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(54) **PHOTOACOUSTIC GAS DETECTION**

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CPC ***G01N 29/022*** (2013.01); ***E21B 49/081*** (2013.01); ***G01N 21/1702*** (2013.01);
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(58) **Field of Classification Search**
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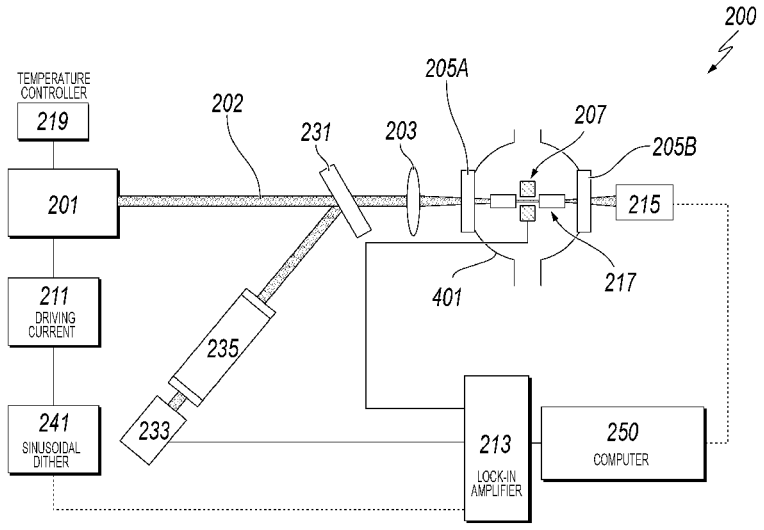
(57) **ABSTRACT**

A downhole system includes a quartz enhanced photoacoustic spectrometer (QEPAS) configured to be positioned within a wellbore formed in a subterranean zone of a hydrocarbon formation, a sampling system coupled to the QEPAS, and a computer system connected to the QEPAS. The sampling system is configured to be positioned in the wellbore and obtain a sample of a wellbore fluid at a downhole location in the subterranean zone. The QEPAS is configured to spectroscopically scan the sample and to determine a plurality of quantities of a corresponding plurality of hydrocarbons in the same. The computer system includes one or more processors to perform operations including receiving the plurality of quantities of the plurality of hydrocarbons in the sample and determining a plurality of ratios, where each ratio is a ratio of one of the plurality of hydrocarbons with another of the plurality of hydrocarbons.

13 Claims, 9 Drawing Sheets



(51) **Int. Cl.**

G01N 29/24	(2006.01)
G01V 1/44	(2006.01)
E21B 49/08	(2006.01)
G01N 29/46	(2006.01)
G01N 21/17	(2006.01)

(52) **U.S. Cl.**
CPC ***G01N 29/228*** (2013.01); ***G01N 29/2418*** (2013.01); ***G01N 29/46*** (2013.01); ***G01V 1/44*** (2013.01); *G01N 2021/1704* (2013.01)

(58) **Field of Classification Search**
USPC 73/24.02, 24.06
See application file for complete search history.

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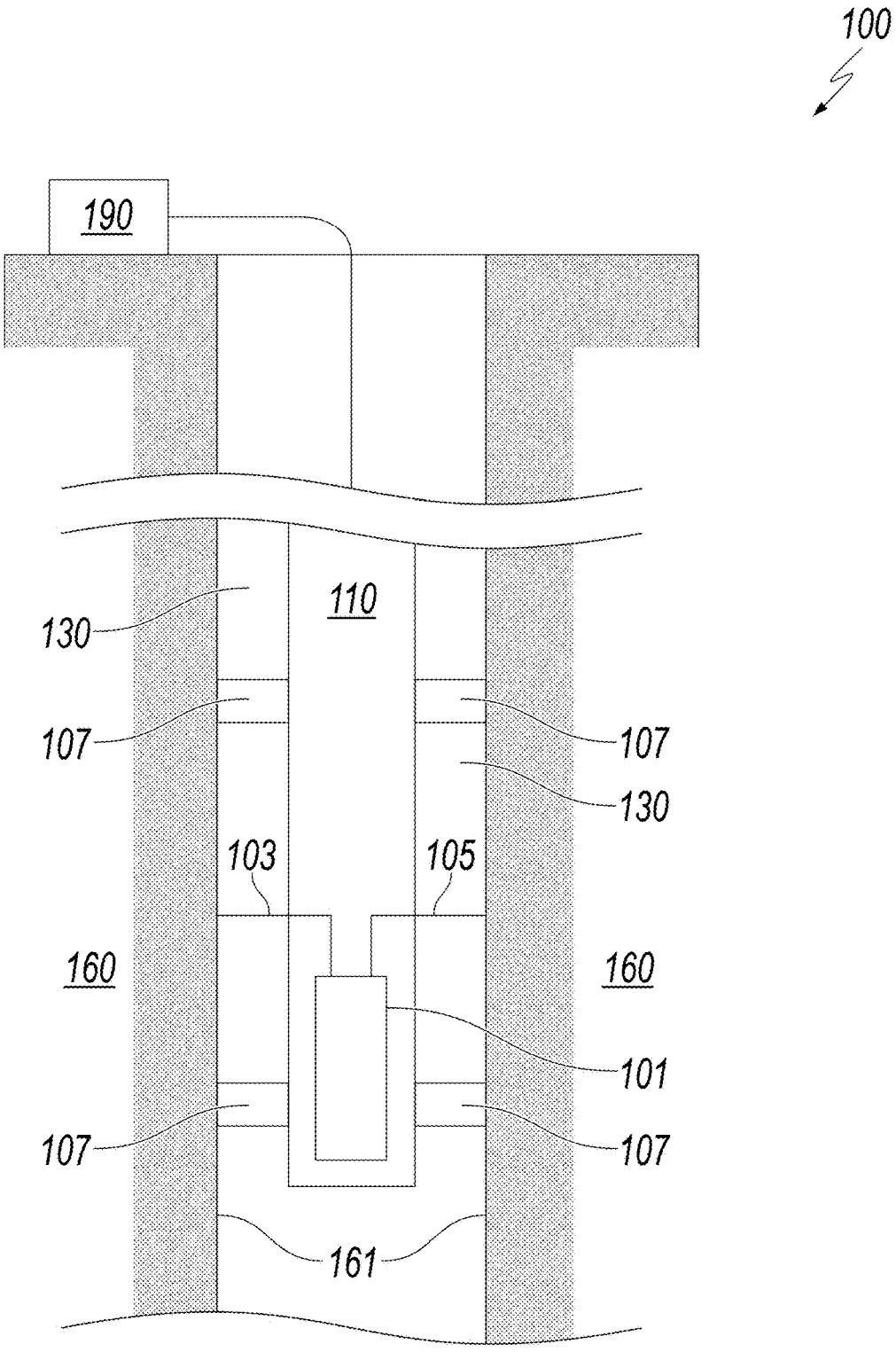

FIG. 1

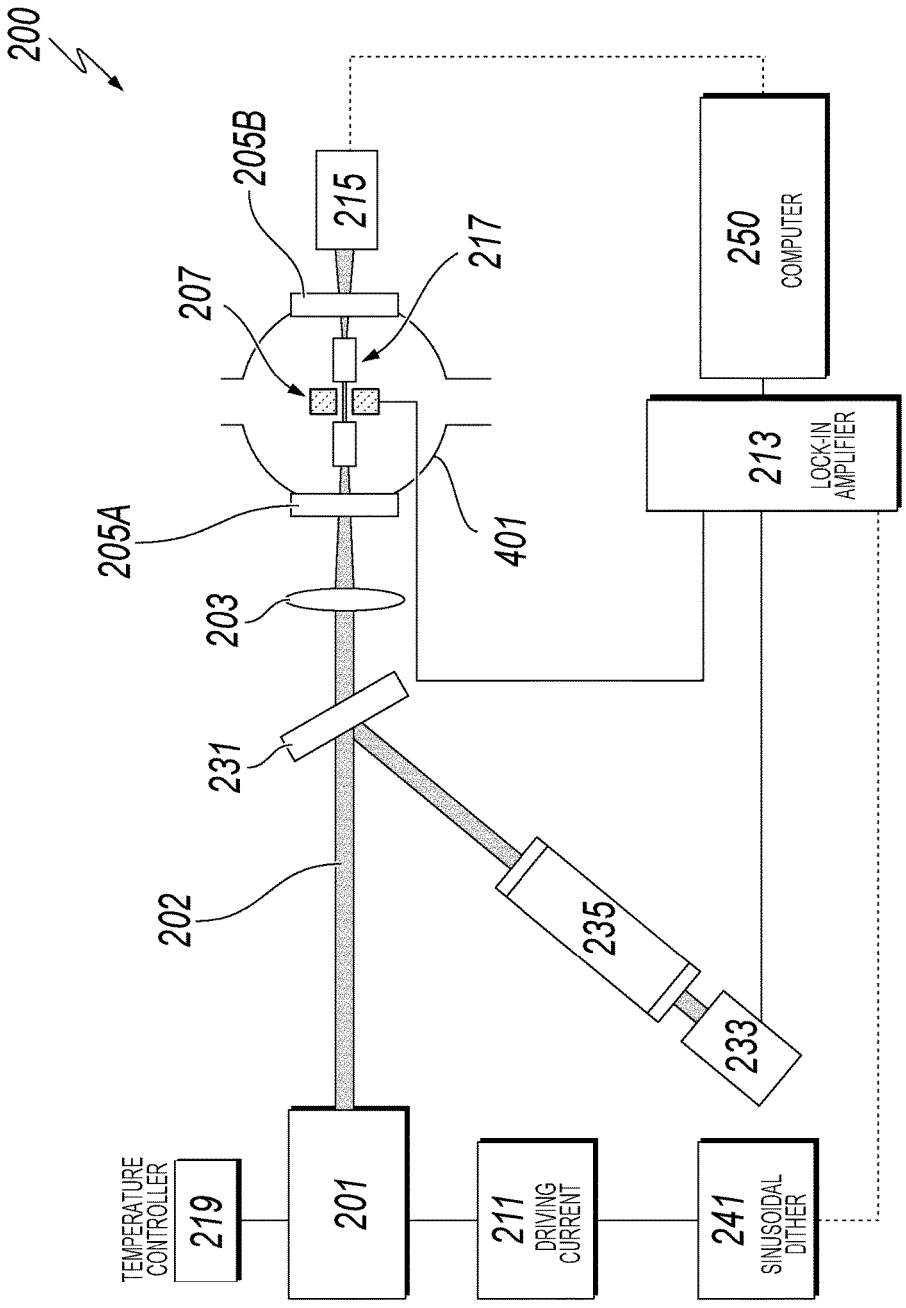
200
205B
215
217
207
250
COMPUTER
213
LOCK-IN
AMPLIFIER
205A
401
203
231
202
235
233
TEMPERATURE
CONTROLLER
219
201
211
DRIVING
CURRENT
241
SINUSOIDAL
DITHER

FIG. 2

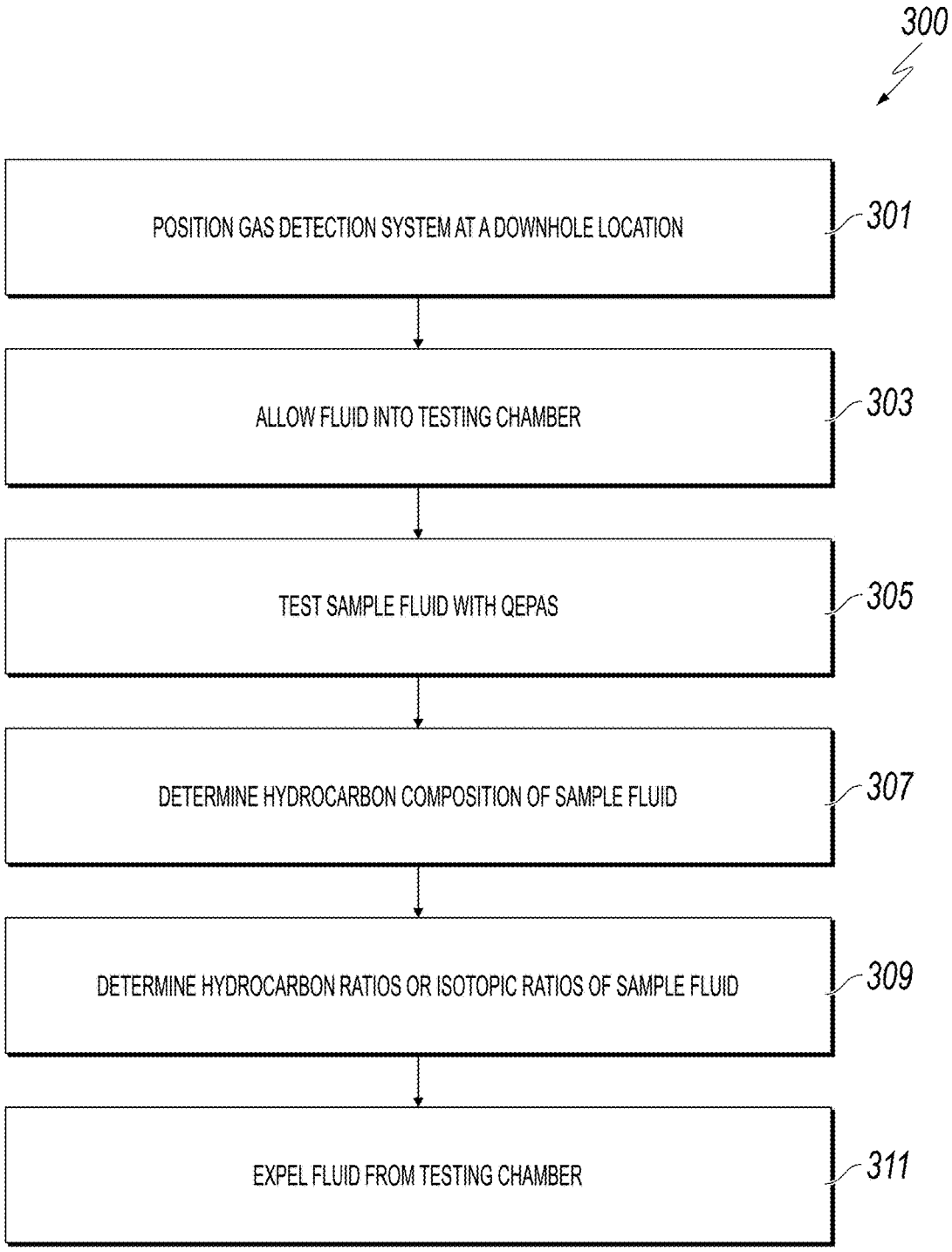
300
POSITION GAS DETECTION SYSTEM AT A DOWNHOLE LOCATION
301
ALLOW FLUID INTO TESTING CHAMBER
303
TEST SAMPLE FLUID WITH QEPAS
305
DETERMINE HYDROCARBON COMPOSITION OF SAMPLE FLUID
307
DETERMINE HYDROCARBON RATIOS OR ISOTOPIC RATIOS OF SAMPLE FLUID
309
EXPEL FLUID FROM TESTING CHAMBER
311

FIG. 3

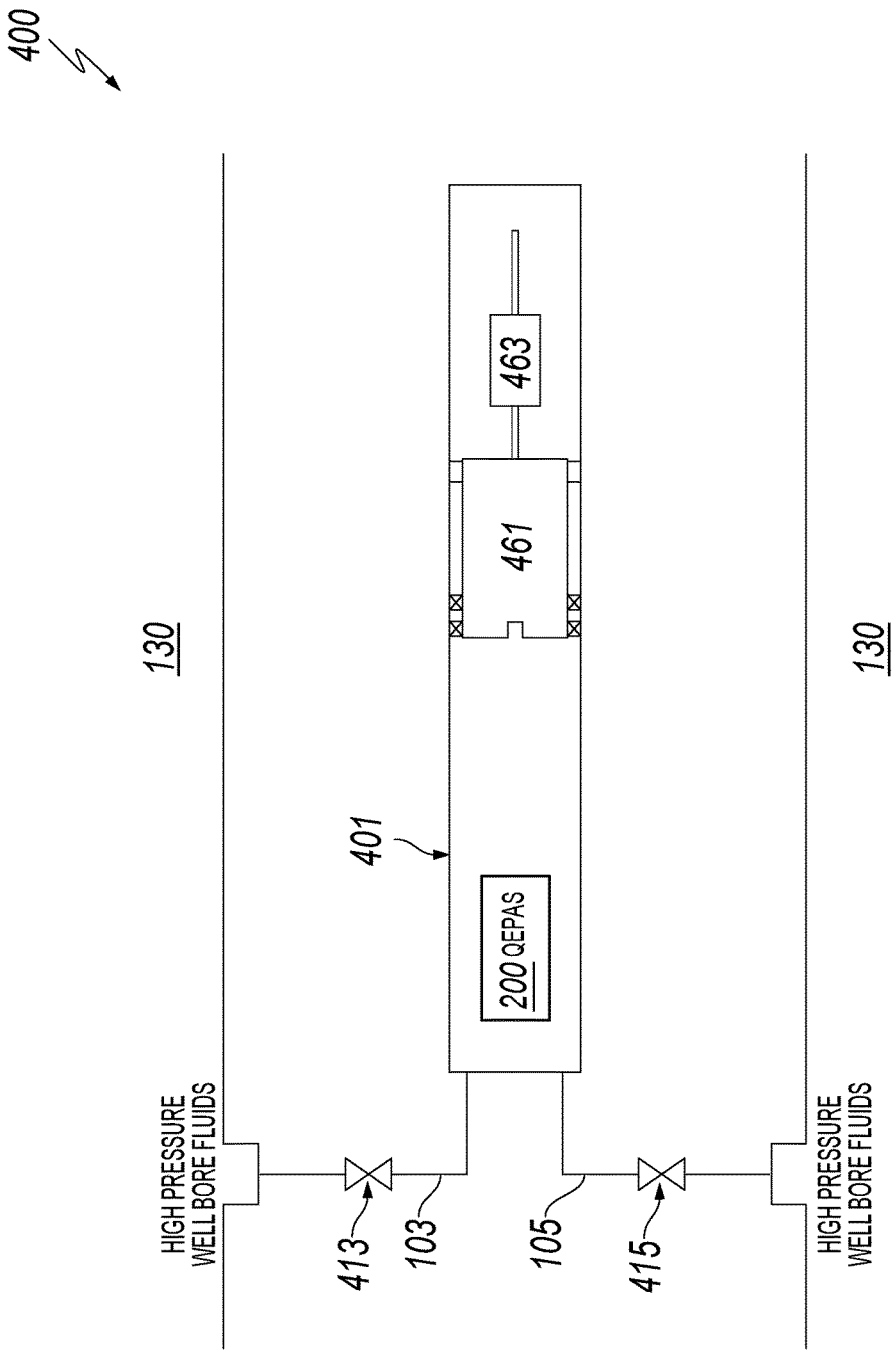
400
130
130
463
461
401
200 QEPAS
HIGH PRESSURE WELL BORE FLUIDS
HIGH PRESSURE WELL BORE FLUIDS
413
103
105
415

FIG. 4A

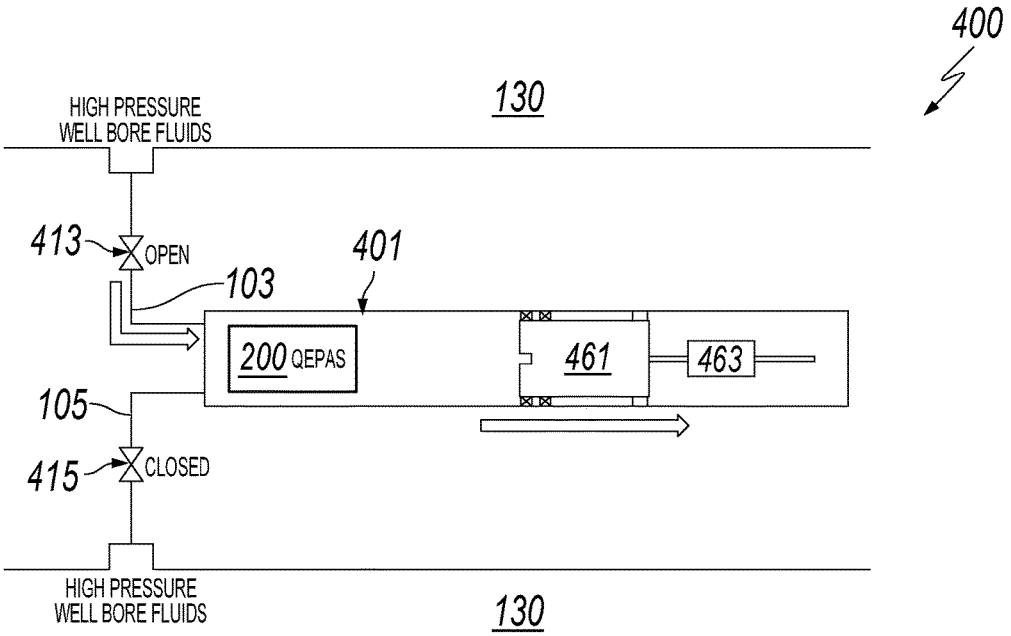
400
130
HIGH PRESSURE WELL BORE FLUIDS
413
OPEN
401
103
200 QEPAS
461
463
105
415
CLOSED
HIGH PRESSURE WELL BORE FLUIDS
130

FIG. 4B

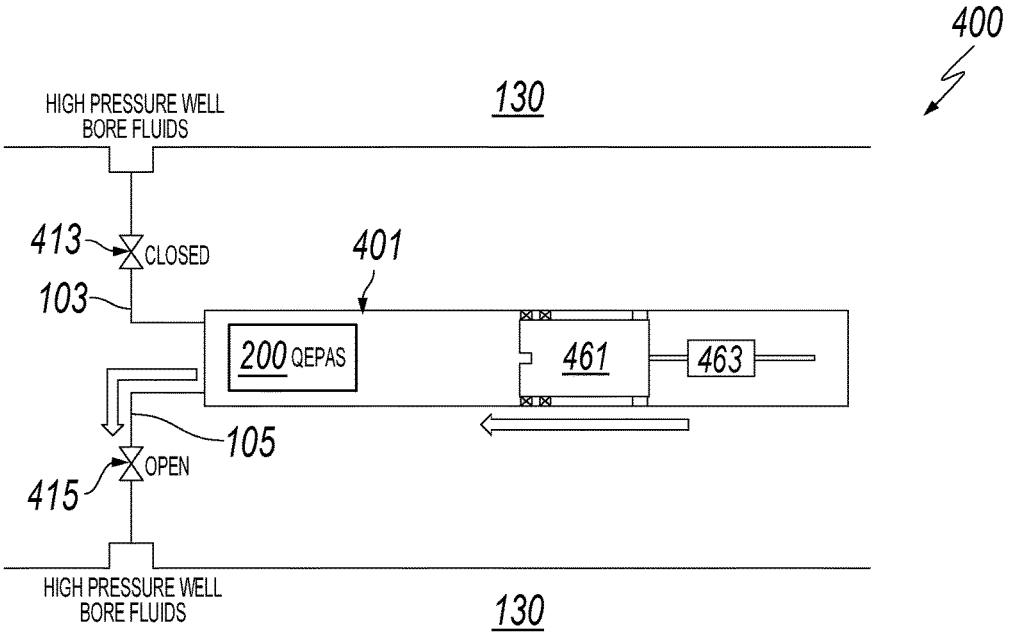
400
130
HIGH PRESSURE WELL BORE FLUIDS
413
CLOSED
401
103
200 QEPAS
461
463
105
415
OPEN
HIGH PRESSURE WELL BORE FLUIDS
130

FIG. 4C

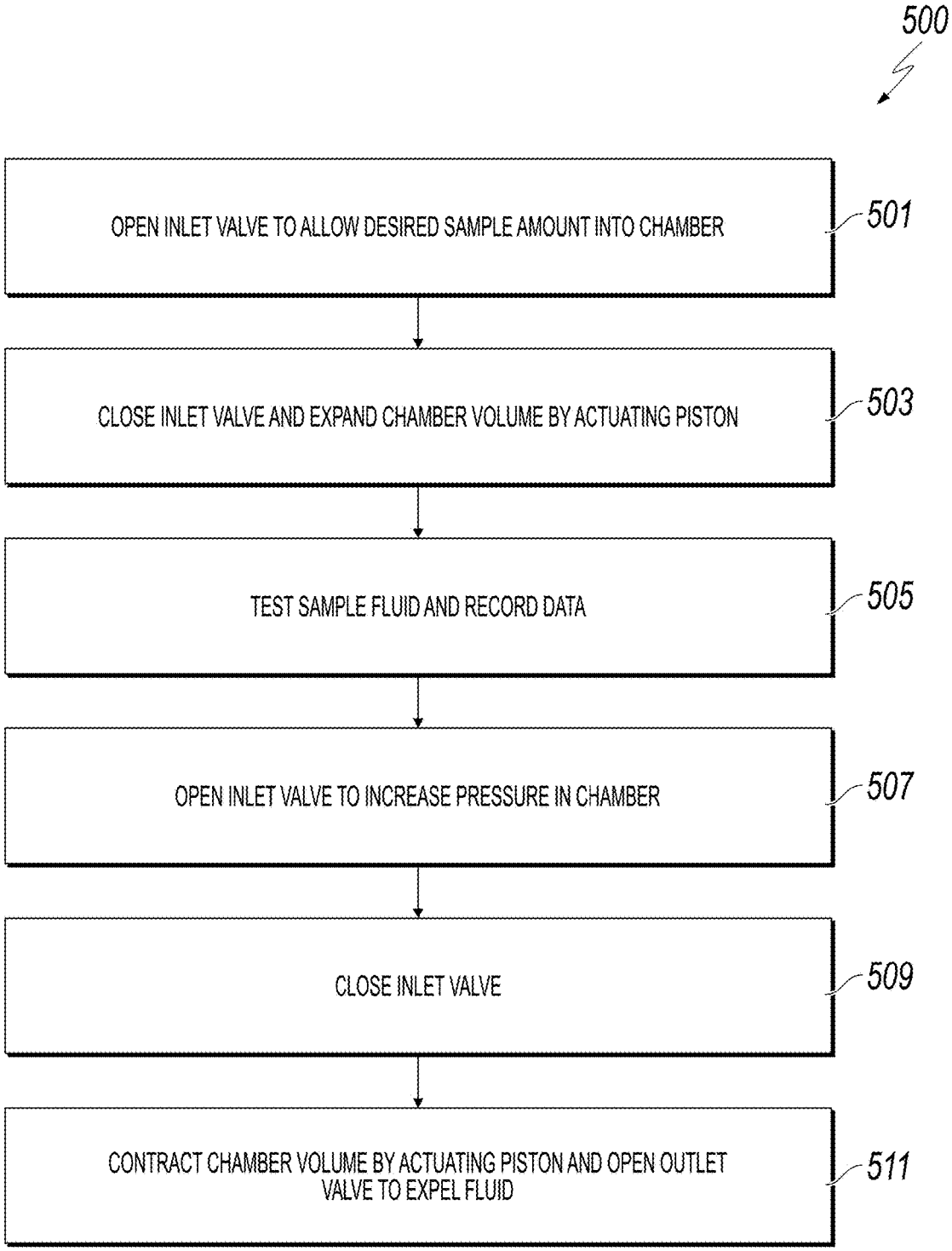
500
OPEN INLET VALVE TO ALLOW DESIRED SAMPLE AMOUNT INTO CHAMBER
501
CLOSE INLET VALVE AND EXPAND CHAMBER VOLUME BY ACTUATING PISTON
503
TEST SAMPLE FLUID AND RECORD DATA
505
OPEN INLET VALVE TO INCREASE PRESSURE IN CHAMBER
507
CLOSE INLET VALVE
509
CONTRACT CHAMBER VOLUME BY ACTUATING PISTON AND OPEN OUTLET VALVE TO EXPEL FLUID
511

FIG. 5

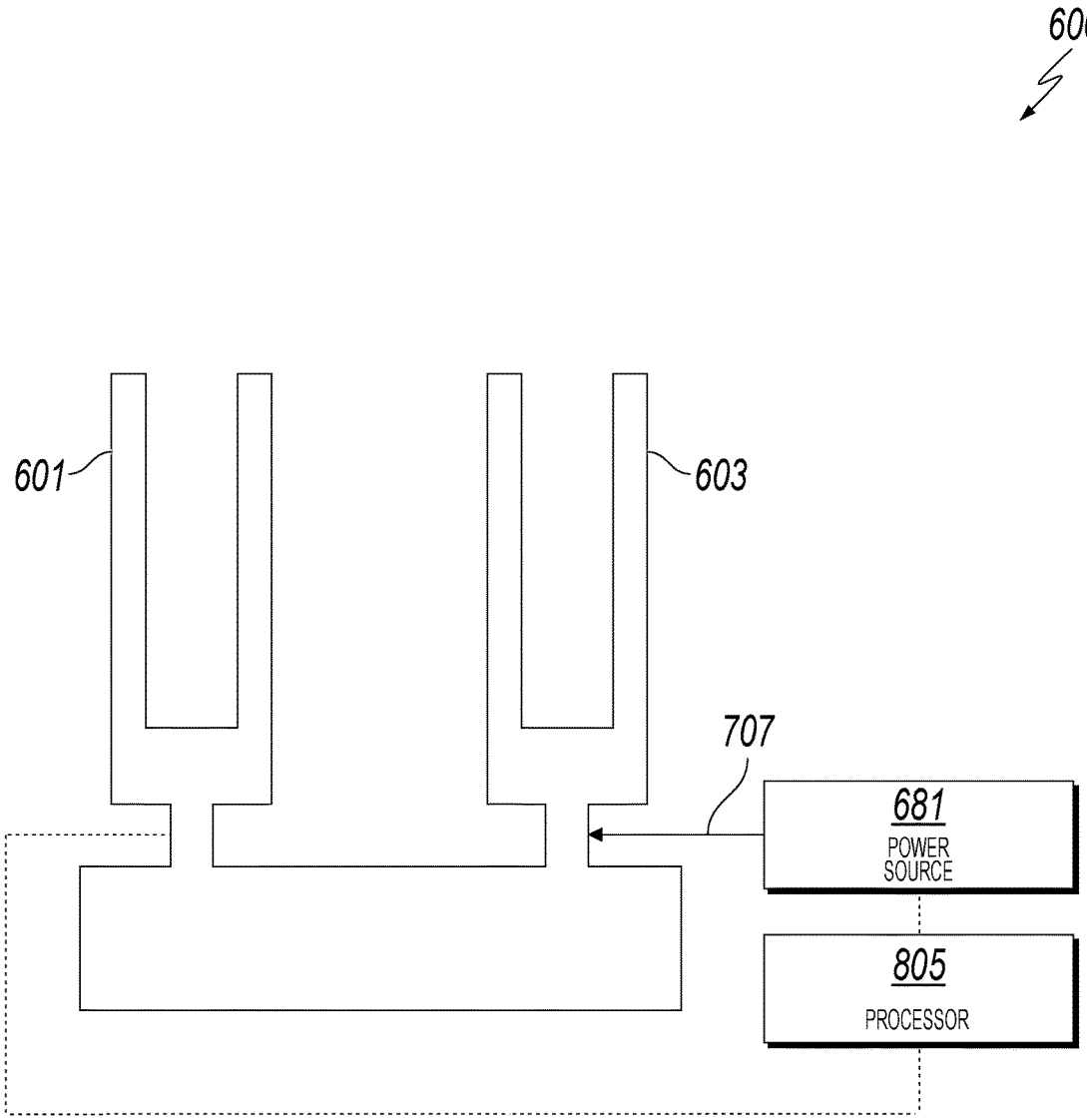

FIG. 6

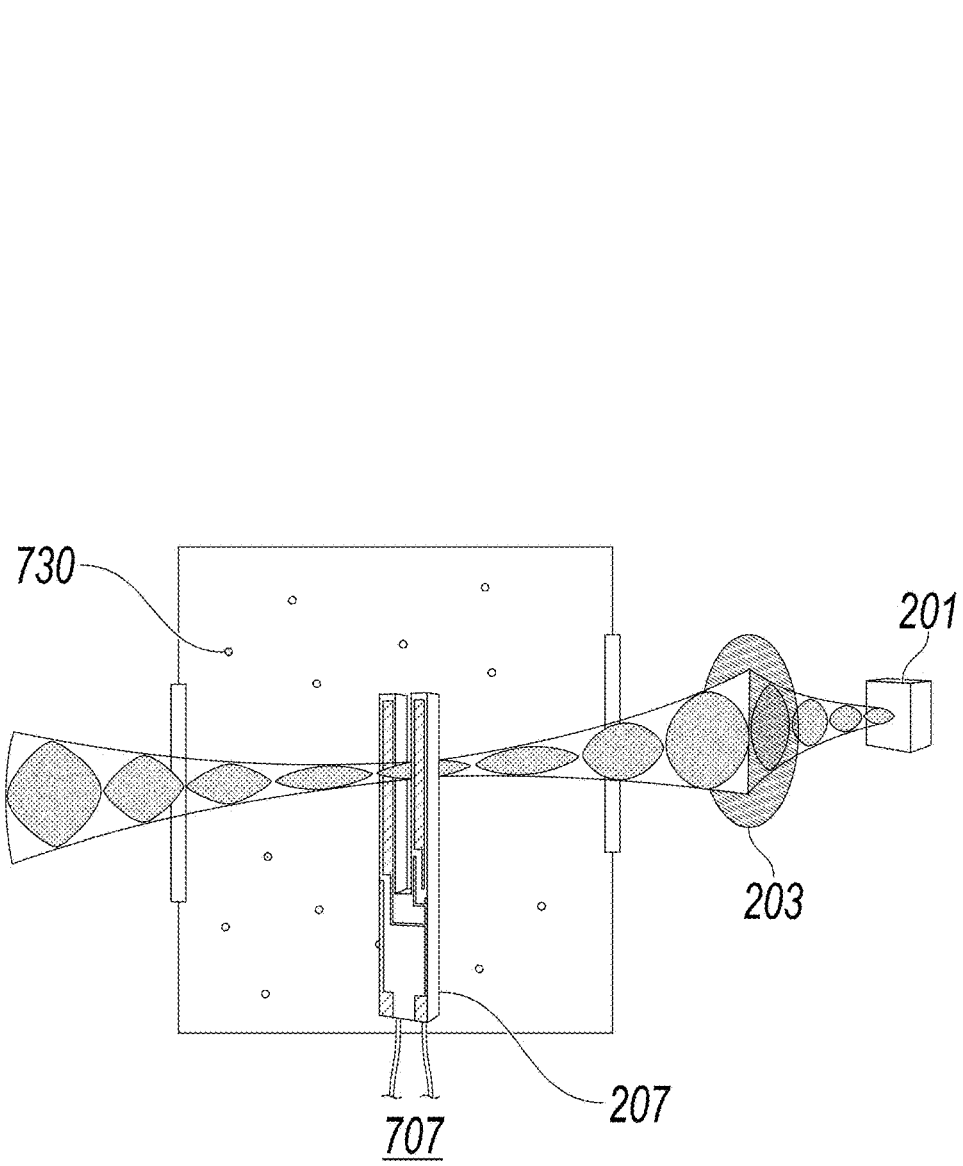

FIG. 7

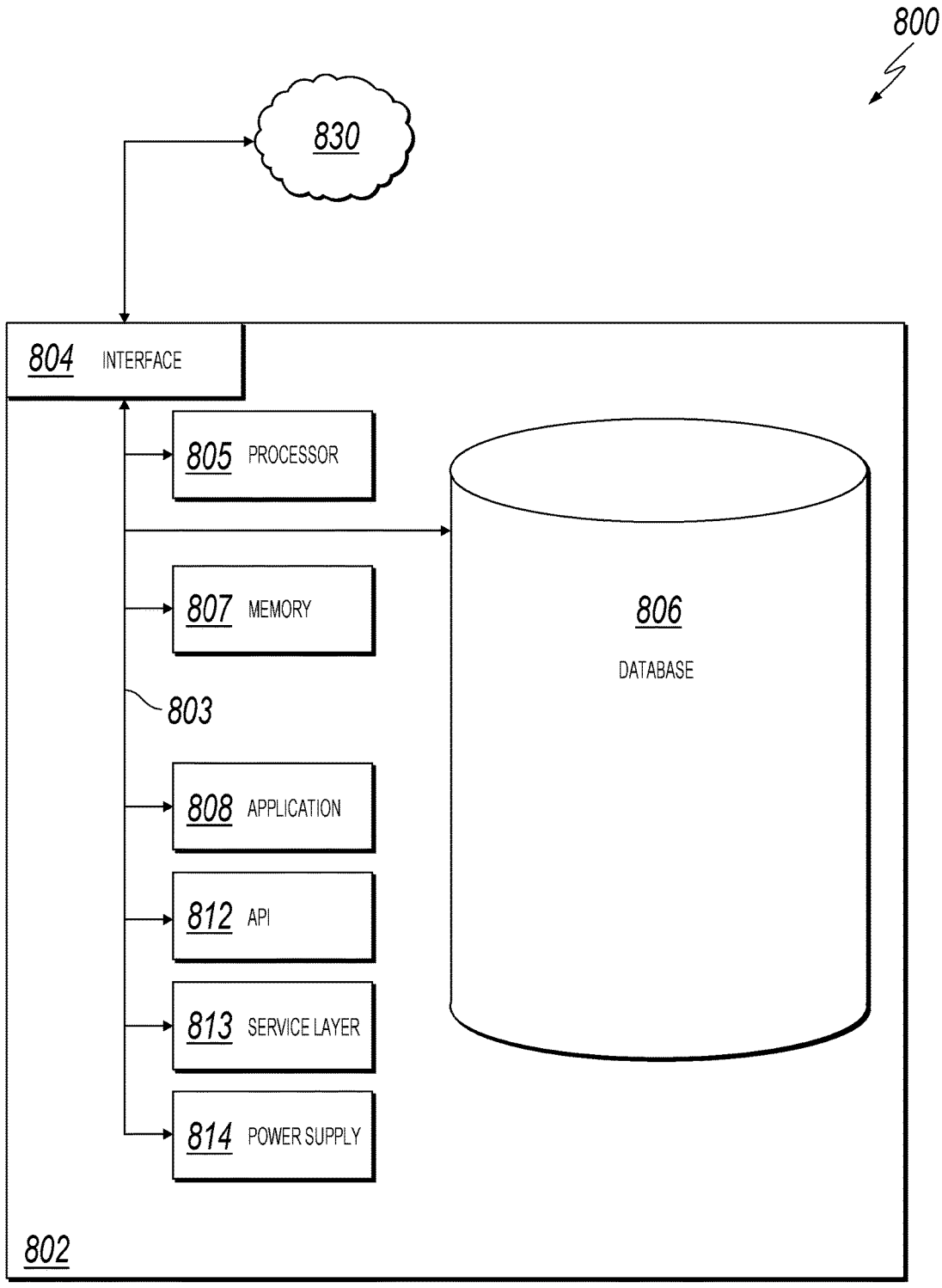
800
830
804 INTERFACE
805 PROCESSOR
807 MEMORY
803
808 APPLICATION
812 API
813 SERVICE LAYER
814 POWER SUPPLY
806
DATABASE
802

FIG. 8

PHOTOACOUSTIC GAS DETECTION

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims the benefit of priority to U.S. Provisional Application Ser. No. 62/531,050, filed Jul. 11, 2017, the contents of which are hereby incorporated by reference.

TECHNICAL FIELD

This specification relates to hydrocarbon gas detection in reservoirs using photoacoustic spectroscopy.

BACKGROUND

Commercial-scale hydrocarbon production from source rocks and reservoirs requires significant capital. It is therefore beneficial to obtain as much accurate data as possible about a formation in order to assess its commercial viability and subsequently to optimize cost and design of development. Hydrocarbon monitoring—especially of methane, ethane, and propane—can be used to predict production, estimate reserves, and assess raw material quality of source rocks and reservoirs. Exploration, reservoir design, and petrochemical manufacturing design are only a few of the many areas that can benefit from comprehensive hydrocarbon monitoring data.

SUMMARY

This specification relates to hydrocarbon gas detection in reservoirs using photoacoustic spectroscopy. Certain aspects of the subject matter described here can be implemented as a system. A downhole system includes a quartz enhanced photoacoustic spectrometer (QEPAS) configured to be positioned within a wellbore formed in a subterranean zone of a hydrocarbon formation, a sampling system coupled to the QEPAS, and a computer system connected to the QEPAS. The sampling system is configured to be positioned in the wellbore and obtain a sample of a wellbore fluid at a downhole location in the subterranean zone. The QEPAS is configured to spectroscopically scan the sample and to determine a plurality of quantities of a corresponding plurality of hydrocarbons in the same. The computer system includes one or more processors and a computer-readable medium storing instructions executable by the one or more processors to perform operations including receiving the plurality of quantities of the plurality of hydrocarbons in the sample and determining a plurality of ratios, where each ratio is a ratio of one of the plurality of hydrocarbons with another of the plurality of hydrocarbons.

This, and other aspects, can include one or more of the following features. The operations can include receiving the plurality of ratios as an input to a design simulation of the hydrocarbon formation and computationally simulating the hydrocarbon formation based, in part, on the plurality of ratios. The QEPAS can include a laser that can be configured to emit light at a wavelength range at which the plurality of hydrocarbons in the sample are simultaneously detectable. The QEPAS can include a plurality of lasers, and each laser can be configured to emit light at a respective wavelength at which a respective hydrocarbon of the plurality of hydrocarbons in the sample is detectable. The QEPAS can include a hydrogen sulfide (H_2S) laser that can be configured to emit light at a wavelength at which H_2S in the sample is detectable. The QEPAS can include a quartz tuning fork (QTF) that can be configured to detect a pressure wave created in a gas in the sample and a laser configured to emit light, and the pressure wave can be created as the light is absorbed by the gas. The QEPAS can include a signal modulator that can be configured to periodically switch a laser injection current to the laser between an on state and an off state or an optical chopper to optically chop the light emitted by the laser. The signal modulator can be configured to generate a periodic function to modulate a frequency of the light. The quality factor (Q factor) of the QTF can be on the order of tens of thousands. The QTF can be a first, passive QTF. The QEPAS can include a second, active QTF configured to induce a pressure wave in the gas, and the first, passive QTF can be configured to detect the induced pressure wave.

The system can include a power source connected to the processor, and the power source can be configured to drive the second, active QTF in response to receiving a signal from the processor. The processor can be configured to transmit the signal to the second, active QTF based on a signal received from the first, passive QTF. The system can include a temperature controller configured to maintain a temperature of the QEPAS. The sampling system can include a chamber, a piston positioned within the chamber, an inlet valve fluidically connected to a chamber inlet, and an outlet valve fluidically connected to a chamber outlet. The piston can seal an inner surface of the chamber to define a sample receiving volume, where the QTF can be positioned within the sample receiving volume. A retraction of the piston in the sample receiving volume and an opening of the inlet valve can cause the sample to flow into the sample receiving volume. An advancement of the piston in the sample receiving volume and an opening of the outlet valve can cause the sample to flow out of the sample receiving volume. The sample can be a two-phase sample including a gas and a liquid. The inlet valve can be configured to de-pressurize the sample to separate the gas from the liquid, and the gas can rise to an upper portion of the sample receiving volume while the liquid can reside in a lower portion of the sample receiving volume. The QEPAS can be configured to spectroscopically scan the gas in the upper portion.

Certain aspects of the subject matter described here can be implemented as a method. A quartz enhanced photoacoustic spectrometer (QEPAS) is positioned at a downhole location within a wellbore formed in a subterranean zone of a hydrocarbon formation. A sample of a wellbore fluid at the downhole location in the subterranean zone is obtained, and the sample is spectroscopically scanned using the QEPAS at the downhole location. A plurality of quantities of a corresponding plurality of hydrocarbons in the sample are determined, and a plurality of ratios, each ratio being a ratio of one of the plurality of hydrocarbons with another of the plurality of hydrocarbons, are determined.

This, and other aspects, can include one or more of the following features. The method can include computationally simulating the hydrocarbon formation based, in part, on the plurality of ratios. Spectroscopically scanning the sample can include emitting light from a single laser to simultaneously detect the plurality of hydrocarbons. Spectroscopically scanning the sample can include emitting a plurality of rays of light from a corresponding plurality of lasers, where each laser can be configured to detect a hydrocarbon of the plurality of hydrocarbons. Spectroscopically scanning the sample can include modulating light emitted by a laser that can be configured to detect the plurality of hydrocarbons.

The details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the following description. Other features, aspects, and advantages of the subject matter will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an example downhole gas detection system.

FIG. **2** is a schematic diagram of an example photoacoustic spectroscopy system.

FIG. **3** is a flow chart illustrating an example method for downhole gas detection.

FIG. **4**A is a schematic diagram of an example sampling system.

FIGS. **4**B & **4**C are flow diagrams of fluid movement in an example sampling system.

FIG. **5** is a flow chart illustrating an example method for downhole gas sampling.

FIG. **6** is a diagram of an example tuning fork used in photoacoustic spectroscopy.

FIG. **7** is a schematic diagram of an example active tuning of a tuning fork used in photoacoustic spectroscopy.

FIG. **8** is a block diagram illustrating an example computer system.

Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

This disclosure describes systems for detecting hydrocarbon gas in reservoirs using photoacoustic spectroscopy. Extracting hydrocarbons from a source rock or a reservoir involves drilling a borehole into the earth with a rotating drill bit attached to a drill string. Downhole devices can take measurements of subterranean operating parameters and various fluid characteristics. Downhole devices that take measurements during the drilling process can be referred to as logging-while-drilling (LWD) or measurement-while-drilling (MWD) devices, while downhole devices that take measurements after drilling can be referred to as wireline logging devices.

Information gathered from a subterranean zone with these devices can be analyzed to evaluate and map a hydrocarbon formation. The analysis can be used to guide well placement, also referred to as geo-steering, so that the wellbore remains within a zone of interest or in the most economically productive portion of a reservoir. Therefore, these devices have helped facilitate the shift of well construction from geometrical designs to designs steered by geological information and have also been utilized to successfully design wells with deviation, extended-reach, and horizontal boreholes to extract hydrocarbons from more difficult and marginal reservoirs. These devices are valuable not only for making informed wellsite decisions, but also for long-term reservoir planning and development.

FIG. **1** is a schematic diagram of an example downhole gas detection system **100**. The gas detection module **101** can travel down and be positioned along a drill string **110** within a wellbore **161** formed in a subterranean zone of a hydrocarbon formation. The drill string **110** can be supported by packers or anchors **107** at various points along the wellbore **161**. The gas detection module **101** includes a quartz enhanced photoacoustic spectrometer (QEPAS) system **200** (described later) and a sampling system **400** (described later) that can be coupled to the QEPAS system **200**. The gas detection system **100** as shown in FIG. **1** is shown as being implemented in a vertical orientation. The gas detection system **100** can also be implemented in horizontal and slanted wellbores. The gas detection module **101** can be positioned in the wellbore **161** and obtain a sample of a wellbore fluid at a downhole location in the subterranean zone, such as a wellbore annulus **130** or a rock formation **160**. The gas detection module **101** can spectroscopically scan the sample and determine multiple quantities of corresponding hydrocarbons in the sample. The gas detection module **101** can allow fluid to enter through an inlet line **103** and to exit through an outlet line **105**.

Still referring to FIG. **1**, the gas measurement data from the gas detection module **101** is sent to a surface process **190**. The gas detection module **101** can spectroscopically scan a gas sample and measure the composition of various hydrocarbons, such as methane (C_1), ethane (C_2), propane (C_3), butane (C_4), and their isotopologues, in a wellbore fluid. The hydrocarbon isotopologues can include carbon isotopes such as ^{13}C or ^{12}C. The hydrocarbon isotopologues can include hydrogen isotopes such as deuterium (D). Some non-limiting examples of hydrocarbon isotopologues are $^{13}CH_3D$, $^{12}CH_3D$, $^{12}CH_4$, and $^{12}CH_2D_2$. The surface process **190** includes a computer system **800** (described later) that includes a processor and a computer-readable medium that can store instructions executable by the processor in order to receive quantities of hydrocarbons in the sample, analyze the various hydrocarbons, and determine hydrocarbon ratios, such as ratio of C_1/C_4, and isotopic ratios, such as $^{13}C/^{12}C$, of a wellbore fluid. The surface process **190** includes incorporating the obtained and manipulated data such as hydrocarbon ratios as input to a mapping, model, or design simulation of a hydrocarbon formation or reservoir. The mapping, model, or simulation, which can be based on multiple hydrocarbon ratios at various locations in the wellbore, can be computational and can be utilized to forecast field performance and production of the formation or reservoir.

FIG. **2** is a schematic diagram of an example of a QEPAS system **200** for the downhole gas detection module **101**. The QEPAS system **200** detects gases utilizing a laser **201** and a quartz tuning fork (QTF) **207** as a detector for a pressure wave induced or created in a gas. The QEPAS system **200** can detect gas composition with sensitivities on the level of parts per trillion (ppt) due to the characteristically large quality factor (Q factor) of the QTF, for example, a Q factor on the order of tens of thousands (10,000) at normal atmospheric pressure. Conventional laser-based spectroscopic techniques, such as tunable diode laser absorption spectroscopy or cavity ring down spectroscopy, typically utilize photodetectors or photodiodes that require a cooling system, such as a thermoelectric or nitrogen-based cooling system, and can be relatively large in size. In some implementations, the QEPAS system **200** is independent of a cooling system, and the laser utilized in the QEPAS system **200** can be tailored to operate at elevated temperatures, such as approximately 45 degrees Celsius (° C.) to 200° C., which is typically characteristic of downhole applications. The QEPAS system **200** can therefore be applied as a portable gas detection system at a wellsite or in the borehole (wireline or LWD).

The QEPAS system **200** includes a tunable laser **201**, which can be a distributed feedback (DFB) quantum cascade laser (QCL), external cavity (EC) QCL, or interband cascade laser (ICL), that emits a laser beam **202**. Examples of lasers include indium arsenide antimonide (InAsSb) lasers with

wavelengths of approximately 1800 to 3000 nanometers (nm), indium gallium arsenide phosphide (InGaAsP) lasers typically used in telecommunication with wavelengths of approximately 1300 to 1700 nm, which can be used for methane detection, and other similar lasers for hydrogen sulfide (H_2S). DFB lasers can be suitable candidates for the QEPAS system **200** as they typically have narrow laser beam **202** widths. Typically, the wavelength (and concurrently, the frequency) of the laser is varied by changing the driving current **211**. The QEPAS system **200** can optionally include a temperature controller **219** to maintain the temperature greater than a borehole temperature. For example, a production field temperature could be approximately 90° C., so the controller **219** could maintain the QEPAS system **200** temperature at approximately 95° C. The laser beam passes through a lens **203** and enters a chamber **401** through a window **205**A. The chamber **401** contains a gas to be tested, for example, a mixture of hydrocarbons and water vapor. As the laser beam **202** travels through the gas, some light is absorbed by the gas sample, and a pressure wave is induced or created in the gas sample. The QEPAS system **200** includes a quartz enhanced tuning fork (QTF) **207** that can detect a pressure wave created in a gas sample. The laser **201** can be tuned to a selected frequency and emit light through the gas such that the gas absorbs some of the light and gets heated, thereby creating a small pressure wave, for example, in a range of approximately 10^{-8} torr to approximately 10^{-3} torr. The pressure wave can be detected by the QTF **207** as the laser beam **202** travels between prongs of the QTF **207**. In some implementations, the laser **201** is modulated at half the resonance frequency of the QTF **207**. The response from the QTF **207** is processed by a lock-in amplifier **213**, which demodulates the QEPAS signal at the QTF resonance frequency. The resonance frequencies can vary from 32 kilohertz (kHz) for standard tuning forks typically employed for timing applications, down to a few kHz (for example, approximately 1 kHz or in a range of approximately 1 kHz to approximately 9 kHz) for custom tuning forks devoted to gas spectroscopy. Then the signal is acquired and analyzed by a processor or computer **250**.

These components can vary depending on the spectral range and targeted molecule in the gas sample. In some implementations, the QEPAS laser **201** can emit light at a wavelength range at which multiple hydrocarbons can be detected simultaneously within a sample because of its wide laser (light) wavelength tuning range, for example, approximately 8 nm. In some implementations, the QEPAS system **200** can be designed to includes multiple lasers if the spectral range covered by the hydrocarbons absorption features is too wide. Multiple laser chips can be packaged on a carrier, and multiple beam splitters can be used to couple the lasers with the tuning fork. In the case with multiple lasers, each laser can be driven one at a time, such that the response of the fork can be acquired from a sample. Each laser can emit light at a respective wavelength corresponding to a molecule such as a hydrocarbon detectable in the sample, for example, one laser for methane and one laser for propane. The QEPAS system **200** can optionally include a dedicated H_2S laser configured to emit light at a wavelength at which H_2S is detectable in the sample gas. A sinusoidal dither **241** can be applied in tuning the laser **201**.

In some implementations, the laser beam **202** is split by a beam-splitter **231**, and a portion of the laser beam **202** is sent to a photodetector **233** through a reference cell **235** containing a concentration of the target gas. The photodetector **233** can send a signal to the lock-in amplifier **213** and pass to the processor or computer **250** where the signal is processed, and the results can be used to tune the laser **201**.

The QEPAS system **200** can optionally include a photodetector **215** to tune the laser **201**. The laser beam **202** can exit the chamber **401** through a window **205**B and be detected by the photodetector **215**. The photodetector **215** can send a signal to the processor or computer **250** where the signal is processed, and the results can be used to tune the laser **201**. The QEPAS system **200** can optionally include micro-resonator tubes **217** which can enhance the QEPAS signal and confine the induced pressure wave. The micro-resonator tubes **217** can include two thin tubes aligned perpendicular to the QTF **207** plane, in line with the laser beam **202**, and carefully positioned, so that the laser beam **202** enters the micro-resonator tubes **217**, but does not touch the walls of the micro-resonator tubes **217** in order to avoid photothermal effects.

FIG. **3** is a flow chart of an example method **300** for detecting gases downhole. At step **301**, a gas detection module, such as the gas detection module **101** shown in FIG. **1**, is positioned at a downhole location. Positioning the gas detection module can include lowering the gas detection module **101** into a borehole with an electrical cable after drilling, which is characteristic of wireline logging. The gas detection module **101** can optionally be a component of a drill collar in a bottomhole assembly, in which case the module **101** travels along a wellbore while drilling occurs, which is a characteristic of LWD or MWD devices. In the case the gas detection module **101** is a component of the bottomhole assembly, the module **101** can take measurements at various depths and points of a reservoir as a well is drilled.

Once the gas detection module **101** is located at a desired point downhole, the gas detection module **101** allows borehole fluid into a testing chamber **401** of the module **101** at step **303**. The fluid can be extracted from a wellbore annulus **130** or a rock formation **160**. Once a desired volume of fluid is allowed into the testing chamber **401**, the gas detection module **101** can be isolated to prevent fluid from entering or exiting the testing chamber **401**. At step **305**, the fluid in the chamber **401** is tested with a QEPAS system, such as the QEPAS system **200** shown in FIG. **2**. At step **307**, a surface process **190** which includes a computer system **800** can determine the quantities of several hydrocarbons in the sample, such as methane and propane. At step **309**, the computer system **800** can determine the ratios of several hydrocarbons in the sample, such as C_1/C_3 ratio. The computer system **800** can also determine the ratios of carbon isotopes in a sample, such as $^{13}C/^{12}C$. After the fluid is tested, the fluid is expelled from the chamber **401** at step **311**. Once the chamber **401** is evacuated, the method **300** can cycle to step **301** at another downhole location. The surface process steps **307** and **309** can optionally be completed after sampling data has been compiled at various downhole points because the data can be coupled with depth or location data that can later be used to model or simulate a formation and also to develop the design of a reservoir.

FIG. **4**A is a schematic diagram of an example of a sampling system **400** for the downhole gas detection module **101**. The sampling system **400** can include a chamber inlet line **103**, an inlet valve **413**, a chamber outlet line **105**, an outlet valve **415**, a chamber **401**, a piston **461**, and a piston actuator **463**. The inlet valve **413** can open to allow a fluid to flow through the chamber inlet line **103** and into the sample receiving volume of the chamber **401**. The chamber inlet **103** can be configured to bring in fluid from the wellbore annulus **130** (as shown) or the rock formation **160**.

The outlet valve **415** can open to allow a fluid to travel out of the sample receiving volume of the chamber **401** and through the chamber outlet line **105**. The chamber outlet **105** can be configured to expel fluid to the wellbore annulus **130** (as shown) or the rock formation **160**. The chamber **401** can have a cylindrical or cuboidal shape. For example, the chamber **401** can be cylindrical with a diameter in a range of approximately 0.38 inches (in) to 3.63 in and a length in a range of approximately 4 in to 96 in. The piston **461** seals an inner surface of the chamber **401**, which determines the sample receiving volume in the chamber **401**. For example, the piston **461** can be a cylinder and have grooves for seals that close off the space between the piston **461** and the walls of the chamber **401**. The volume can be varied by retracting or advancing the piston **461** with the actuator **463**. The actuator **463** can utilize, for example, mechanical screw drives, pressure actuation, or driven gears. In relation to the QEPAS system **200** (shown in FIG. **2**), the QTF **207** can be located in the upper portion of the chamber **401**, and the laser beam **202** produced by the laser **201** can pass through the chamber **401** and between the prongs of the QTF **207**.

FIGS. **4**B and **4**C illustrate the movement of fluid through the sampling system **400** for the downhole gas detection module **101**. Referring to FIG. **4**B, to bring fluid into the chamber **401**, the inlet valve **413** can be opened partially or fully, the outlet valve **415** can be closed, and the piston **461** can be retracted by the actuator **463** to increase the volume of the chamber **401**. Referring to FIG. **4**C, to expel fluid out of the chamber **401**, the outlet valve **415** can be opened partially or fully, the inlet valve **413** can be closed, and the piston **461** can be advanced by the actuator **463** to decrease the volume of the chamber **401**.

FIG. **5** is a flow chart of an example method **500** for sampling a downhole fluid. At step **501**, the inlet valve **413** is opened to allow a desired amount of fluid into the chamber **401**. The sample can have multiple phases. For example, the sample can be a two-phase sample of liquid and gas. As the fluid travels through the inlet valve **413**, the sample fluid can de-pressurize. In other words, the fluid's pressure can be reduced as it travels through the inlet valve **413**. The reduction in pressure can cause the fluid to flash (evaporate) across the inlet valve **413**. At step **503**, the inlet valve **413** is closed to stop flow of fluid into the chamber **401**. The volume of the chamber **401** is increased by retracting the piston **461** with the actuator **463**. The increase in volume of the chamber **401** further reduces the pressure inside the chamber **401**. The resulting pressure inside the chamber **401** can be close to atmospheric pressure, for example, 0 pounds per square inch gauge (psig). As a result of the decreased pressure in the chamber **401**, a majority of the fluid is vapor. For example, the liquid phase of the fluid can make up 0% to 4% of the volume of the chamber **401**. Any liquid within the chamber **401** travels to a lower portion of the sample receiving volume in the chamber **401** and can optionally be drained before the fluid is tested. The vapor or gas can rise to an upper portion of the sample receiving volume in the chamber **401**. At step **505**, the fluid can be tested, for example, by the QEPAS system **200**, and the data can be recorded. The QEPAS system **200** can be configured to spectroscopically scan the sample gas in the upper section of the chamber **401**. Once testing is complete, the inlet valve **413** is opened to allow additional fluid to enter the chamber **401** at step **507**. At downhole locations, the pressure of borehole fluid can be, for example, 6,000 psig or greater. By allowing additional borehole fluid to enter the chamber **401**, the pressure in the chamber **401** can increase to equal the borehole pressure. At step **509**, the inlet valve **413** is closed. At step **511**, the outlet valve **415** is opened, and the volume of the chamber **401** is decreased by advancing the piston **461** with the actuator **463**. The decrease in volume of the chamber **401** increases the pressure within the chamber **401** and allows fluid to travel out of the chamber **401** through outlet valve **415**. The method **500** can cycle to step **501** at another downhole location or at the same location in the case that multiple data runs are desired. At another downhole location, the gas detection module **101** can optionally cycle through allowing fluid into the chamber **401** and expelling fluid out of the chamber **401** in order to purge any fluid that is carried from a previous location.

FIG. **6** illustrates an example of a dual QTF **600** that can be part of a QEPAS system **200**. The QEPAS signal can be enhanced utilizing parametric amplification. The dual QTF **600** can include two tuning forks **601** and **603** that are mechanically coupled. The dimensions and size of the QTF **601** can vary, for example, from 3.2 to 20 millimeters (mm) in prong length, 0.25 to 0.8 mm in prong width, 0.34 to 1.4 mm in thickness, and 0.3 to 1 mm in prong spacing. In some implementations, QTF **601** can be a first, passive signal detector of a QEPAS system **200** that can detect an induced pressure wave in the gas sample. The QEPAS system **200** can include a power source **681** that can provide a current **707** to a second, active QTF **603**, that can serve as the signal amplifier and can be driven non-linearly and induce a pressure wave in the gas sample. The processor **805** (described in more detail later) can receive a signal from the first, passive QTF **601**. In response to the signal from the first, passive QTF **601**, the processor **805** can transmit a signal to the power source **681** that provides the current **707** to the second, active QTF **603**. The dual QTF **600** can be described as a coupled resonating system where tuning fork **601** has a frequency f, and tuning fork **603** has a frequency 2f. In some implementations, a resonator or amplifier can be made of magnetic material and embedded in a varying magnetic field to enhance the resonance and therefore, the QEPAS signal. Parametric amplification can enhance resonance, especially in cases where the QEPAS signal can be degraded, such as when the sample gas is wet. In downhole conditions, gases such as methane can be wet, for example 100% saturation of methane. The QEPAS signal can also be degraded when the sample gas is at a greater pressure than atmospheric pressure. Another case in which the QEPAS signal can be degraded is when the sample gas includes large concentrations of a gas, such as in gas wells, where the methane concentration can be approximately 60% to 80% or even greater.

The tunability of lasers, such as QCLs, can be combined with various modulation techniques to allow a spectroscopic gas sensor, such as a QEPAS, to reach detection sensitivities, for example, on the order of parts per trillion compositions of components. Amplitude modulation (AM) can include switching a laser injection current to a laser, for example QEPAS laser **201**, between on state and off state by a signal modulator or optically chopping the light or laser beam **202** emitted by the laser **201** with an optical chopper. Wavelength modulation (WM) can include modulating the frequency of the light or laser beam **202** by a signal modulator with a periodic function, such as a sine wave. WM inherently modulates frequency, as wavelength is the inverse of frequency. With WM, any noise centered at the QTF **207** detection frequency and within the detection bandwidth or range can affect trace gas measurements, and noise outside the detection bandwidth do not. The interaction between the chemical components to be detected and the modulated light or laser beam **202** can lead to a generation of signals at the

modulation frequency and its harmonics. Each harmonic of the analytical WM signal can be detected with phase-sensitive detection devices, such as a lock-in amplifier. For gas sensing techniques based on cavity-enhanced and multi-pass absorption cell, the choice of modulation frequency can be limited by the detection bandwidth. The detection bandwidth can be chosen to limit 1/f laser noise, but exceeding 100 kHz, for example, is not necessary because noise can level off at frequencies greater than or equal to approximately 100 kHz. With QEPAS, the modulation frequency matches the resonance frequency of the QTF **207** or its sub-harmonics, but resonance frequencies exceeding 40 kHz, for example, can be unsuitable, as they can exceed the vibration-translational relaxation rates of a target gas.

WM can include dithering the laser **201** injection current with a sine function, which can result in simultaneous AM and WM with a phase-shift that depends on the laser **201**. The WM description can be based on an intensity representation of an optical wave, so that the absorption of the sample can be considered, and the dispersion effects due to the sample can be neglected. The WM description can be based on the instantaneous laser frequency:

$$\nu(t)=\nu_0-\Delta\cos(\omega t) \tag{1}$$

where ν_0 is the optical carrier frequency and $\omega=2\pi f$ is the modulation angular frequency due to the laser injection current that is modulated at the same angular frequency.

In addition to frequency modulation, the current waveform applied to the laser **201**, such as a QCL, can produce a sinusoidal modulation of the laser intensity:

$$I(t)=I_0+\Delta I\cos(\omega t) \tag{2}$$

where the amplitude ΔI of the sinusoidal intensity modulation is determined by the slope of the laser power versus the current characteristics, which can be assumed constant across a wavelength scan.

The instantaneous laser frequency can interact with the absorption feature. The absorption coefficient $\alpha(\nu(t))$ for a small $\Delta\nu$ around the absorption feature considered can be expanded:

$$\alpha(\nu(t))= \tag{3}$$
$$\alpha_0+\left(\frac{\partial\alpha}{\partial\nu}\middle|\nu=\nu_0\right)\Delta\nu\cos(\omega t)+\frac{1}{2}\left(\frac{\partial^2\alpha}{\partial\nu^2}\middle|\nu=\nu_0\right)(\Delta\nu)^2\cos^2(\omega t)+\ldots$$

where α_0 can be considered to be the background absorption contribution. The laser **201** can be modulated both in intensity and in wavelength simultaneously. From the Lambert-Beer law, a small absorption I_{abs} can be expressed as:

$$I_{abs}(t)=(I_0+\Delta I\cos(\omega t)) \tag{4}$$
$$\left[1-L\left(\alpha_0+\left(\frac{\partial\alpha}{\partial\nu}\middle|_{\nu=\nu_0}\right)\Delta\nu\cos(\omega t)+\frac{1}{2}\left(\frac{\partial^2\alpha}{\partial\nu^2}\middle|_{\nu=\nu_0}\right)(\Delta\nu)^2\cos^2(\omega t)\right)\right]$$

where L is the effective length over which the absorption takes place to produce an acoustic wave that can be detected by the QTF **207**. L can be comparable to the thickness of the QTF **207**. The 1ω-signal, $S_{1\omega}$, can be expressed as:

$$S_{1\omega}=L\Delta I\alpha_0-L\left(\frac{\partial\alpha}{\partial\nu}\middle|_{\nu=\nu_0}\right)\Delta\nu \tag{5}$$

and the 2ω-signal, $S_{2\omega}$, can be expressed as:

$$S_{2\omega}=-L\Delta I\frac{\partial\alpha}{\partial\nu}\middle|_{\nu=\nu_0}\Delta\nu+\frac{I_0}{2}\left(\frac{\partial^2\alpha}{\partial\nu^2}\middle|_{\nu=\nu_0}\right)(\Delta\nu)^2 \tag{6}$$

Referring to Eqs. 5 and 6, the background absorption α_0 contributes to $S_{1\omega}$ and does not contribute to $S_{2\omega}$. If the absorption coefficient is assumed to have a pure Lorentzian line shape, $S_{1\omega}$ can have a pure first derivative line shape with constant background, and $S_{2\omega}$ can include two terms—a first term from a residual amplitude modulation that is proportional to the first derivative, and a second term from a laser wavelength modulation. $S_{2\omega}$ is not a pure second derivative of the Lorentzian line shape and is distorted by a contribution from the residual amplitude modulation. This distortion does not affect the peak position of $S_{2\omega}$ because the first derivative of the Lorentzian line shape vanishes when $\nu=\nu_0$.

The QEPAS signal can be demodulated by utilizing a lock-in amplifier at the fundamental frequency f or its successive harmonics nf. When the laser beam **202** is modulated at a resonance frequency f_0, and the QEPAS signal is demodulated at the same frequency, the demodulated signal can be called the 1f-QEPAS signal. When the laser beam **202** is modulated at a resonance frequency $f_0/2$, and the QEPAS signal is demodulated at f_0, the demodulated signal can be called the 2f-QEPAS signal. In the case of the 2f-QEPAS approach, the QTF **207** can detect sound oscillations at the second harmonic of the modulation frequency caused by a double intersection of the absorption line by the laser beam **202** during a modulation period.

A strong background signal can be observed for the 1f-QEPAS approach, originating from stray light from the walls of the chamber **401**. The amplitude of the offset can increase with increased misalignment of the laser beam **202** in lateral directions, so that the beam **202** tails touch the QTF **207**. The 2f-QEPAS approach can be background-free. Distortions in a demodulated signal displaying asymmetry on both sides of the spectrum around a peak can be attributed to an amplitude-intrinsic modulation contribution, which can be introduced by current modulation. The WM amplitude Δf and light intensity modulation ΔI can be manipulated to improve a 2f-QEPAS signal at various sample gas pressures.

In some implementations, the QTF **207** can be actively driven with a current as the QTF **207** detects a photoacoustic signal. FIG. **7** is a schematic diagram of an example of an actively driven QTF **207**. The laser source **201** produces a laser beam that can be modulated. The laser beam passes through the lens **203** and induces a pressure wave in a target gas **730**, such as methane. The tuning fork **207** detects the photoacoustic signal from the vibration of its prongs due to the induced pressure wave. In the case that the tuning fork **207** is actively driven with a current e(t) as it detects a photoacoustic x(t), according to the superposition principle, the received signal y(t) is:

$$y(t)=x(t)+e(t) \tag{7}$$

By actuating (or actively driving) the tuning fork with a current **707**, the photoacoustic signal can be modulated and shifted to a passband where: the signals associated with various gas peaks can be more easily separated; the signal versus noise ratio (SNR) can be improved, that is, increased at the passband in comparison to the noise floor; the actuation frequency can be tuned to achieve a better signal; and

a closed loop can be formed to compensate for pressure or temperature drift in the gas sample. The physical limit in the QEPAS system **200** detection is set by the thermal noise of the QTF **207** due to its resistance. QTF **207** (or resonator) resistance values can typically be on the order of magnitude of hundreds of kilo-ohms (kΩ), which can result in a thermal noise signal processed by a lock-in amplifier that is less than 1 microvolt (μV). In some implementations, the total noise given by the electrical component introduced by amplification stages and the optical component due to photothermal heating of the prongs by the laser beam **202**, can be kept as small as a few μV.

The driving current or excitation signal e(t) can be of any general form, for example, harmonic form. If the tuning fork **207** active excitation frequency is ω_e, then the excitation signal e(t) to the tuning fork **207** can be expressed as:

$$e(t)=\alpha_e \cos(\omega_e t+\phi_e) \tag{8}$$

where α_e and ϕ_e are the magnitude and initial phase, respectively. Similarly, the photoacoustic signal can be expressed as:

$$x(t)=\alpha_x \cos(\omega_x t+\phi_x) \tag{9}$$

Assuming there also exists noise n(t) in the received signal, the received signal y(t) can be expressed as:

$$\begin{aligned} y(t) &= x(t) + e(t) + n(t) \\ &= a_x\cos(\omega_x t + \phi_x) + a_e\cos(\omega_e t + \phi_e) + n(t) \end{aligned} \tag{10}$$

The demodulated signal z(t) can be obtained by multiplying the received signal y(t) by the excitation harmonic signal:

$$\begin{aligned} z(t) &= y(t)\cos(\omega_e t) \\ &= [x(t) + e(t) + n(t)]\cos(\omega_e t) \\ &= [a_x\cos(\omega_x t + \phi_x) + a_e\cos(\omega_e t + \phi_e) + n(t)] \\ &\quad \cos(\omega_e t) \end{aligned} \tag{11}$$

With trigonometric manipulation, the demodulated signal z(t) can also be expressed as:

$$\begin{aligned} z(t) = \frac{a_x}{2}[\cos((\omega_x - \omega_e)t + \phi_x) + \cos((\omega_x + \omega_e)t + \phi_x)] + \\ \frac{a_e}{2}[\cos(\phi_e) + \cos(2\omega_e t + \phi_e)] + n(t)\cos(\omega_e t) \end{aligned} \tag{12}$$

Referring to Eq. 12, only the terms within the first set of square brackets contain information about the photoacoustic signal, where the first term is located at a lesser frequency band corresponding to the difference between ω_x and ω_e, and the second term is at a greater frequency of $\omega_x+\omega_e$, either one of which can be separated from the other by filtering the photoacoustic signal z(t). In QEPAS applications, ω_x is generally determined by the photoacoustic effect following gas absorption of the laser energy, and is therefore associated with the molecular properties of the target gas **730**. With the active modulation scheme with driving current e(t), ω_e becomes the design parameter that can be chosen adaptively to increase SNR and improve tuning. In the case of photoacoustic signal drift due to temperature or pressure effects as the sample gas is subjected to laser illumination, ω_e can be adaptively adjusted to determine the amount or extent of frequency drifting and utilize that information to tune the laser source **201** to compensate accordingly. This adaptive pressure and temperature compensation can effectively form a closed feedback loop to iteratively adjust the laser frequency at which the target gas **730** molecules are excited in order to fine-tune the laser **201** and achieve greater sensitivities. The closed feedback loop can also be applicable to the dual QTF **600** shown in FIG. **6**.

FIG. **8** is a block diagram of an example computer system **800** used to provide computational functionalities associated with described algorithms, methods, functions, processes, flows, and procedures, as described in the instant disclosure, according to an implementation. The illustrated computer **802** is intended to encompass any computing device such as a server, desktop computer, laptop/notebook computer, wireless data port, smart phone, personal data assistant (PDA), tablet computing device, one or more processors within these devices, and physical or virtual instances (or both) of the computing device. Additionally, the computer **802** can include an input device that can accept user information, such as a keypad, keyboard, or touch screen and an output device that conveys information associated with the operation of the computer **802**, such as digital data, visual, or audio information (or a combination of information), or a graphical user interface (GUI).

The computer **802** can serve in a role, for example, as a client, network component, a server, a database, or a combination of roles of a computer system for performing the subject matter described in the instant disclosure. The illustrated computer **802** is communicably coupled with a network **830**. In some implementations, one or more components of the computer **802** can be configured to operate within environments, such as a cloud-computing-based environment, local environment, global environment, or combinations of these.

In summary, the computer **802** is an electronic computing device operable to receive, transmit, process, store, or manage data and information associated with the described subject matter. According to some implementations, the computer **802** can also include or be communicably coupled with an application server, e-mail server, web server, caching server, streaming data server, or a combination of servers.

The computer **802** can receive requests over network **830** from a client application (for example, executing on another computer **802**) and respond to the received requests by processing the received requests using an appropriate software application(s). In addition, requests can also be sent to the computer **802** from internal users (for example, from a command console), external users, third-parties, or combinations of these.

Each of the components of the computer **802** can communicate using a system bus **803**. In some implementations, any or all of the components of the computer **802**, hardware or software (or a combination of both hardware and software), can interface with each other or the interface **804** (or a combination of both), over the system bus **803** using an application programming interface (API) **812** or a service layer **813** (or a combination of the API **812** and service layer **813**). The API **812** can include specifications for routines, data structures, and object classes. The API **812** can be either computer-language independent or dependent and refer to a complete interface, a single function, or even a set of APIs. The service layer **813** provides software services to the computer **802** or other components (whether or not illus-

trated) that are communicably coupled to the computer **802**. The functionality of the computer **802** can be accessible for all service consumers using this service layer. Software services, such as those provided by the service layer **813**, provide reusable, defined functionalities through a defined interface. For example, the interface can be software written in JAVA or C++. While illustrated as an integrated component of the computer **802**, some implementations can illustrate the API **812** or the service layer **813** as stand-alone components in relation to other components of the computer **802** or other components (whether or not illustrated) that are communicably coupled to the computer **802**. Moreover, any or all parts of the API **812** or the service layer **813** can be implemented as child or sub-modules of another software module, enterprise application, or hardware module without departing from the scope of this disclosure.

The computer **802** includes an interface **804**. Although illustrated as a single interface **804** in FIG. **8**, two or more interfaces **804** can be used according to particular needs, desires, or particular implementations of the computer **802**. The interface **804** is used by the computer **802** for communicating with other systems that are connected to the network **830** (whether illustrated or not) in a distributed environment. Generally, the interface **804** comprises logic encoded in software or hardware (or a combination of software and hardware) and is operable to communicate with the network **830**. More specifically, the interface **804** can comprise software supporting one or more communication protocols associated with communications such that the network **830** or interface's hardware is operable to communicate physical signals within and outside of the illustrated computer **802**.

The computer **802** includes a processor **805**. Although illustrated as a single processor **805** in FIG. **8**, two or more processors can be used according to particular needs, desires, or particular implementations of the computer **802**. Generally, the processor **805** executes instructions and manipulates data to perform the operations of the computer **802** and any algorithms, methods, functions, processes, flows, and procedures as described in the instant disclosure.

The computer **802** also includes a database **806** that can store data for the computer **802** or other components (or a combination of both) that can be connected to the network **830** (whether illustrated or not). For example, database **806** can be an in-memory or conventional. In some implementations, database **806** can be a combination of two or more different database types (for example, a hybrid in-memory and conventional database) according to particular needs, desires, or particular implementations of the computer **802** and the described functionality. Although illustrated as a single database **806** in FIG. **8**, two or more databases (of the same or combination of types) can be used according to particular needs, desires, or particular implementations of the computer **802** and the described functionality. While database **806** is illustrated as an integral component of the computer **802**, in some implementations, database **806** can be external to the computer **802**.

The computer **802** also includes a memory **807** that can store data for the computer **802** or other components (or a combination of both) that can be connected to the network **830** (whether illustrated or not). For example, memory **807** can be random access memory (RAM), read-only memory (ROM), optical memory, or magnetic memory storing data consistent with this disclosure. In some implementations, memory **807** can be a combination of two or more different types of memory (for example, a combination of RAM and magnetic storage) according to particular needs, desires, or particular implementations of the computer **802** and the described functionality. Although illustrated as a single memory **807** in FIG. **8**, two or more memories **807** (of the same or combination of types) can be used according to particular needs, desires, or particular implementations of the computer **802** and the described functionality. While memory **807** is illustrated as an integral component of the computer **802**, in some implementations, memory **807** can be external to the computer **802**.

The application **808** is an algorithmic software engine providing functionality according to particular needs, desires, or particular implementations of the computer **802**, particularly with respect to functionality described in this disclosure. For example, application **808** can serve as one or more components, modules, or applications. Further, although illustrated as a single application **808**, the application **808** can be implemented as multiple applications **808** on the computer **802**. In addition, although illustrated as integral to the computer **802**, in some implementations, the application **808** can be external to the computer **802**.

The computer **802** can also include a power supply **814**. The power supply **814** can include a rechargeable or non-rechargeable battery that can be configured to be either user- or non-user-replaceable. In some implementations, the power supply **814** can include power-conversion or management circuits (such as recharging and standby). In some implementations, the power-supply **814** can include a power plug to allow the computer **802** to be plugged into a power source (such as a wall socket) to power, for example, the computer **802** or recharge a rechargeable battery.

There can be any number of computers **802** associated with, or external to, a computer system containing computer **802**, each computer **802** communicating over network **830**. Further, the term "client," "user," and other appropriate terminology can be used interchangeably, as appropriate, without departing from the scope of this disclosure. Moreover, this disclosure contemplates that many users can use one computer **802**, or that one user can use multiple computers **802**.

Implementations of the subject matter and the functional operations described in this specification can be implemented in digital electronic circuitry, in tangibly embodied computer software or firmware, in computer hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Software implementations of the described subject matter can be implemented as one or more computer programs, that is, one or more modules of computer program instructions encoded on a tangible, non-transitory, computer-readable computer-storage medium for execution by, or to control the operation of, data processing apparatus. Alternatively, or additionally, the program instructions can be encoded in/on an artificially generated propagated signal, for example, a machine-generated electrical, optical, or electromagnetic signal that is generated to encode information for transmission to suitable receiver apparatus for execution by a data processing apparatus. The computer-storage medium can be a machine-readable storage device, a machine-readable storage substrate, a random or serial access memory device, or a combination of computer-storage mediums.

The term "real-time," "real time," "realtime," "real (fast) time (RFT)," "near(ly) real-time (NRT)," "quasi real-time," or similar terms (as understood by one of ordinary skill in the art), means that an action and a response are temporally proximate such that an individual perceives the action and the response occurring substantially simultaneously. For

example, the time difference for a response to display (or for an initiation of a display) of data following the individual's action to access the data can be less than 1 millisecond (ms), less than 1 second, or less than 5 seconds. While the requested data need not be displayed (or initiated for display) instantaneously, it is displayed (or initiated for display) without any intentional delay, taking into account processing limitations of a described computing system and time required to, for example, gather, accurately measure, analyze, process, store, or transmit the data.

The terms "data processing apparatus," "computer," or "electronic computer device" (or equivalent as understood by one of ordinary skill in the art) refer to data processing hardware and encompass all kinds of apparatus, devices, and machines for processing data, including by way of example, a programmable processor, a computer, or multiple processors or computers. The apparatus can also be or further include special purpose logic circuitry, for example, a central processing unit (CPU), an FPGA (field programmable gate array), or an ASIC (application-specific integrated circuit). In some implementations, the data processing apparatus or special purpose logic circuitry (or a combination of the data processing apparatus or special purpose logic circuitry) can be hardware- or software-based (or a combination of both hardware- and software-based). The apparatus can optionally include code that creates an execution environment for computer programs, for example, code that constitutes processor firmware, a protocol stack, a database management system, an operating system, or a combination of execution environments. The present disclosure contemplates the use of data processing apparatuses with or without conventional operating systems, for example, LINUX, UNIX, WINDOWS, MAC OS, ANDROID, or IOS.

A computer program, which can also be referred to or described as a program, software, a software application, a module, a software module, a script, or code can be written in any form of programming language, including compiled or interpreted languages, or declarative or procedural languages, and it can be deployed in any form, such as a stand-alone program, a module, component, or subroutine. A computer program can, but need not, correspond to a file in a file system. A program can be stored in a portion of a file that stores other programs or data, for example, one or more scripts stored in a markup language document, in a single file dedicated to the program in question, or in multiple coordinated files, for example, files that store one or more modules, sub-programs, or portions of code. A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a communication network. While portions of the programs illustrated in the various figures are shown as individual modules that implement the various features and functionality through various objects, methods, or other processes, the programs can instead include a number of sub-modules, third-party services, components, libraries, and such, as appropriate. Conversely, the features and functionality of various components can be combined into single components, as appropriate. Thresholds used to make computational determinations can be statically, dynamically, or both statically and dynamically determined.

The methods, processes, or logic flows described in this specification can be performed by one or more programmable computers executing one or more computer programs to perform functions by operating on input data and generating output. The methods, processes, or logic flows can also be performed by, and apparatus can also be implemented as, special purpose logic circuitry, for example, a CPU, an FPGA, or an ASIC.

Computers suitable for the execution of a computer program can be based on general or special purpose microprocessors, both, or any other kind of CPU. Generally, a CPU will receive instructions and data from a read-only memory (ROM) or a random access memory (RAM), or both. The essential elements of a computer are a CPU, for performing or executing instructions, and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to, receive data from or transfer data to, or both, one or more mass storage devices for storing data, for example, magnetic, magneto-optical disks, or optical disks. However, a computer need not have such devices. Moreover, a computer can be embedded in another device, such as a mobile telephone, a personal digital assistant (PDA), a mobile audio or video player, a game console, a global positioning system (GPS) receiver, or a portable storage device (for example, a universal serial bus (USB) flash drive).

Computer-readable media (transitory or non-transitory, as appropriate) suitable for storing computer program instructions and data includes all forms of non-volatile memory, media and memory devices, including by way of example semiconductor memory devices, for example, erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), and flash memory devices; magnetic disks, for example, internal hard disks or removable disks; magneto-optical disks; and CD-ROM, DVD+/-R, DVD-RAM, and DVD-ROM disks. The memory can store various objects or data, such as caches, classes, frameworks, applications, backup data, jobs, web pages, web page templates, database tables, and repositories storing dynamic information. The data can include, for example, parameters, variables, algorithms, instructions, rules, constraints, references, or combinations of these. Additionally, the memory can include any other appropriate data, such as logs, policies, security or access data, and reporting files. The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

To provide for interaction with a user, implementations of the subject matter described in this specification can be implemented on a computer having a display device, for example, a CRT (cathode ray tube), LCD (liquid crystal display), LED (Light Emitting Diode), or plasma monitor, for displaying information to the user and a keyboard and a pointing device, for example, a mouse, trackball, or trackpad by which the user can provide input to the computer. Input can also be provided to the computer using a touchscreen, such as a tablet computer surface with pressure sensitivity or a multi-touch screen using capacitive or electric sensing. Other kinds of devices can be used to provide for interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback, for example, visual feedback, auditory feedback, or tactile feedback; and input from the user can be received in any form, including acoustic, speech, or tactile input. In addition, a computer can interact with a user by sending documents to and receiving documents from a device that is used by the user; for example, by sending web pages to a web browser on a user's client device in response to requests received from the web browser.

The term "graphical user interface," or "GUI," can be used in the singular or the plural to describe one or more graphical user interfaces and each of the displays of a

particular graphical user interface. Therefore, a GUI can represent any graphical user interface, including but not limited to, a web browser, a touch screen, or a command line interface (CLI) that processes information and efficiently presents the information results to the user. In general, a GUI can include a plurality of user interface (UI) elements, some or all associated with a web browser, such as interactive fields, pull-down lists, and buttons. These and other UI elements can be related to or represent the functions of the web browser.

Implementations of the subject matter described in this specification can be implemented in a computing system that includes a back-end component, for example, as a data server, or that includes a middleware component, for example, an application server, or that includes a front-end component, for example, a client computer having a graphical user interface or a Web browser through which a user can interact with an implementation of the subject matter described in this specification, or any combination of one or more such back-end, middleware, or front-end components. The components of the system can be interconnected by any form or medium of wireline or wireless digital data communication (or a combination of data communication), for example, a communication network. Examples of communication networks include a local area network (LAN), a radio access network (RAN), a metropolitan area network (MAN), a wide area network (WAN), Worldwide Interoperability for Microwave Access (WIMAX), a wireless local area network (WLAN) using, for example, 802.11 a/b/g/n or 802.20 (or a combination of 802.11x and 802.20), all or a portion of the Internet, or communication systems at one or more locations (or a combination of communication networks). The network can communicate with, for example, Internet Protocol (IP) packets, Frame Relay frames, Asynchronous Transfer Mode (ATM) cells, voice, video, or data between network addresses.

The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other.

This description is presented to enable any person skilled in the art to make and use the disclosed subject matter in the context of one or more particular implementations. Various modifications, alterations, and permutations of the disclosed implementations can be made and will be readily apparent to those or ordinary skill in the art, and the general principles defined may be applied to other implementations and applications, without departing from scope of the disclosure. In some instances, details unnecessary to obtain an understanding of the described subject matter may be omitted so as to not obscure one or more described implementations with unnecessary detail and inasmuch as such details are within the skill of one of ordinary skill in the art. The present disclosure is not intended to be limited to the described or illustrated implementations, but to be accorded the widest scope consistent with the described principles and features.

While this specification contains many specific implementation details, these should not be construed as limitations on the scope of the subject matter or on the scope of what may be claimed, but rather as descriptions of features that may be specific to particular implementations. Certain features that are described in this specification in the context of separate implementations can also be implemented, in combination, in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations, separately, or in any suitable sub-combination. Moreover, although previously described features may be described as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can, in some cases, be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

Particular implementations of the subject matter have been described. Other implementations, alterations, and permutations of the described implementations are within the scope of the following claims as will be apparent to those skilled in the art. While operations are depicted in the drawings or claims in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed (some operations may be considered optional), to achieve desirable results.

Moreover, the separation or integration of various system modules and components in the previously described implementations should not be understood as requiring such separation or integration in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

Accordingly, the previously described example implementations do not define or constrain this disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of this disclosure.

Furthermore, any claimed implementation is considered to be applicable to at least a computer-implemented method; a non-transitory, computer-readable medium storing computer-readable instructions to perform the computer-implemented method; and a computer system comprising a computer memory interoperably coupled with a hardware processor configured to perform the computer-implemented method or the instructions stored on the non-transitory, computer-readable medium.

What is claimed is:

1. A downhole system comprising:

a quartz enhanced photoacoustic spectrometer (QEPAS) configured to be positioned within a wellbore formed in a subterranean zone of a hydrocarbon formation, the QEPAS comprising:

a laser configured to emit light;

a first, passive quartz tuning fork (QTF) configured to detect a pressure wave created in a gas, wherein the pressure wave is created as the light is absorbed by the gas; and

a second, active QTF configured to amplify the pressure wave in the gas, wherein the first, passive QTF is configured to detect the amplified pressure wave;

a sampling system coupled to the QEPAS, the sampling system configured to be positioned in the wellbore, the sampling system configured to obtain a sample of a wellbore fluid at a downhole location in the subterranean zone, the QEPAS configured to spectroscopically scan the sample and to determine a plurality of quantities of a corresponding plurality of hydrocarbons in the sample; and

a computer system connected to the QEPAS, the computer system comprising:

one or more processors; and

a computer-readable medium storing instructions executable by the one or more processors to perform operations comprising:

receiving the plurality of quantities of the plurality of hydrocarbons in the sample; and

determining a plurality of ratios, each ratio being a ratio of one of the plurality of hydrocarbons with another of the plurality of hydrocarbons.

2. The system of claim **1**, wherein the operations further comprise:

receiving the plurality of ratios as an input to a design simulation of the hydrocarbon formation; and

computationally simulating the hydrocarbon formation based, in part, on the plurality of ratios.

3. The system of claim **1**, wherein the laser is configured to emit light at a wavelength range at which the plurality of hydrocarbons in the sample are simultaneously detectable.

4. The system of claim **1**, wherein the QEPAS comprises a plurality of lasers, each configured to emit light at a respective wavelength at which a respective hydrocarbon of the plurality of hydrocarbons in the sample is detectable.

5. The system of claim **1**, wherein the QEPAS comprises a hydrogen sulfide (H2S) laser configured to emit light at a wavelength at which H2S in the sample is detectable.

6. The system of claim **1**, wherein the QEPAS comprises a signal modulator configured to periodically switch a laser injection current to the laser between an on state and an off state or an optical chopper to optically chop the light emitted by the laser.

7. The system of claim **6**, wherein the signal modulator is configured to generate a periodic function to modulate a frequency of the light.

8. The system of claim **1**, wherein a quality factor (Q factor) of at least one of the first, passive QTF and the second, active QTF is of the order of tens of thousands.

9. The system of claim **1**, further comprising a power source connected to the processer, wherein the power source is configured to drive the second, active QTF in response to receiving a signal from the processor.

10. The system of claim **9**, wherein the processor is configured to transmit the signal to the second, active QTF based on a signal received from the first, passive QTF.

11. The system of claim **1**, further comprising a temperature controller configured to maintain a temperature of the QEPAS.

12. The system of claim **1**, wherein the sampling system comprises:

a chamber;

a piston positioned within the chamber, the piston sealing an inner surface of the chamber to define a sample receiving volume, wherein the first, passive QTF and the second, active QTF are positioned within the sample receiving volume;

an inlet valve fluidically connected to a chamber inlet, wherein a retraction of the piston in the sample receiving volume and an opening of the inlet valve causes the sample to flow into the sample receiving volume; and

an outlet valve fluidically connected to a chamber outlet, wherein an advancement of the piston in the sample receiving volume and an opening of the outlet valve causes the sample to flow out of the sample receiving volume.

13. The system of claim **12**, wherein the sample is a two-phase sample comprising a gas and a liquid, wherein the inlet valve is configured to de-pressurize the sample to separate the gas from the liquid, wherein the gas rises to an upper portion of the sample receiving volume and the liquid resides in a lower portion of the sample receiving volume, the QEPAS configured to spectroscopically scan the gas in the upper portion.

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