temperature curve 225 includes time segments 233 at a high temperature T_1 , and time segments 231 at a low temperature T_2 . Time segments 233 may overlap at least in part with duty cycle 215 of filament 115. Indeed, when filament 115 is operated at voltage 223 (V_1), a current resistively heats filament 115 to temperature T_1 . The heating process may include a small time delay, as thermal equilibrium is reached in filament 115. This time delay is shown in FIG. 2 as a small displacement of time segments 233 to the right relative to voltage pulses, along the abscissa. Likewise, time segments 231 approximately overlap with portions of signal 125 where voltage 221 applied to filament 115 is zero, or low. When the voltage applied to filament 115 is zero or low, no current or a very limited amount of current flows through filament 115. The result is a cooling of the filament down to temperature T_2 , as the resistive heating stops.

[00029] In some embodiments, voltage 223 (V_1) may be approximately 20 V, with a duty cycle 215 of approximately 1.5 μs and a period 210 of approximately 100 μs (switching frequency of 10 kHz). In such embodiments, time segments 233 (approximately 1.5 μs or less) may be much shorter than time segments 231 (approximately 98.5 μs). Thus, light source 110 may have enhanced lifetime and operational stability, since the maximum stress for filament 115 at time segments 233 is reduced and interleaved with limited or no stress at time segments 231.

[00030] Duty cycle 215, voltage 221, and pulse period 210 are selected so that filament 115 is heated to high temperature T_1 . Temperature T_1 is selected to emit black body radiation in a continuum spectral range. In some embodiments, it is desirable to obtain a broad continuum spectral band, including the VIS, NIR, and MIR regions up to about 5 μm or more, with high enough emission intensity. In such configurations, it is desirable that temperature T_1 be as high as several thousand degrees Kelvin (K). For

- 5 example, in some embodiments T_1 may reach about 2000 K, 3000 K, or up to about 5000 K. Further according to some embodiments, duty cycle 215, voltage 221, and pulse period 210 may be selected so that filament 115 reaches temperature T_2 . Temperature T_2 may be selected to emit blackbody radiation in a second continuum spectral range different from the continuum spectral range emitted by filament 115, at temperature T_1 . In some
10 embodiments, the continuum spectral range emitted at temperature T_1 and the second continuum spectral range emitted at temperature T_2 may be used in a differential spectrum configuration to enhance the SNR of the measurement.
- 15 **[00031]** In some embodiments, the signal from detector 150 is demodulated in controller 130 at a first frequency (f_1) approximately equal to the frequency of pulse width modulated signal 125. In some embodiments, the signal from detector 150 is synchronized in controller 130 with duty cycle 215 in pulse width modulated signal 125. Further according to some embodiments, detector 150
20 may be a cascaded voltage detector that is turned 'on' synchronously with pulse width modulated signal 125 provided to filament 115. In such embodiments, the SNR of the measurement is increased due to the filtering of low frequency and $1/f_1$ flicker noise, where f_1 is the modulation frequency (i.e., the frequency of the voltage pulses in pulse width modulated signal 125).
- 25 **[00032]** FIG. 3A shows a chart 300A including non-normalized spectral radiance curves 331A and 333A. The abscissa axis (X-axis) in FIG. 3A corresponds to wavelength in microns ($1 \text{ micron} = 1 \mu\text{m} = 10^{-6} \text{ m}$). The ordinate axis (Y-axis) in FIG. 3A is the spectral radiance in Watts per meter squared, per micron. Curve 331A is obtained at a low temperature $T_2 = 2000\text{K}$, and curve 333A is obtained at a high temperature $T_1 = 2100 \text{ K}$. The wavelength ranges for curves 331A and 333A are similar, but the overall radiance intensity (ordinate axis, or Y-axis) increases due to the temperature increase. Temperatures T_1 and T_2 in chart 300A are exemplary only and are not limiting of embodiments
30 consistent with the present disclosure. Accordingly, low temperature T_2 may be the filament temperature during a time segment 231, and high temperature T_1 may be the filament temperature during a time segment 233, as described in detail above (cf. FIG. 2). FIG. 3A illustrates data point 351 corresponding to a

- 5 maximal spectral radiance for curve 331A at a wavelength λ_1 . Likewise, data point 353 in curve 333A corresponds to a maximal spectral radiance for curve 333A, at a wavelength λ_2 .

[00033] FIG. 3B shows a differential spectrum response 300B, according to
10 some embodiments. Differential spectrum response 300B includes a first normalized response curve 331B at a low temperature T_2 , and a second normalized response curve 333B at a high temperature T_1 . Low temperature T_2 may be the filament temperature during one of the time segments 231, and high temperature T_1 may be the filament temperature during one of the time
15 segments 233, as described in detail above (cf. FIG. 2). The first normalized response curve 331B and the second normalized response curve 333B may reflect a spectral distribution of sample light 112 resulting from the interaction of illumination light 111 with sample 170. Response curves 331B and 333B may be normalized to the maximum value of a detector response to sample light 112
20 across the bandwidth of light source 110. The second response curve 333B at temperature T_1 has a signal 311 at wavelength λ_1 and signal 312 at wavelength λ_2 . The first response curve 331 at temperature T_2 has a signal 321 at wavelength λ_1 and signal 322 at wavelength λ_2 . Signal 311 has a response level A_1 and signal 312 has a response level A_2 . Signal 321 has a response
25 level B_1 and signal 322 has a response level B_2 . Response levels A_1 , A_2 , B_1 , and B_2 , may be related to signals obtained using a photodetector such as photodetector 150 (cf. FIG. 1).

[00034] Response curves 331B and 333B may represent detector signal
30 levels for a plurality of wavelengths within the bandwidth of light source 110. In some embodiments, response curves 331B and 333B may include Raman, Brillouin, Rayleigh, fluorescence, or absorption spectra from the sample. According to some embodiments, a plurality of response curves such as normalized curves 331 and 333 may be stored in memory circuit 135. For
35 example, a normalized response curve may be stored in memory circuit 135 for each of a chemical component that may be found in a sample. Furthermore, for each of the chemical components that may be found in a sample, a plurality of

- 5 normalized response curves may be stored in memory circuit 135, each corresponding to a different temperature of filament 115 in light source 110.

[00035] In a differential spectrum measurement as shown in FIG. 3B, a contrast value is obtained from response signals at two different wavelengths λ_1 and λ_2 , for a given normalized spectral response curve. In some embodiments, a contrast value may be obtained by subtracting a response value from the spectral response curve at wavelength λ_2 from a response value from the spectral response curve at wavelength λ_1 . Further, a differential spectrum measurement may use the contrast values from two different spectral response curves to enhance the SNR of a detected signal. For example, a differential spectrum measurement may subtract a contrast value from a first spectral response curve from the contrast value of a second spectral response curve.

20 **[00036]** As described in FIG. 3B a first spectral response curve may be normalized curve 333B and a first difference contrast value from the response at wavelength λ_2 and wavelength λ_1 may be $\Delta A = A_2 - A_1$. A second spectral response curve may be normalized curve 331B, and a second difference contrast value may be $\Delta B = B_2 - B_1$. In such case, a differential spectrum measurement may be

$$\delta\Delta = \Delta B - \Delta A \quad (1)$$

[00037] If the difference contrast value ΔA or ΔB indicates a signal of interest in the sample, then difference $\delta\Delta$ in Eq.(1) results in a greater signal than would be obtained by using the difference contrast value of a single spectral response curve. For example, in FIG. 3B the sign of difference contrast value ΔA is opposite to the sign of difference contrast value ΔB . Thus, the subtraction in Eq.(1) increases the value of $\delta\Delta$ over the value of both ΔA and ΔB , increasing the SNR of the measurement. The signal of interest in the sample may be the fractional concentration of a specific chemical component in a fluid. In some embodiments, the signal of interest may be the octane value of a gasoline in a

5 fluid coming from an oil refining process. In some embodiments, the signal of interest may be the fractional water content in a crude oil sample extracted from a downhole drilling tool. Further according to some embodiments, the signal of interest may be the gas-oil-ratio (GOR) in a crude oil sample extracted from a downhole drilling tool.

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[00038] In some embodiments, a contrast value may be obtained from a ratio of the value of the response curve at wavelength λ_1 to the value of the response curve at wavelength λ_2 . In such embodiments, a similar analysis leading to an enhanced differential signal $\delta\Delta$ according to Eq. (1) follows from the logarithmic values of a first spectral response curve such as curve 333B and the logarithmic values of a second spectral response curve such as curve 331B. Thus, a ratio $rA = A_2/A_1$ and a ratio $rB = B_2/B_1$ may be enhanced in a differential configuration, by finding

20

$$\delta R = \frac{rB}{rA} = \frac{B_2}{B_1} \cdot \frac{A_1}{A_2} \quad (2)$$

25

[00039] Referring to FIG. 3B, it is seen that $B_2 > B_1$ and $A_1 > A_2$, thus the value of δR is greater than B_2/B_1 , because $A_1 > A_2$. Also, the value of δR is greater than A_2/A_1 because $\delta R > 1$. Thus, the value of δR is greater than both of the ratio contrast values rB and rA . When the ratio contrast value rB or rA is related to a signal of interest for a sample, then a differential spectrum configuration as shown above enhances the SNR of the measurement.

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[00040] FIG. 4 shows an optical sensor 400 including a modulated light source 110 and an Integrated Computational Element (ICE) 410, according to some embodiments. Optical sensor 400 is similar to optical sensor 100 described in detail above (cf. FIG. 1). Optical sensor 400 includes a reference light detector 450, and an ICE 410 interacting with sample light 112. Reference light detector 450 measures a reference light 113 separated from illumination light 111 by a first beam splitter 421, before illumination light 111 interacts with the sample 170. In some embodiments, reference light 113 is separated from

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5 the illumination light 111 before passing through optical modulator 180. Reference light 113 is sent through a second beam splitter 422 towards detector 450 by mirror 430.

10 **[00041]** One of ordinary skill will recognize that the specific combination of mirror, lenses, and beam splitters in optical sensor 100 (cf. FIG. 1), and in optical sensor 400 is not limiting. Different optical elements well known in the art may be used in a variety of configurations to produce the same effects for collection, collimation, and delivery of light from light source 110, through sample 170, and to detectors 150 and 450. In some embodiments, beam
15 splitters, mirrors, and lenses may be replaced entirely or partially by optical fiber components such as splitters, circulators, and collimators.

[00042] ICE 410 modifies and separates sample light 112 into a modified transmitted light 415 and a modified reflected light 414. Modified transmitted
20 light 415 is sent to detector 150. Modified reflected light 414 is collected by optical collection system 465 and sent to detector 450, by second beam splitter 422. In some embodiments, ICE 410 may include a multilayered dielectric filter that separates sample light 112 into modified reflected portion 415 and modified transmitted portion 415 according to wavelength. Thus, the sum of the intensity
25 of modified reflected portion 414 and the intensity of modified transmitted portion 415 of sample light 112 may be equal to or approximately equal to the intensity of sample light 112. Furthermore, the relative intensity of modified transmitted portion 415 to modified reflected portion 414 of sample light 112 may depend on the chemical composition of sample 170.

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[00043] In some embodiments, ICE 410 may be selected so that the relative difference between modified reflected portion 414 of the sample light and modified transmitted portion 415 of the sample light is maximized when a certain chemical of interest is present in the sample. In some embodiments,
35 ICE 410 may be designed such that a contrast value is obtained from measuring modified reflected portion 414 and transmitted portion 415 of sample light 112, separately. For example, for a contrast value such as difference

5 contrast values ΔA and ΔB (cf. Eq. (1) and FIG. 3), ICE 410 may be selected such that modified transmitted portion 415 includes value A_1 , and B_1 , and modified reflected portion 414 includes values A_2 and B_2 . Accordingly, the opposite choice may be selected, e.g., ICE 410 may be selected such that modified transmitted portion 415 includes values A_2 and B_2 , and modified
10 reflected portion 414 includes values A_1 and B_1 . In such embodiments, the difference contrast values ΔA and ΔB may be obtained simply by subtracting the signals measured in detectors 150 and 450. In embodiments using a ratio as a contrast value, such as ratio contrast values rA and rB (cf. Eq. (2) and FIG.3), the contrast value may be obtained by dividing the signals measured in
15 detectors 150 and 450. Signal processing such as subtraction and division of the signals from detectors 150 and 450 is performed in controller 130 by processing circuit 133. Further data processing may include use of lookup tables and reference spectra stored in memory circuit 135.

20 **[00044]** FIG. 5 shows a flow chart for a method 500 to determine chemical composition of a sample using an optical sensor, according to some embodiments. The optical sensor used in method 500 may be optical sensor 100 or optical sensor 400, described in detail above (cf. FIGS. 1 and 4). Method 500 may be performed by the controller circuit in an optical sensor,
25 such as controller 130 in optical sensor 100 (cf. FIG. 1). The controller circuit may include a processor circuit such as processor circuit 133, to perform operations using commands and data, the commands and data stored in a memory circuit such as memory circuit 135 (cf. FIG. 1). Furthermore, some steps in method 500 may be performed by a power circuit in the optical sensor,
30 such as power circuit 120 in optical sensor 100 (cf. FIG. 1). In some embodiments some steps in method 500 may be performed by power circuit 120 upon receiving commands and signals from the controller circuit.

[00045] Step 510 includes providing a voltage modulation pulse to a light
35 source, to generate an illumination light (e.g. illumination light 111, cf. FIG. 1). According to some embodiments, the voltage modulation pulse may be included in a pulse width modulated signal such as pulse width modulated

5 signal 125, provided to filament 115 in light source 110 by power circuit 120. The voltage pulse has a duty cycle such as duty cycle 215 within a period of time such as period 210 (cf. FIG. 2). Thus, in embodiments where a modulation signal such as pulse width modulated signal 125 is provided to light source 110, step 510 may be repeated for a plurality of times while a signal is collected. In
10 some embodiments, the frequency of the pulses provided in step 510 may be approximately 10 kHz, or higher.

[00046] Step 520 includes measuring a reference light from a portion of the illumination light. Step 520 may include forming a reference light by splitting a
15 portion of the light emitted by the light source in step 510 with a beam splitter such as beam splitter 421 (cf. FIG. 4). Step 520 may further include reflecting the reference light with a mirror such as mirror 430, and passing the reference light through a beam splitter such as beam splitter 422. Step 520 may also include measuring the reference light with a detector such as detector 450.

20 **[00047]** Step 530 includes passing the illumination light provided in step 510 through an optical modulator. In some embodiments, step 530 may include collimating the illumination light into a beam using an optical delivery system such as system 165 (cf. FIG. 1). The optical modulator may be optical
25 modulator 180. In some embodiments, the optical modulator may be an optical chopper, operating at a low modulation frequency, compared to the frequency of the pulses provided in step 510. For example, in embodiments where the frequency of the pulses provided in step 510 is about 10 kHz, an optical modulator in step 530 may operate at a frequency of a few hundred Hz, 100 Hz,
30 or even lower.

[00048] Step 540 includes directing the illumination light to a sample. The sample in step 540 may be as sample 170 (cf. FIG. 1). The illumination light in step 540 may interact with the sample through scattering phenomena such as
35 Raman, Brillouin or Rayleigh scattering, or an absorption phenomenon such as VIS or NIR absorption. Interaction of the illumination light with the sample in step 540 may also include an absorption and emission phenomenon such as fluorescence emission. Further according to some embodiments, and

- 5 depending on the chemical composition of the sample, step 540 may include a combination of scattering, absorption, and emission phenomena as described above.

[00049] Step 550 includes collecting a sample light. In some embodiments, step 550 may include using an optical collection system such as optical collection system 162 (cf. FIG. 1). Step 560 includes directing the sample light to an ICE, such as ICE 410 described in detail above (cf. FIG. 4). Step 570 includes measuring a first portion of the sample light (e.g., modified transmitted light 415 in FIG. 4). In some embodiments, step 570 includes using a first
15 detector such as detector 150 to measure a first portion of the sample light transmitted through the ICE in step 560. Step 580 includes measuring a second portion of the sample light (e.g., the modified reflected light 414 in FIG. 4) using a second detector, such as detector 450. In some embodiments the second portion of the sample light may be a light reflected from the ICE in step
20 560. In some embodiments, measuring a first portion and a second portion of the sample light includes synchronizing the two detectors with a duty cycle of the voltage modulation pulse. In some embodiments, measuring a first portion and a second portion of the sample light includes synchronizing the two detectors with a combination frequency including a sum or a difference of the
25 optical modulator frequency and the frequency of the voltage modulation signal.

[00050] Step 590 includes determining a chemical component in the sample. According to some embodiments, step 590 may be performed by the controller circuit using a processor circuit and a memory circuit. For example, a controller
30 circuit may use the signals measured in steps 520, 570, and 580 to determine a chemical component in the sample. Furthermore, in step 590 the controller circuit may also use a lookup table or a reference spectrum stored in the memory circuit. Thus, step 590 may include comparing a value obtained from the measured signal to a value stored in a lookup table or in a reference
35 spectrum. Moreover, the memory circuit may store a calibration table, such that a difference between the value obtained from the measured signal and the value stored in the lookup table or the reference spectrum may be converted by the processor circuit into a concentration value for the chemical component in

- 5 step 590. In some embodiments, step 590 may include use of a multivariate analysis to determine multiple component concentrations in the sample.

[00051] In some embodiments, step 590 may include determining whether a certain chemical component is present in the sample or not. In some
10 embodiments, step 590 may further determine the fractional concentration of a chemical component in the sample. The fractional concentration may be a value provided by mass of the sample (e.g., weight percent, %Wt), by volume of the sample (e.g., volume percent, % vol), by molecular counts of the sample (e.g. parts per thousand, million, billion, trillion). In some embodiments, an
15 absolute count of a chemical component may be provided in step 590.

[00052] FIG. 6 shows an optical sensor 100 using a modulated optical source in a sensor 620 for a wireline logging application, according to some embodiments. Wireline logging performs measurements of fluids and
20 substrates in wellbores drilled for oil and hydrocarbon exploration. In some embodiments, a movable unit 610 includes a processor circuit 611 and a memory circuit 612 to provide commands for sensor 620 to perform measurements and store data obtained from the measurements. Accordingly, once a wellbore 650 has been drilled, a wireline logging measurement may be
25 performed by introducing sensor 620 into wellbore 650, using a wireline 600. Wellbore 650 may traverse through a layered ground formation 670. Sensor 620 may have an optical sensor system 100 including a modulated optical source, as disclosed herein. Furthermore, sensor 620 may include a portion of an optical delivery system such as light delivery system 165 and a portion of an
30 optical collection system such as collection system 162 (cf. FIG. 3). In some embodiments, a portion of light delivery system 165 and an illumination lamp 110 using a modulated optical source, and power circuit 120 may be included in movable unit 610. Likewise, a portion of optical collection system 162 may be included in movable unit 610, such as a detector, an amplifier, and an
35 analog-to-digital converter circuit. In some embodiments, optical delivery system 165 and optical collection system 162 may include an optical fiber, or fiber bundle. The optical fiber or fiber bundle carries light signals along wireline 600.

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[00053] FIG. 7 shows a drill bore including an optical sensor 100 using a modulated optical source in a logging-while-drilling (LWD) application, according to some embodiments. An LWD configuration logs acoustic and optical data while a wellbore is being drilled. According to FIG. 7, a bottom hole assembly 720 includes a drill 721 to form a wellbore 750, traversing through layered ground formation 670. Drill 721 may be operated by a controller 705 through drill string 700. A drilling rig 710 provides structural support to drill string 700. Controller 705 may include a processor circuit 706 and a memory circuit 707. Memory circuit 707 stores commands and data used by processor circuit 706 to control bottom hole assembly 720. Controller 705 may also include sensor 620 proximate to drill 721. Sensor 620 may include an optical sensor 100. Sensor 620 may also include a portion of a light illumination system and a portion of a light detection system, as described in detail above (cf. FIG. 6).

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[00054] In some embodiments, a sensor as disclosed herein may be implemented in permanent monitoring applications. For example, in an oil extraction rig similar to drilling rig 710, optical sensor 100 may determine the chemical composition of the extracted hydrocarbons during regular operations. Further according to some embodiments, an optical sensor such as sensor 100 may be used in a subsea environment of a wireline operation (cf. FIG. 6), an LWD operation (cf. FIG. 7), or a permanent monitoring operation.

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[00055] Embodiments described herein may provide measurement stability and high SNR ratio in a broad spectral band to more accurately determine the chemical composition of fluids including hydrocarbons such as crude oils, natural gas, and other downhole fluids. Embodiments described herein are exemplary only. One skilled in the art may recognize various alternative embodiments from those specifically disclosed. Those alternative embodiments are also intended to be within the scope of this disclosure. As such, embodiments disclosed herein are limited only by the following claims.

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Claims

What is claimed is:

1. A light source for use in an optical sensor, the light source comprising:
a resistively heated element; and
10 a power circuit configured to provide a pulse width modulated voltage to the resistively heated element, the pulse width modulated voltage comprising:
a duty cycle with a first voltage; and
a pulse period including a period with a second voltage, wherein:
the duty cycle, the first voltage, and the pulse period are
15 selected so that the resistively heated element is heated to a first temperature; and
the first temperature is selected to emit black body radiation in a continuum spectral range.
- 20 2. The light source of Claim 1 wherein the second voltage is lower than the first voltage.
3. The light source of Claim 1 wherein the second voltage is zero.
- 25 4. The light source of any one of claims 1, 2, or 3 wherein the duty cycle, the second voltage, and the pulse period are selected so that the resistively heated element is heated to a second temperature lower than the first temperature.
- 30 5. The light source of Claim 4 wherein the second temperature is selected to emit black body radiation in a second continuum spectral range.
6. An optical sensor for determining a chemical composition of a sample, the optical sensor comprising:
35 a light source comprising a resistively heated element;
a power circuit configured to provide a pulse width modulated voltage signal to the resistively heated element;
an optical delivery system to direct an illumination light to a sample;

5 a sample cavity containing the sample and configured to receive the
illumination light;
 an optical collection system to collect a sample light; and
 a detector synchronized to the pulse width modulated voltage signal, the
detector configured to measure the sample light from the optical collection
10 system.

7. The optical sensor of Claim 6 further comprising a controller circuit to
provide the pulse width modulated voltage signal having a first frequency and a
duty cycle, the controller circuit having a processor circuit to synchronize the
15 detector to the pulse width modulated voltage signal.

8. The optical sensor of Claim 6 further comprising an optical modulator
configured to modulate the illumination light at a second frequency.

20 9. The optical sensor of any one of claims 6, 7, and 8 further comprising an
Integrated Computational Element (ICE) to separate the sample light into a first
light portion and a second light portion.

10. The optical sensor of Claim 9 wherein the first light portion comprises a
25 sample light reflected from the ICE; and the second light portion comprises a
sample light transmitted from the ICE.

11. The optical sensor of Claim 6 further comprising a beam splitter
configured to separate a reference light from the illumination light.

30 12. The optical sensor of any one of claims 9 through 11 further comprising a
second detector synchronized to the pulse width modulated voltage signal.

13. A method of determining a chemical composition of a sample using an
35 optical sensor, the method comprising:
 generating an illumination light using a pulse width modulated voltage;
 collecting a sample light;

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measuring the sample light with a detector; and
determining a chemical component in the sample; wherein the pulse width modulated voltage comprises a plurality of pulses having a first frequency, and a duty cycle.

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14. The method of Claim 13, wherein collecting a sample light further comprises directing the sample light to an Integrated Computational Element (ICE).

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15. The method of Claim 13, wherein measuring the sample light with a detector further comprises measuring a first portion of the sample light with a first detector and a second portion of the sample light with a second detector.

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16. The method of Claim 15, further comprising:
passing the illumination light through an optical modulator operating at a second frequency lower than the first frequency; and
synchronizing the two detectors to a combination frequency including a sum or a difference of the first frequency and the second frequency.

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17. The method of any one of claims 14 through 15 further comprising:
obtaining a first measurement at a first temperature and a second measurement at a second temperature; and
determining a contrast value from the first measurement and the second measurement, the contrast value indicative of an analyte concentration in the sample.

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18. The method of Claim 17 wherein the contrast value comprises a difference in a measurement at a first wavelength and a measurement at a second wavelength.

19. The method of Claim 17 wherein the contrast value comprises a ratio of a measurement at a first wavelength and a measurement at a second wavelength.

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20. The method of any one of claims 14 and 15, wherein the sample comprises at least one of the group consisting of a crude oil and a natural gas.

21. The method of Claim 13 wherein the sample comprises a fluid in a
10 wellbore formed in a procedure selected from the group consisting of a wireline logging procedure and a logging while drilling (LWD) procedure.

AMENDED CLAIMS

received by the International Bureau on 14 November 2013 (14.11.2013)

What is claimed is:

1. A light source for use in an optical sensor, the light source comprising:
a resistively heated element; and
5 a power circuit configured to provide a pulse width modulated voltage to
the resistively heated element, the pulse width modulated voltage comprising:
a duty cycle with a first voltage; and
a pulse period including a period with a second voltage, wherein:
the duty cycle, the first voltage, and the pulse period are
10 selected so that the resistively heated element is heated to a first
temperature; and
the first temperature is selected to emit black body
radiation in a continuum spectral range.
2. The light source of Claim 1 wherein the second voltage is lower than the
15 first voltage.
3. The light source of Claim 1 wherein the second voltage is zero.
4. The light source of any one of claims 1, 2, or 3 wherein the duty cycle,
the second voltage, and the pulse period are selected so that the resistively
heated element is heated to a second temperature lower than the first
20 temperature.
5. The light source of Claim 4 wherein the second temperature is selected
to emit black body radiation in a second continuum spectral range.
6. An optical sensor for determining a chemical composition of a sample,
the optical sensor comprising:
25 a light source comprising a resistively heated element;
a power circuit configured to provide a pulse width modulated voltage
signal to the resistively heated element to heat the resistively heated element to
a temperature selected to emit black body radiation in a continuum spectral
range;

- an optical delivery system to direct an illumination light to a sample;
a sample cavity containing the sample and configured to receive the illumination light;
an optical collection system to collect a sample light; and
5 a detector synchronized to the pulse width modulated voltage signal, the detector configured to measure the sample light from the optical collection system.
7. The optical sensor of Claim 6 further comprising a controller circuit to provide the pulse width modulated voltage signal having a first frequency and a
10 duty cycle, the controller circuit having a processor circuit to synchronize the detector to the pulse width modulated voltage signal.
8. The optical sensor of Claim 6 further comprising an optical modulator configured to modulate the illumination light at a second frequency.
9. The optical sensor of any one of claims 6, 7, and 8 further comprising an
15 Integrated Computational Element (ICE) to separate the sample light into a first light portion and a second light portion.
10. The optical sensor of Claim 9 wherein the first light portion comprises a sample light reflected from the ICE; and the second light portion comprises a sample light transmitted from the ICE.
- 20 11. The optical sensor of Claim 6 further comprising a beam splitter configured to separate a reference light from the illumination light.
12. The optical sensor of claim 9 further comprising a second detector synchronized to the pulse width modulated voltage signal.
- 25 13. A method of determining a chemical composition of a sample using an optical sensor, the method comprising:
generating an illumination light using a pulse width modulated voltage, wherein generating the illumination light comprises heating a resistively heated

element to a temperature selected to emit black body radiation in a continuum spectral range;

collecting a sample light;

measuring the sample light with a detector; and

- 5 determining a chemical component in the sample; wherein the pulse width modulated voltage comprises a plurality of pulses having a first frequency, and a duty cycle.

14. The method of Claim 13, wherein collecting a sample light further comprises directing the sample light to an Integrated Computational Element
10 (ICE).

15. The method of Claim 13, wherein measuring the sample light with a detector further comprises measuring a first portion of the sample light with a first detector and a second portion of the sample light with a second detector.

16. The method of Claim 15, further comprising:
15 passing the illumination light through an optical modulator operating at a second frequency lower than the first frequency; and
 synchronizing the two detectors to a combination frequency including a sum or a difference of the first frequency and the second frequency.

17. The method of any one of claims 14 through 15 further comprising:
20 obtaining a first measurement at a first temperature and a second measurement at a second temperature; and
 determining a contrast value from the first measurement and the second measurement, the contrast value indicative of an analyte concentration in the sample.

18. The method of Claim 17 wherein the contrast value comprises a
25 difference in a measurement at a first wavelength and a measurement at a second wavelength.

19. The method of Claim 17 wherein the contrast value comprises a ratio of a measurement at a first wavelength and a measurement at a second wavelength.
20. The method of any one of claims 14 and 15, wherein the sample
5 comprises at least one of the group consisting of a crude oil and a natural gas.
21. The method of Claim 13 wherein the sample comprises a fluid in a wellbore formed in a procedure selected from the group consisting of a wireline logging procedure and a logging while drilling (LWD) procedure.

STATEMENT UNDER ARTICLE 19(1)

In the International Search Report ("ISR") the International Searching Authority ("ISA") indicated that claim 12 does not comply with PCT Rule 6.4(a) and that claims 1-5, 8-10, 14, and 16-19 are novel and inventive. The ISA also indicated that claims 6, 7, 11, 13, 15, 20, and 21 lacked an inventive step in view of U.S. Patent Application Publication No. 2011/0184678 ("D1") and U.S. Patent Application Publication No. 2007/0049809. U.S. Patent No. 7,150,312 ("D3"), U.S. Patent No. 5,430,259 ("D4"), and U.S. Patent No. 6,354,146 ("D5").

Applicant gratefully acknowledges the indication that claims 1-5, 8-10, 14, and 16-19 are novel and inventive.

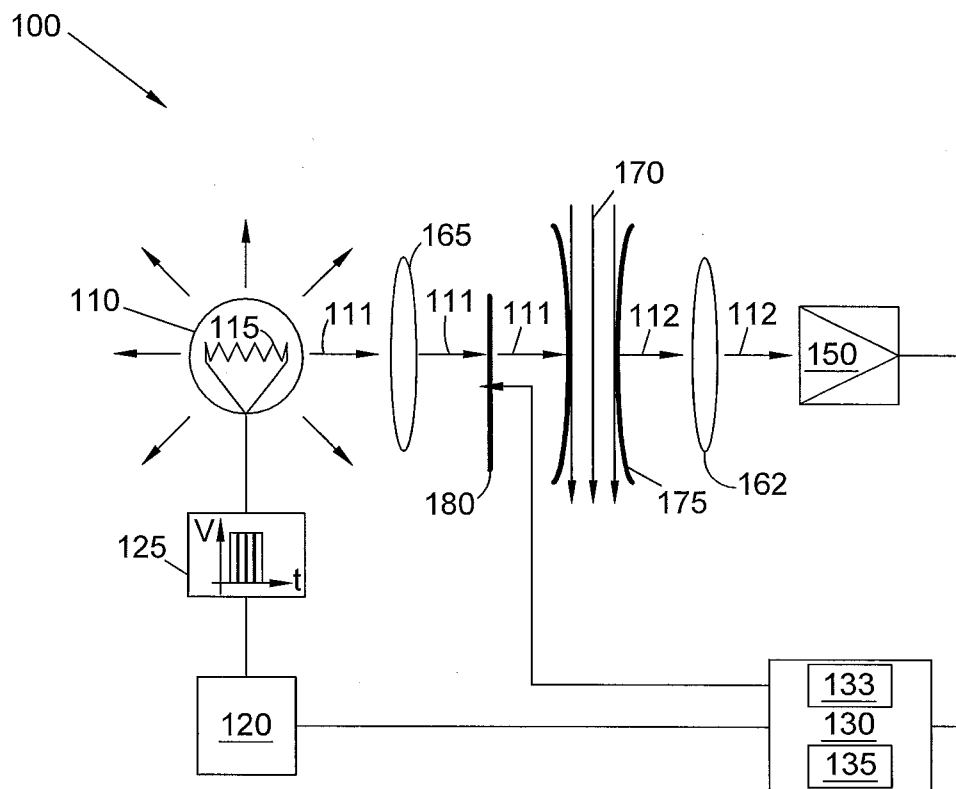
In response to the ISR, Applicant amends claim 12 to remove the improper multiple dependency.

Furthermore, Applicant proposes amending claims 6 and 13 to further distinguish over the prior art. In the ISR, the ISA states "[t]he subject matter of claim 1 differs from these

prior art documents D1-D5 in that a light source comprises a power circuit configured to provide a pulse width modulated voltage to the resistively heated element ... selected so that the resistively heated element is heated to a first temperature and the first temperature is selected to emit black body radiation in a continuum spectral range." Consequently, Applicant proposes amending claim 6 to recite "a power circuit configured to provide a pulse width modulated voltage signal to the resistively heated element to heat the resistively heated element to a temperature selected to emit black body radiation in a continuum spectral range" (emphasis added) and amending claim 13 to recite "generating an illumination light using a pulse width modulated voltage, wherein generating the illumination light comprises heating a resistively heated element to a temperature selected to emit black body radiation in a continuum spectral range" (emphasis added). Amended claims 6 and 13 would include elements similar to those recited in claim 1 and, thus, would be novel and inventive for at least the same reasons as claim 1. Moreover, claims 7 and 11 would be novel and inventive at least due to their dependency from amended claim 6, and claims 15, 20, and 21 would be novel and inventive at least due to their dependency from amended claim 13.

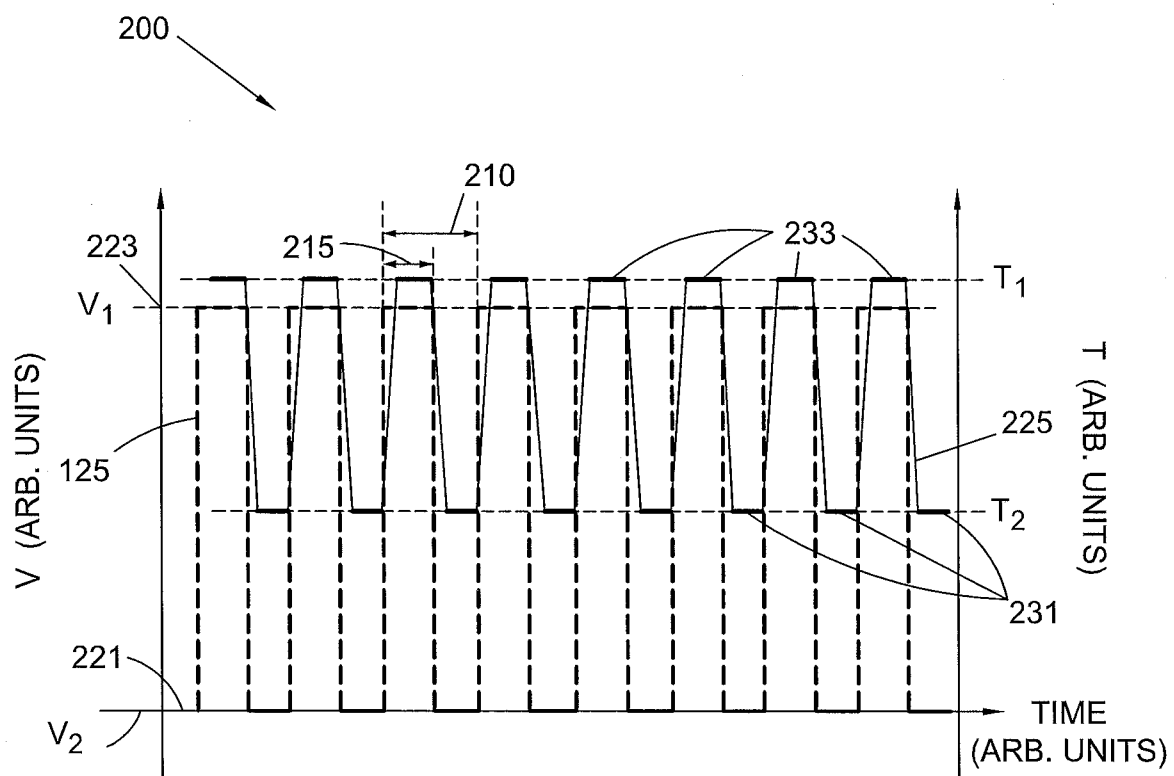
If the Authorized Officer has any questions regarding the above, the Authorized Officer is requested to telephone the undersigned at (408) 660-4120.

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FIG. 1



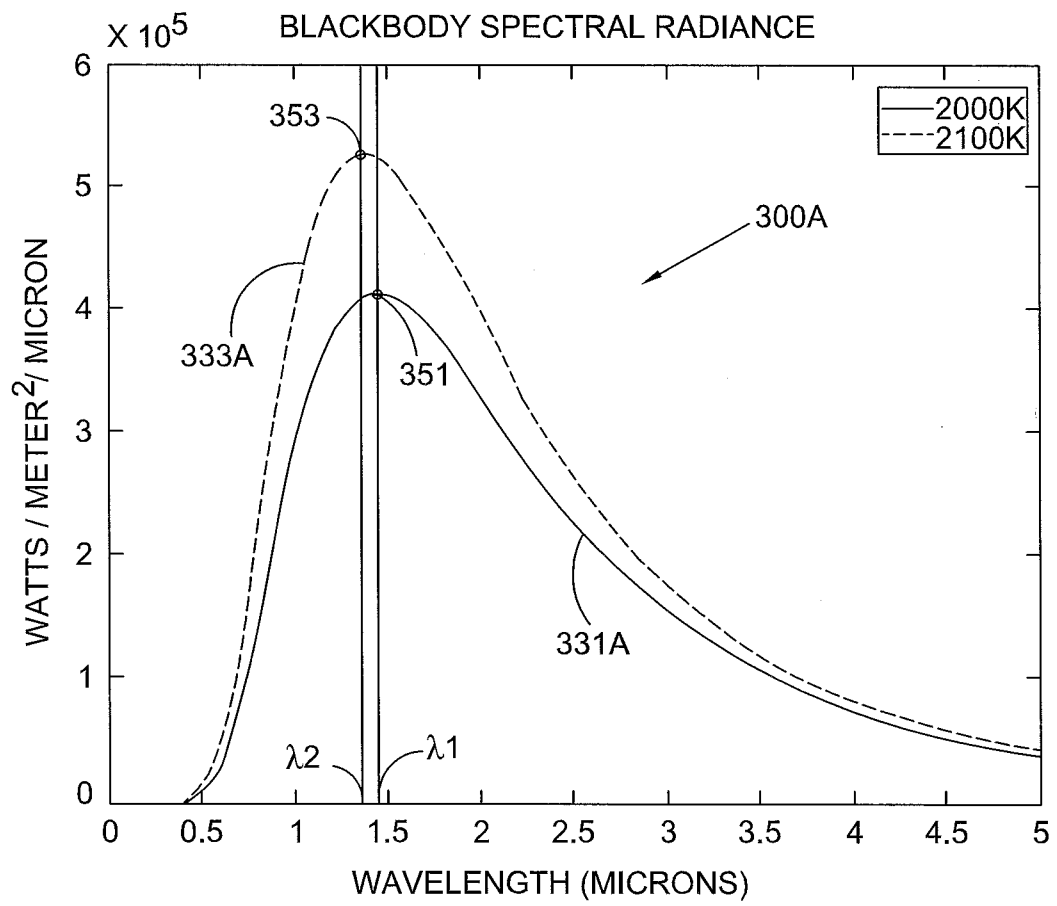
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FIG. 2

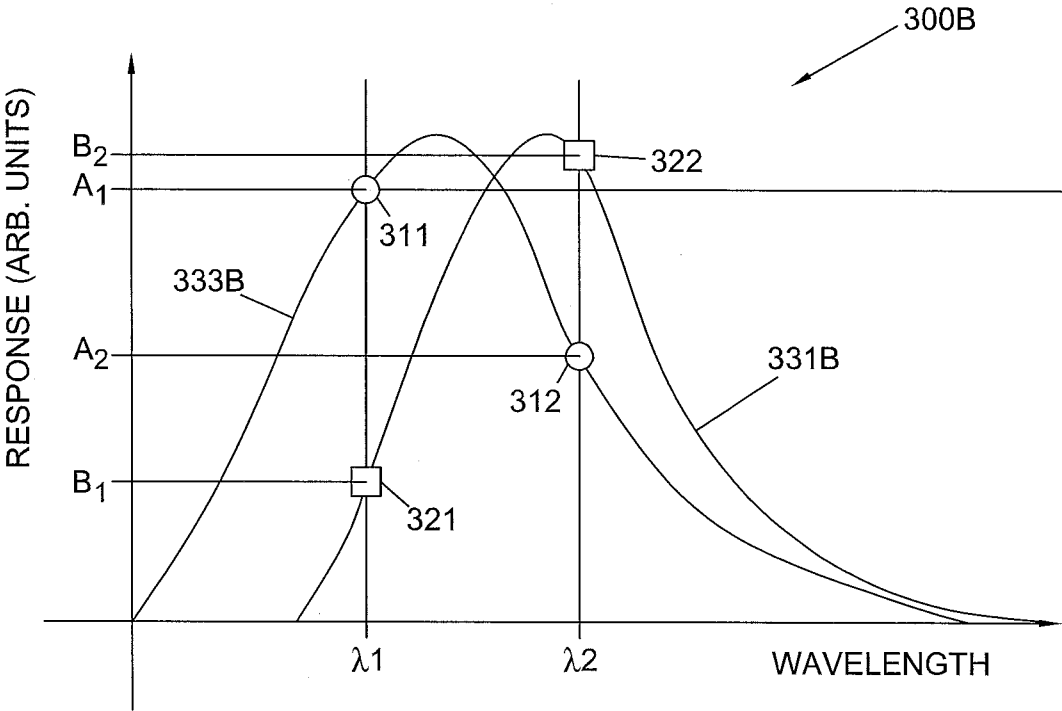


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FIG. 3A

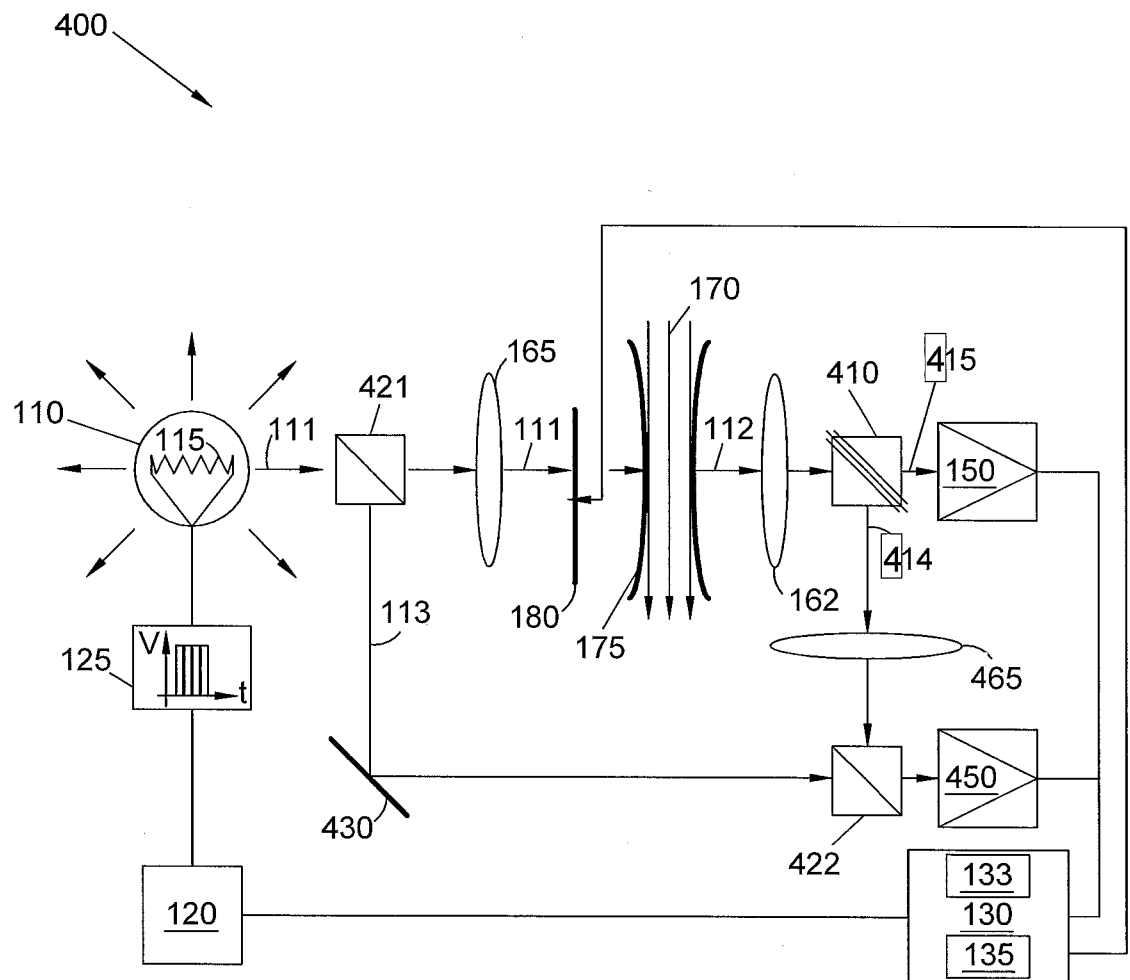


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FIG. 3B



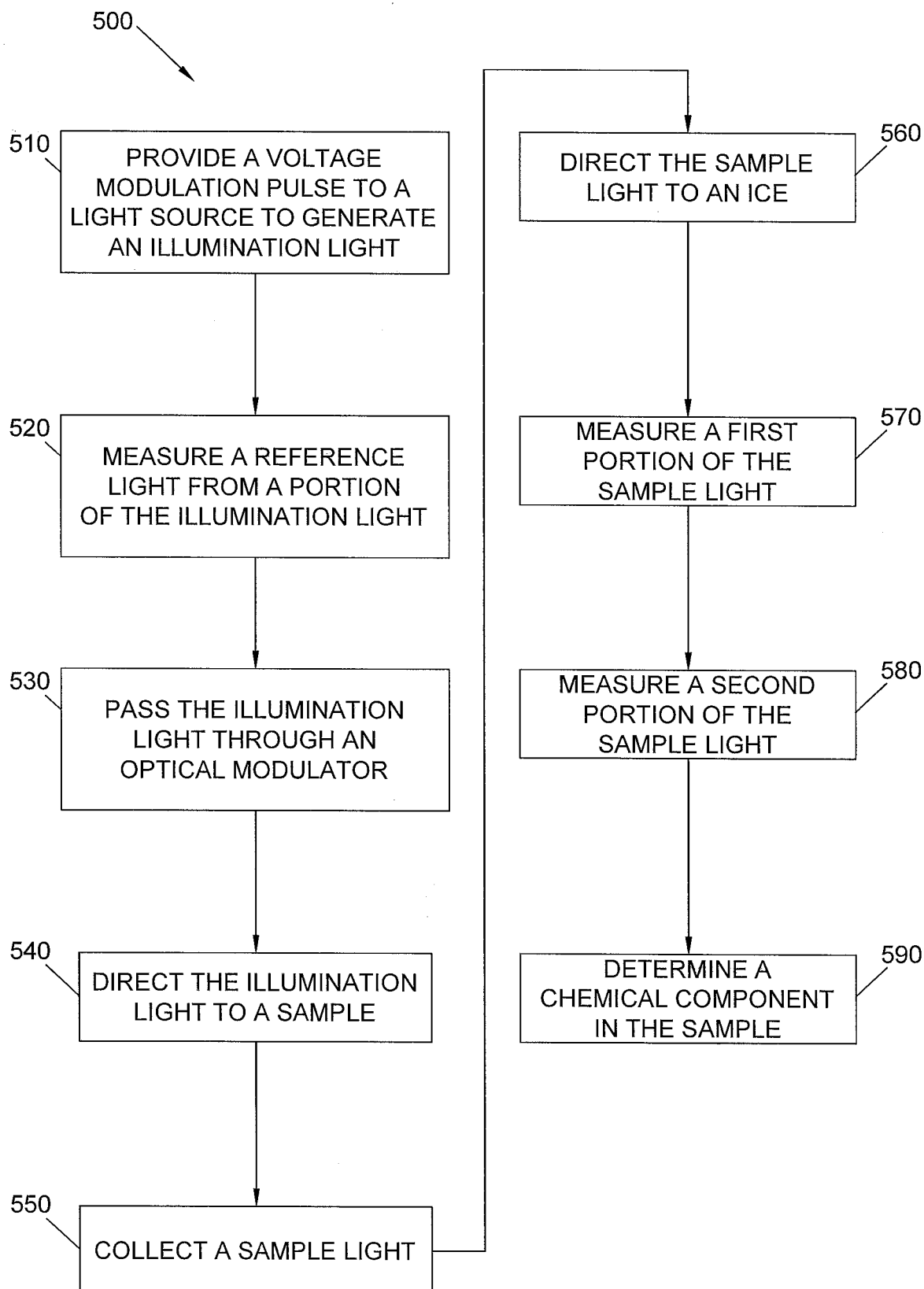
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FIG. 4

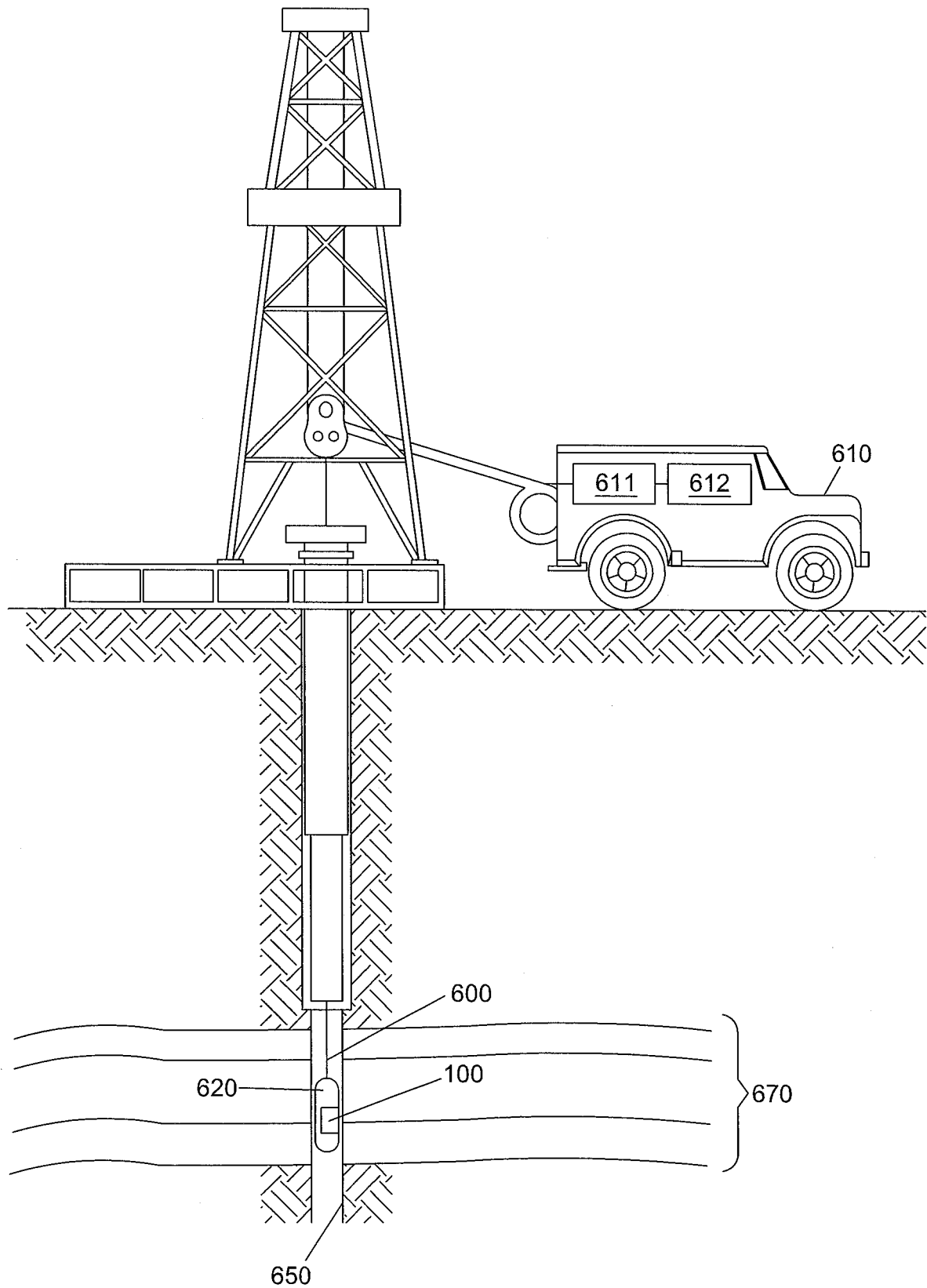


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FIG. 5

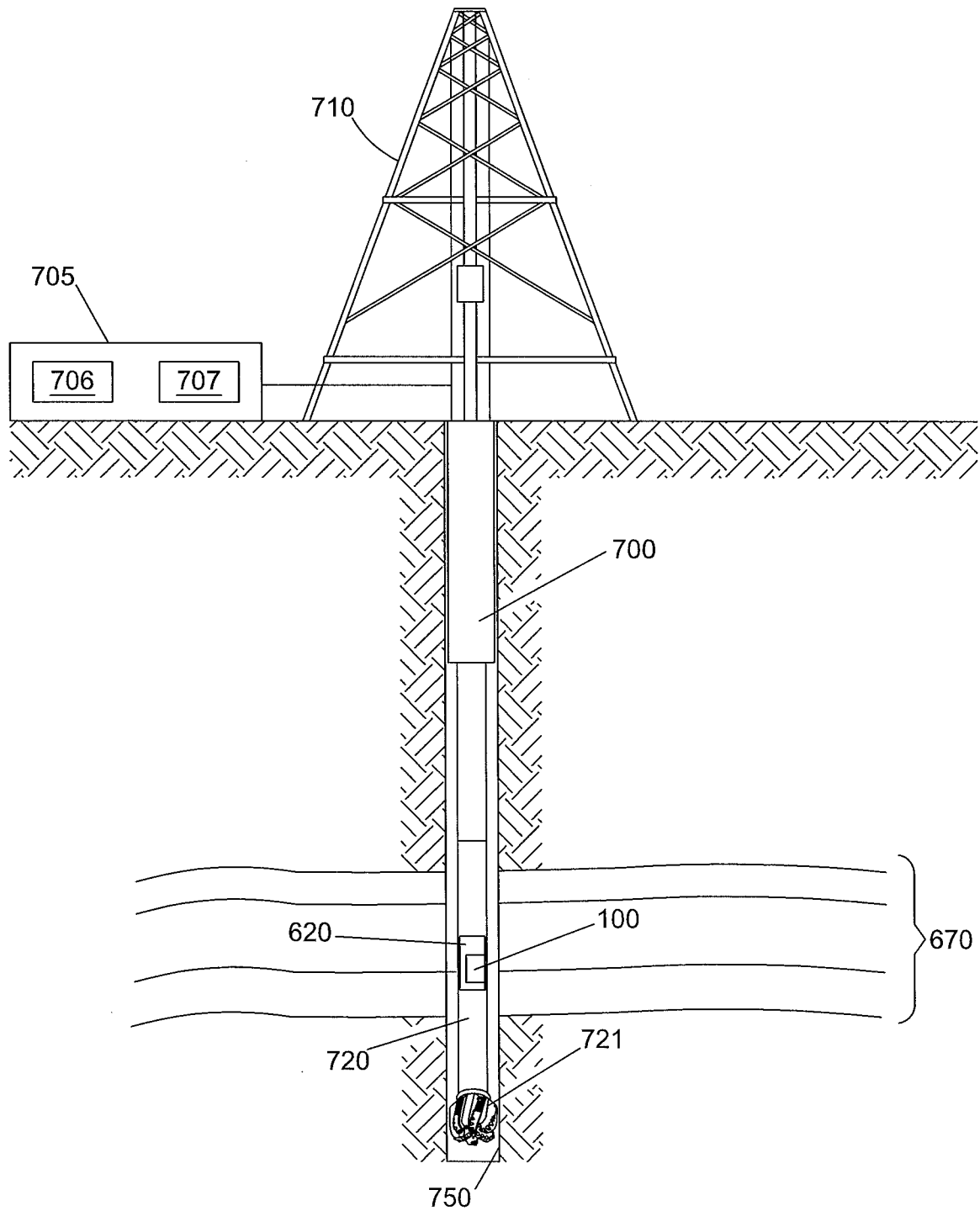


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FIG. 6



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FIG. 7



A. CLASSIFICATION OF SUBJECT MATTER**G01V 8/00(2006.01)i, G01V 8/10(2006.01)i, G01N 21/00(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01V 8/00; G06F 19/00; G01V 8/10; G01J 3/42; G01R 19/00; G01R 31/02; G01J 3/45; A61B 5/00; G01B 9/02; G01N 21/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: light source, duty cycle, pulse width modulation, voltage, temperature, optical, detector, sensor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011-0184678 A1 (LEE et al.) 28 July 2011 see claims 10-13,15 and figure 2.	13,21
Y		6-7, 11, 15, 20
A		1-5, 8-10, 14, 16-19
Y	US 2007-0049809 A1 (BECHTEL et al.) 01 March 2007 See claims 1,8,11,30,34,39,60 and figure 3.	6-7, 11, 15, 20
A	US 2010-0117667 A1 (LO, WILLIAM K.) 13 May 2010 See claims 1,16,19 and figure 1.	1-11, 13-21
A	US 2011-0108720 A1 (FORD et al.) 12 May 2011 See claims 1,40,41 and figure 2A.	1-11, 13-21
A	US 2007-0279636 A1 (LI et al.) 06 December 2007 See claims 1,2,4 and figures 2,10.	1-11, 13-21



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 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

26 September 2013 (26.09.2013)

Date of mailing of the international search report

27 September 2013 (27.09.2013)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/072194

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 12
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2012/072194

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011-0184678 A1	28/07/2011	None	
US 2007-0049809 A1	01/03/2007	WO 2007-014173 A2 WO 2007-014173 A3	01/02/2007 21/06/2007
US 2010-0117667 A1	13/05/2010	None	
US 2011-0108720 A1	12/05/2011	AU 2010-227020 A1 BR PI1004700 A2 CA 2718449 A1 EP 2320213 A2 EP 2320213 A3	26/05/2011 26/02/2013 06/05/2011 11/05/2011 07/08/2013
US 2007-0279636 A1	06/12/2007	US 7446877 B2 WO 2006-026513 A2 WO 2006-026513 A3	04/11/2008 09/03/2006 25/01/2007