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(54) GAS SENSOR MODULE

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(52) **U.S. Cl.**

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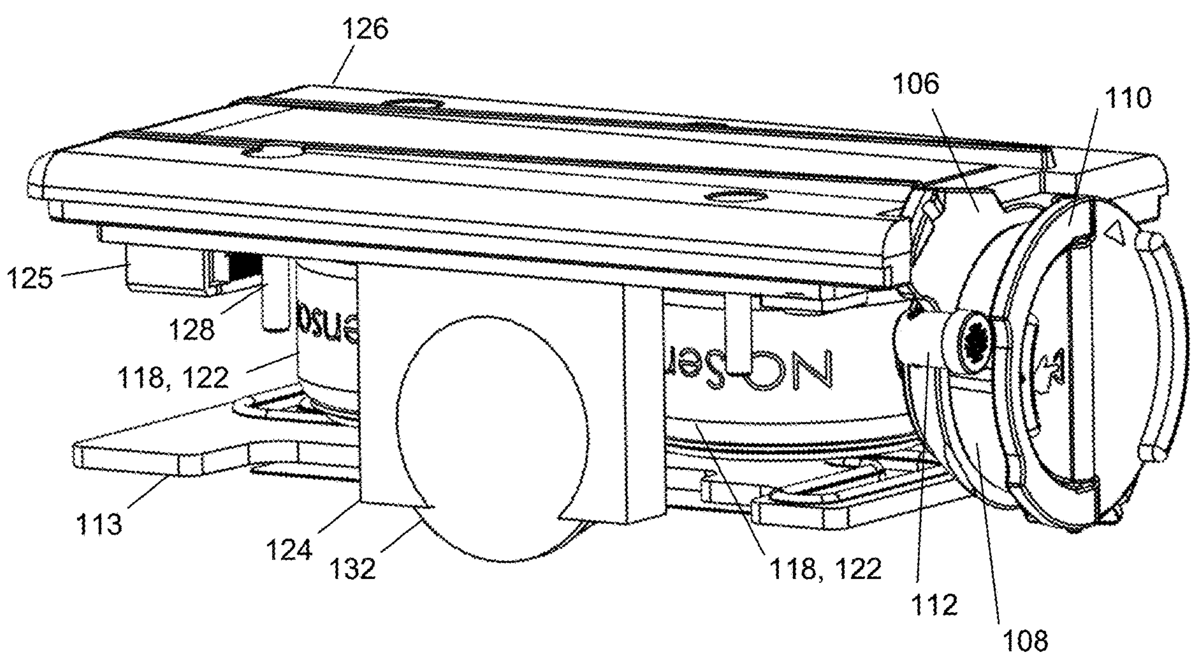
(57) **ABSTRACT**

A removable gas sensor module is provided for a therapeutic gas delivery device. The gas sensor module includes a sample chamber which receives a sample gas from the therapeutic gas delivery device. A gas detection unit includes a plurality of sensors operable to measure at least one property of the sample gas. The sensors include two or more of a gas detection sensor, a humidity sensor, a temperature sensor, or a combination thereof. The gas sensor module is self-contained within the therapeutic gas delivery device and swappable with another gas sensor module.



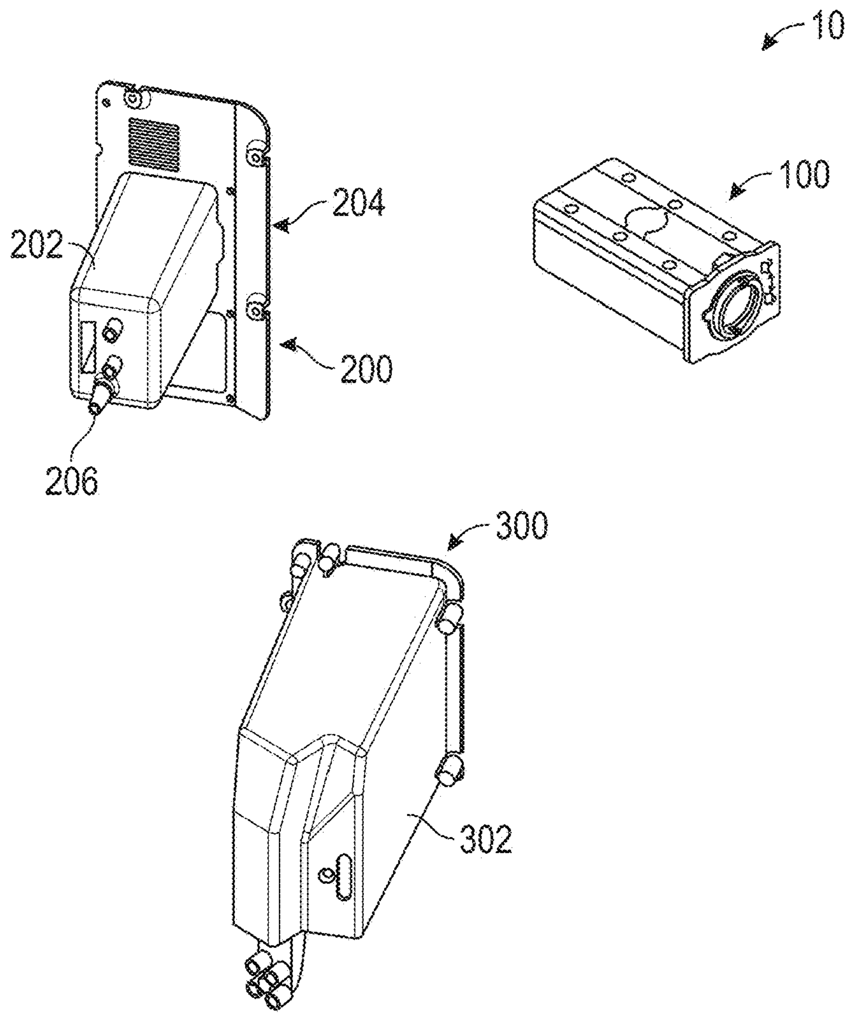


FIG. 1A

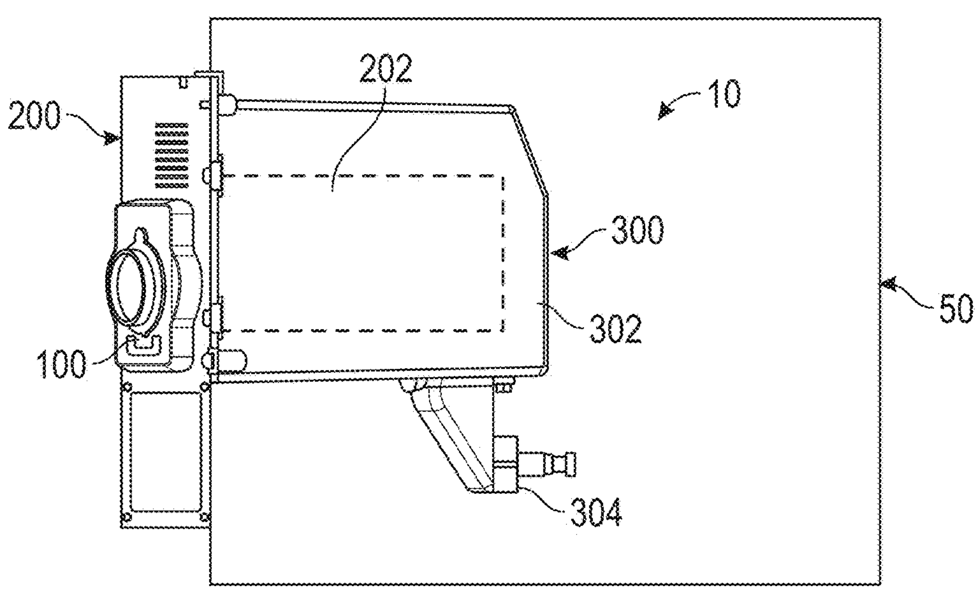
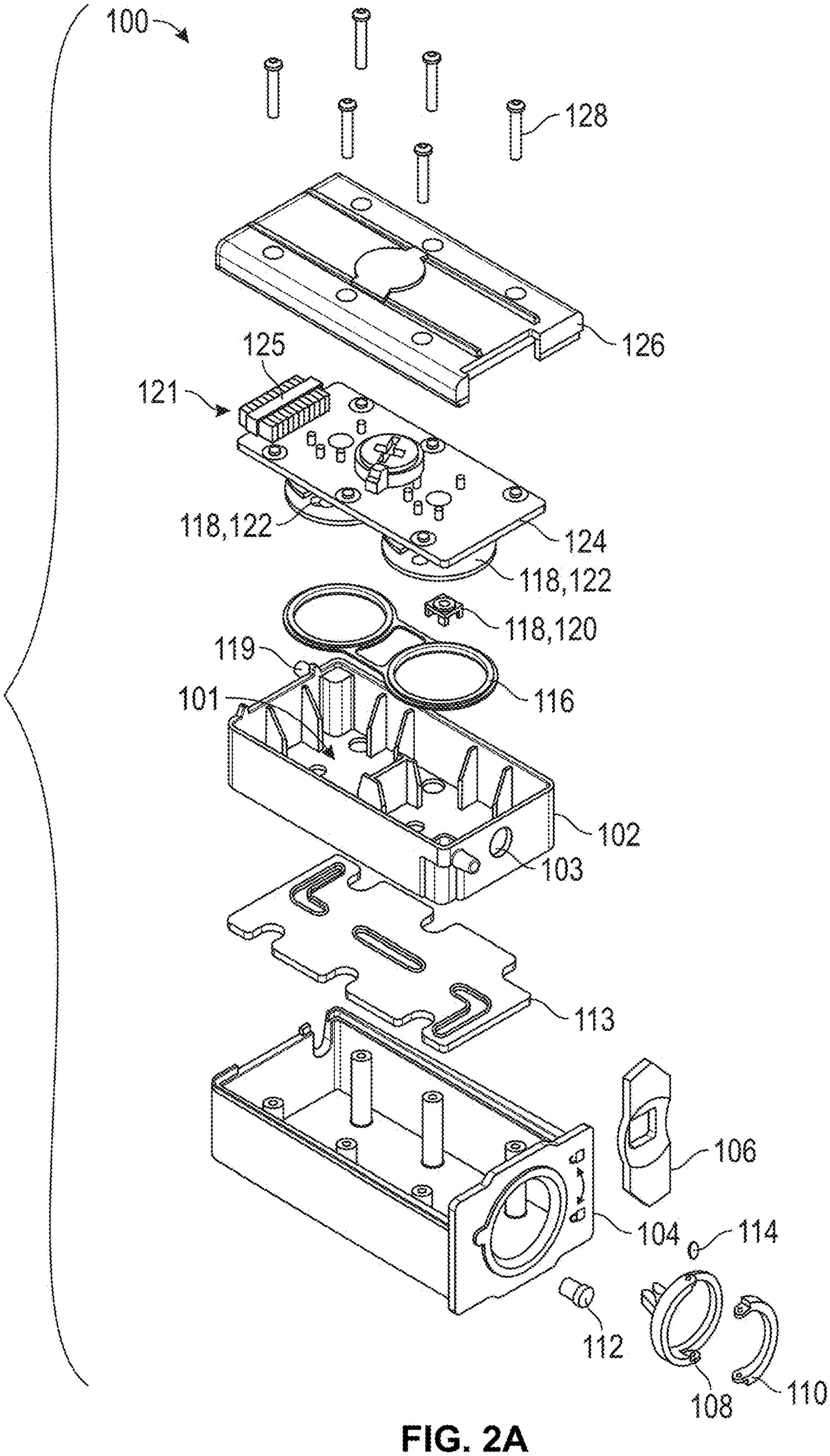


FIG. 1B


100
128
126
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121
118,122
124
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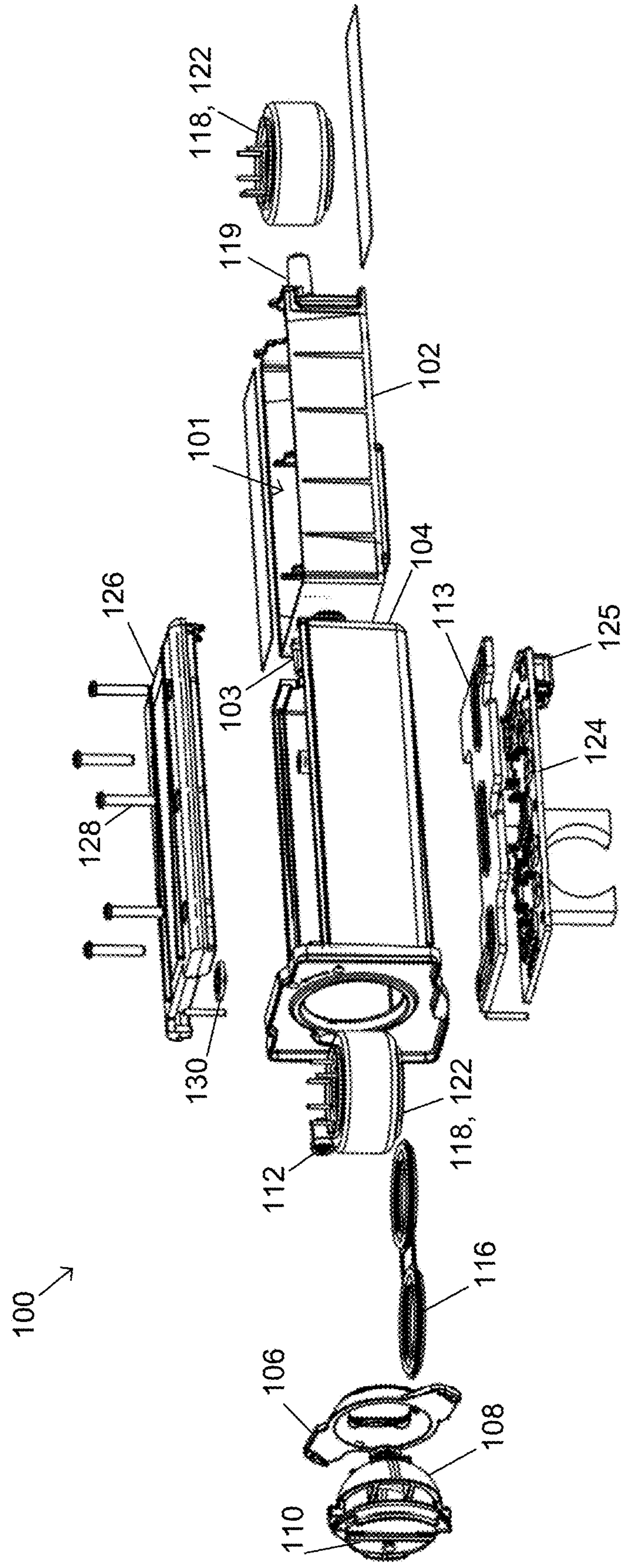
114
112
108
110

FIG. 2A



118, 122
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118, 122
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FIG. 2B

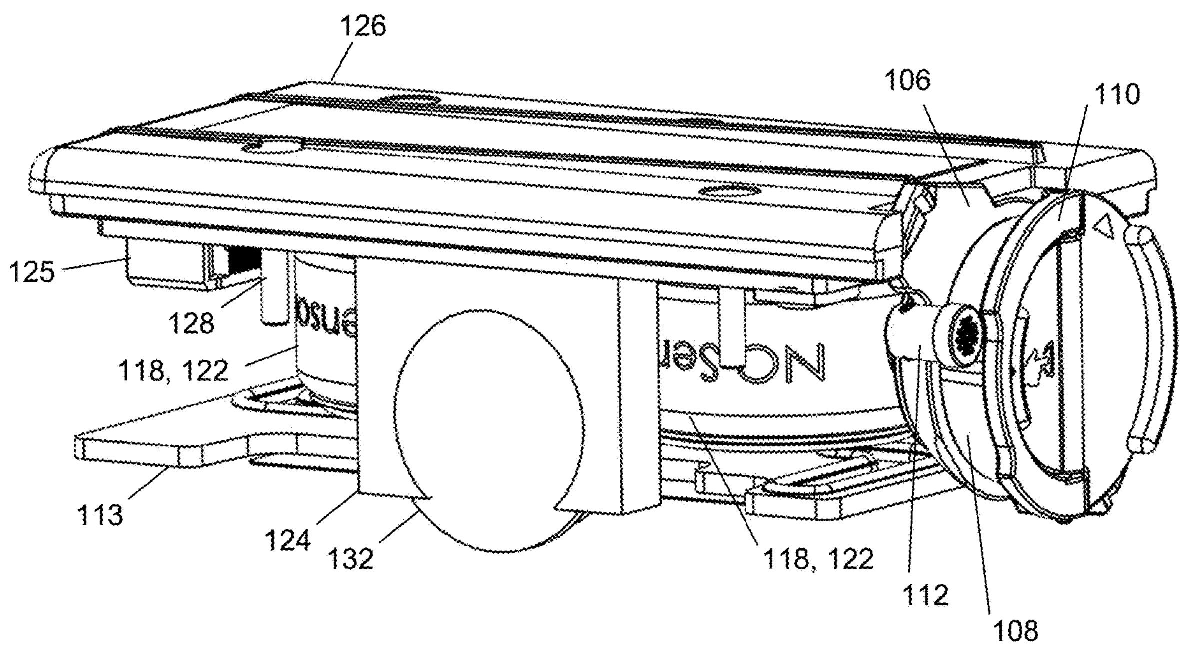

FIG. 2C

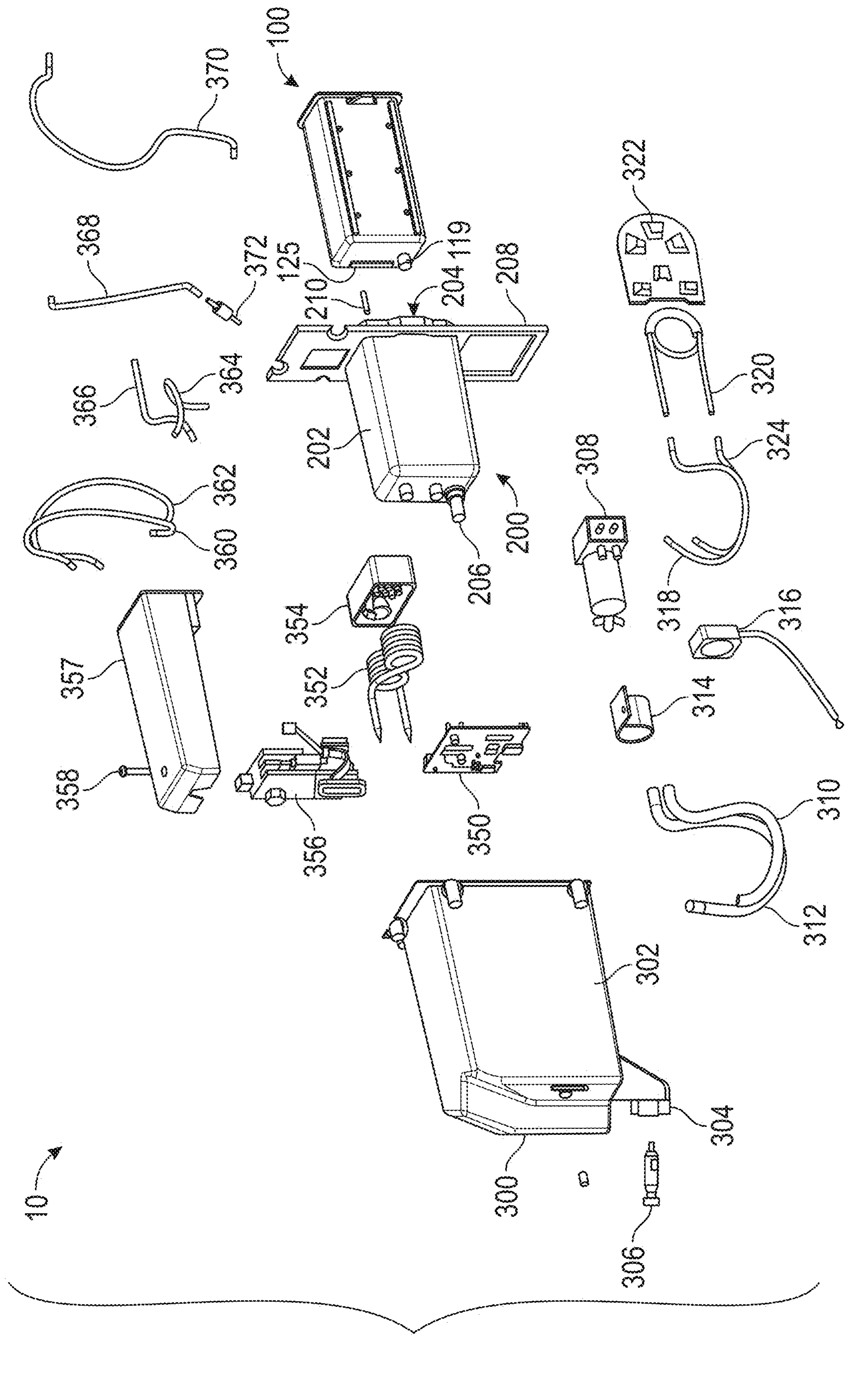
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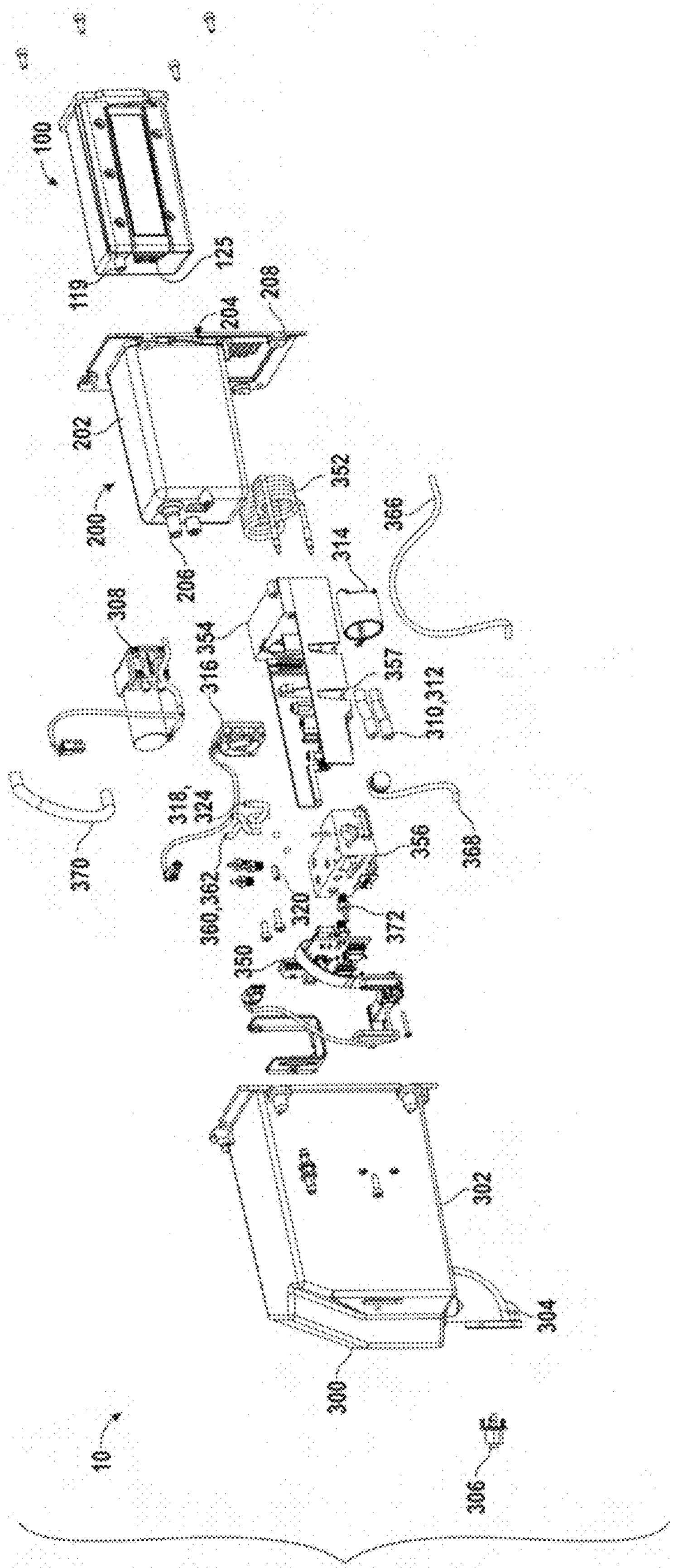
FIG. 3A



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304
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FIG. 3B

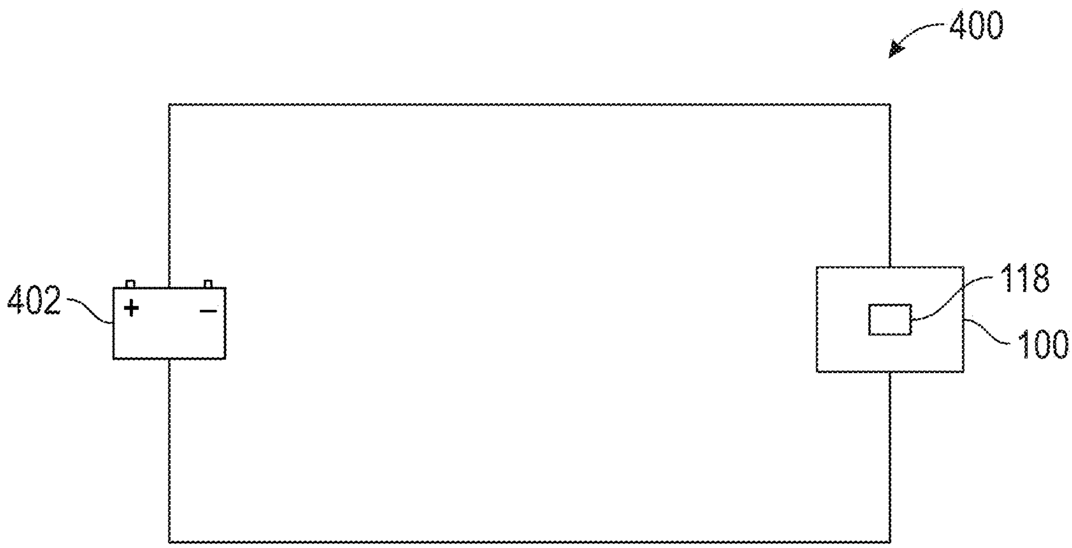

FIG. 4

GAS SENSOR MODULE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. application Ser. No. 17/299,171, filed Jun. 2, 2021 which claims the benefit of International Patent Application No. PCT/US2019/064278, filed Dec. 3, 2019, which claims priority to U.S. Provisional Application No. 62/774,687, filed Dec. 3, 2018, the contents of which are entirely incorporated by reference herein.

FIELD

[0002] The present disclosure relates generally to gas sensor modules. In one example, the present disclosure relates to gas sensor modules for therapeutic gas delivery devices.

BACKGROUND

[0003] Conventionally, a gas detection system needs to be calibrated by the user at intervals detailed in the user manual. For example, high calibration of a gas sampling system may be carried out monthly and may require calibration gas supplies to be available at the facility, as well as a change of sample line connections. During high calibration of the gas sampling system and the change of sample line connections, a gas detection system cannot sample gas. Additionally, incorrect connection of the calibration tubing kit can result in incorrect readings or equipment damage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Implementations of the present technology will now be described, by way of example only, with reference to the attached figures, wherein:

[0005] FIG. **1**A is an exploded view of an exemplary gas sensor assembly according to the present disclosure;

[0006] FIG. **1**B is an assembled view of the gas sensor assembly of FIG. **1**A;

[0007] FIG. **2**A is an exploded view of an exemplary gas sensor module;

[0008] FIG. **2**B is an exploded view of an exemplary gas sensor module;

[0009] FIG. **2**C is an assembled view of the gas sensor module of FIG. **2**B with the outer housing and inner housing removed;

[0010] FIG. **3**A is a detailed, exploded view of an exemplary gas sensor assembly;

[0011] FIG. **3**B is a detailed, exploded view of an exemplary gas sensor assembly; and

[0012] FIG. **4** is a schematic diagram of an apparatus including a voltage source electrically coupled with a gas sensor module to maintain calibration stability of the gas sensor module.

DETAILED DESCRIPTION

[0013] It will be appreciated that for simplicity and clarity of illustration, where appropriate, reference numerals have been repeated among the different figures to indicate corresponding or analogous elements. In addition, numerous specific details are set forth in order to provide a thorough understanding of the examples described herein. However, it will be understood by those of ordinary skill in the art that the examples described herein can be practiced without these specific details. In other instances, methods, procedures and components have not been described in detail so as not to obscure the related relevant feature being described. Also, the description is not to be considered as limiting the scope of the embodiments described herein. The drawings are not necessarily to scale and the proportions of certain parts may be exaggerated to better illustrate details and features of the present disclosure.

[0014] Several definitions that apply throughout the above disclosure will now be presented. The term “coupled” is defined as connected, whether directly or indirectly through intervening components, and is not necessarily limited to physical connections. The connection can be such that the objects are permanently connected or releasably connected. The term “substantially” is defined to be essentially conforming to the particular dimension, shape or other word that substantially modifies, such that the component need not be exact. For example, “substantially cylindrical” means that the object resembles a cylinder, but can have one or more deviations from a true cylinder. The terms “comprising,” “including” and “having” are used interchangeably in this disclosure. The terms “comprising,” “including” and “having” mean to include, but not necessarily be limited to the things so described. The term “hot swap,” “hot swapped,” or “hot swappable” is defined to mean that a sensor is removed and a new calibrated sensor can be replaced such that the downtime of the therapeutic gas delivery device for the replacement sensor to reach operational readiness is less than approximately 5 minutes. For example, a gas sensor module may be hot swapped with a calibrated gas sensor module, and the downtime of the therapeutic gas delivery device is approximately 3 minutes. As used herein, “swap” can include “hot swap” or any corresponding variations.

[0015] Disclosed herein is a removable gas sensor module with a plurality of sensors for measuring at least one property of a sample gas in a therapeutic gas delivery device. The sample gas may be a sample of the therapeutic gas being delivered to a patient by the therapeutic gas delivery device. The gas sensor module is self-contained within the therapeutic gas delivery device, thereby facilitating its replacement in the field in a fashion that can be thought of as “Plug‘n’Play” and/or capable of a hot swap. In some examples, the gas sensor module is self-contained within a gas sensor assembly, which is further contained within the therapeutic gas delivery device. The gas sensor module can be pre-calibrated, such that it is ready to be used upon installation in the gas sensor assembly/therapeutic gas delivery device without further calibration. The gas sensor module can be factory calibrated, and, in at least one example, can maintain calibration stability while in storage for a substantial period of time, for example over a 6-month period.

[0016] Conventionally, if a sensor fails any of the calibration tests, the sensor is replaced by a trained responsible person or service technician. For example, sensor replacement may be carried out by opening a panel on the back of the device casing, removing the failed sensor and fitting a replacement sensor. After replacing a sensor, the sample detection circuit is out of operation for a period of time as the new sensor has to be conditioned in the gas-flow, which for example sensor change for oxygen (O_2) and nitrogen dioxide (NO_2) may be about 40 minutes, while nitric oxide (NO) sensors may require about 5 hours conditioning. Once the new sensor has been conditioned, a low and then high calibration is then carried out before gas sample detection can be continued. Thus, the replacement of conventional gas sensors in a therapeutic gas delivery device is time consuming and causes an interruption in both gas sensor detection/analysis and therapeutic gas delivery to a patient that can interfere with the effective treatment of the patient.

[0017] The conventional solution to sensor drift is to carry out periodic low and high level calibration of the sensors. Low level calibration may be automatically managed and controlled by the device, but high level calibration of the sensors requires a user to disconnect the sampling line from the patient line and then attach calibration gas supplies of the appropriate gas before enabling the high calibration protocol. Again, performing the high calibration is time consuming and causes an interruption in gas sensor detection/analysis that can interfere with the effective treatment of the patient.

[0018] The gas sensor module described herein overcomes the limitations of the conventional gas sensors. The gas sensor module is pre-calibrated, self-contained, and hot swappable, such that it can be replaced in a therapeutic gas delivery device without causing an interruption in therapeutic gas delivery to a patient and only has minimal down time in gas sensor detection/analysis. This provides for continuous, effective treatment of the patient. In addition, the hot swappable feature of the self-contained gas sensor module provides for the gas sensor module to be replaced by a user without significant training. Rather than ask the user to implement a monthly high calibration of the NO and NO_2 sensors, the gas sensor module can simply be removed and replaced by a separate pre-calibrated gas sensor module. The first gas sensor module can then be returned to a central facility for recalibration and/or be discarded. The gas sensor module has been pre-calibrated for high calibration such that only low calibration is needed to be performed, which, in at least one example, can occur automatically upon insertion of the gas sensor module.

[0019] The gas sensor module can be utilized in an exemplary gas sensor assembly shown, for example, in FIGS. **1**A and **1**B. The gas sensor assembly **10** includes a gas sensor module **100** and an assembly inner housing **200** operable to removably receive the gas sensor module **100**. The assembly inner housing **200** includes a module receiving portion **202** which forms a module receiving recess **204**. The gas sensor module **100** is removably received in the module receiving recess **204**. As such, the gas sensor module **100** is removably coupled with the assembly inner housing **200**. The gas sensor assembly **10** can also include a gas analyzer unit **300** with an assembly main housing **302** operable to receive the assembly inner housing **200**. In some examples, the assembly inner housing **200** is removably coupled with the assembly main housing **302**. In other examples, the assembly inner housing **200** is fixedly coupled with the assembly main housing **302**. The gas analyzer unit **300** is contained within a therapeutic gas delivery device **50**. In at least one example, the assembly main housing **302** is coupled with and in fluid communication with the therapeutic gas delivery device **50**. In some examples, the gas sensor module **100** is nested within the assembly inner housing **200**, which is nested within the assembly main housing **302**, such that the gas sensor module **100** is coupled with and in fluid communication with the therapeutic gas delivery device **50**. In other examples, the assembly inner housing **200** and the gas analyzer unit **300** can be integrated as a single unit operable to receive the gas sensor module **100**. In additional examples, the therapeutic gas delivery device **50** is operable to receive the gas sensor module **100**.

[0020] The therapeutic gas delivery device **50** is operable to deliver therapeutic gas to a patient. For example, the therapeutic gas delivery device **50** can deliver therapeutic nitric oxide (NO) gas to a patient. The gas sensor module **100**, the assembly inner housing **200**, and the assembly main housing **302** are positioned such that gas can flow from a breathing circuit of the therapeutic gas delivery device **50**, through a sample tube, through the gas analyzer unit **300**, through the assembly inner housing **200**, to the gas sensor module **100**. In at least one example, a sample tube can be fluidly connected to a breathing circuit of the gas delivery device **50** and the gas sensor module **100** is operable to receive the sample gas from the sample tube. In at least one example, the breathing circuit of the therapeutic gas delivery device **50** includes a sample tee which is operable to receive the sample tube such that at least a portion of the gas in the breathing circuit flows through the sample tube. Additionally, in at least one example, the assembly inner housing **200** can include a port **206** which can be fluidly connected with a port **306** on the gas analyzer unit **300**, which can be fluidly connected with the sample tube. The port **206** can receive the sample gas from the therapeutic gas delivery device **50**, through the gas analyzer unit **300** port **304** and provide the sample gas to the gas sensor module **100**.

[0021] FIGS. **2**A and **2**B illustrate exploded views of the gas sensor module **100**. The gas sensor module **100** includes a sample chamber **101**. The sample chamber **101** receives the sample gas from the therapeutic gas delivery device **50**. The sample chamber **101** is fluidly connected with a sample inlet **119**. The sample inlet **119** is fluidly connected with a therapeutic gas delivery device and is operable to receive the sample gas. In some examples, the sample inlet **119** is fluidly connected to the port **206** of the assembly inner housing **200**, which is fluidly connected to the port **304** of the gas analyzer unit **300**, which is fluidly connected with the sample tube in the therapeutic gas delivery device **50**. In at least one example, the sample chamber **101** is operable to receive the sample gas from the therapeutic gas delivery device **50**. The sample chamber **101** can include an inner housing **102**. The inner housing **102** can include a vent **103** through which the sample gas can be removed from the sample chamber **101**. The vent **103** can be, for example, an opening formed in the inner housing **102**. In at least one example, the gas sensor module **100** includes an outer housing **104** which at least partially surrounds the inner housing **102**. In some examples, the outer housing **104** can include at least one of the following: a cam element **106**, a cam spindle **108**, a handle **110**, a handle axle **114**, a vent cap **112**, and/or a gasket **113**. In at least some examples, the cam element **106**, the cam spindle **108**, the handle **110**, and/or the handle axle **114** can be used to facilitate ease of insertion/removal of the gas sensor module **100** by the user via a locking/unlocking action of the vent cap **112**. In some examples, the handle **110** can be a flip-up pull tab, as seen in FIG. **2**B. The gasket **113** can help to prevent leaks from the pneumatic circuit, stopping sample gas from interacting with the electronics. In at least one example, the gasket **113** can be made of silicon rubber.

[0022] The gas sensor module **100** includes a gas detection unit **121** which includes a plurality of sensors **118**. The sensors **118** are operable to measure at least one property of the sample gas. For example, the sensors **118** can include two or more of gas detection sensors, humidity sensors, and/or temperature sensors.

[0023] In at least one example, the gas detection unit **121** can include two or more gas detection sensors **122**. In at least one example, the gas detection unit **121** can include two or more different sensors **118**. As illustrated in FIGS. **2**A and **2**B, the gas detection unit **121** can include a humidity sensor **120** and two gas detection sensors **122**. In other examples, the gas detection unit **121** can include one or more gas detection sensors **122** and a humidity sensor **120**. The gas detection sensors **122** can include one or more of an NO sensor, an NO_2 sensor, an O_2 sensor, or combinations thereof. In at least one example, the gas detection sensors **122** can include an NO sensor and an NO_2 sensor. While FIGS. **2**A and **2**B illustrate two gas detection sensors **122**, one, three, or more gas detection sensors **122** can be included. The property of the sample gas being measured can be one or more of a concentration of NO, a concentration of NO_2, a concentration of O_2, humidity, temperature, or a combination thereof. As illustrated in FIGS. **2**A and **2**B, the gas sensor module **100** includes a sensor seal **116** coupled with at least one of the sensors **118**.

[0024] As illustrated in FIG. **2**B, the gas sensor module **100** can include a humidity sensor seal **130** operable to be coupled with a humidity sensor **120** (not shown) that can be integrated with the sensing circuit **124**.

[0025] The gas sensor module **100** includes a sensing circuit **124** coupled with the sensors **118**. The sensing circuit **124** is operable to detect and report the measured properties of the sample gas from the sensors **118**. The sensing circuit **124** can be communicatively coupled with the gas delivery device **50**. In an example, the sensing circuit **124** can be operable to report measured properties of the sample gas to a gas analyzer controller **350** in the gas analyzer unit **300**. In an example, the gas analyzer controller **350** can be operable to report measured properties of the sample gas to the therapeutic gas delivery device **50**. The sensing circuit **124** can be coupled with the gas analyzer controller **350** and/or the gas delivery device **50** by any suitable wired or wireless connection, for example Ethernet, Bluetooth, RFID, or fiber optic cable. In at least one example, the sensing circuit **124** and/or the gas analyzer controller **350** can be operable to store measured properties of the sample gas. The gas detection unit **121**, by the sensing circuit **124**, can be operable to electronically retain serial numbers, calibration data, and/or usage information of the gas sensor module **100**. In another example, the gas analyzer controller **350** can be operable to electronically retain serial numbers, calibration data, and/or usage information of the gas sensor module **100**. Thereby, components can continue to be tracked and traced even when the gas sensor module **100** is disconnected from the gas delivery device **50**. The sensing circuit **124** can include a connector **125** operable to connect the sensing circuit **124** of the gas sensor module **100** with the gas analyzer controller **350**, and thus, the gas delivery device **50**.

[0026] Accordingly, the gas sensor module **100** can be hot swapped, and the connector **125** is easily connected with the gas delivery device **50** without additional expertise or tools.

[0027] The gas sensor module **100** additionally includes a cover **126**, which can be coupled with the outer housing **104**. In at least one example, the cover **126** can be removably coupled with the outer housing **104** by fasteners **128**. Fasteners **128** can be, for example, at least one of: screws, nails, nuts and bolts, hook and loop fasteners, adhesives, and/or any other suitable fasteners.

[0028] The gas sensor module **100** is self-contained within the therapeutic gas delivery device **50** and is swappable with another gas sensor module **100**. The containment of all of the sensors and/or analysis elements for the gas sample provides for the ability of a hot-swap in the event of a need for recalibration, component failure, and/or contamination. For example, the gas sensor module **100** can be replaced in the event of gas sensor module **100** failure, sample line filter failure, and/or when the service period for the calibration of the gas sensor module **100** is due to expire. Additionally, the modularization of the gas sensor module **100** simplifies the future addition of sensors **118** for analytes such as O_2 or volatile organic compounds (VOCs) without the need to modify the overall gas delivery device **50**, instead "upgrading" to a next-generation gas sensor module. A replacement gas sensor module **100** can simply be installed and the gas delivery device **50** can then immediately be put back into service. The gas sensor module **100** can be replaced with a pre-calibrated gas sensor module **100** by a responsible person in a matter of minutes without the need for special tools or equipment. For example, the replacement of the gas sensor module **100** can result in less than five minutes of down time in the measurement of at least one property of the sample gas. In at least one example, the replacement of the gas sensor module **100** can result in less than three minutes of down time in the measurement of at least one property of the sample gas.

[0029] In another example, the replacement of the gas sensor module **100** can result in no down time in delivery of therapeutic gas from the therapeutic gas delivery device **50**. In this example, the delivery of therapeutic gas to the patient is uninterrupted by the replacement of the gas sensor module **100** because the gas sensor module **100** analyzes sample gas, separate from the therapeutic gas in the breathing circuit. In addition, because the gas sensor module **100** is self-contained, it does not require shutdown of the therapeutic gas delivery device **50** or any stoppage in flow of therapeutic gas to the patient. This allows for the therapeutic gas delivery device **50** to continuously deliver therapeutic gas to the patient through the breathing circuit while the gas sensor module **100** is swapped for a new pre-calibrated gas sensor module **100**. In at least one example, the therapeutic gas delivery device **100** can be continuously operable when the gas sensor module **100** is replaced. Additionally, sample detection by the gas sensor module **100** can begin approximately five minutes after installation, following completion of a low calibration protocol. In at least one example, the low calibration protocol can start automatically upon installation of a new gas sensor module **100**. The hot-swap ability of the gas sensor module **100** has a significant, positive impact on user experience and device downtime. The gas sensor module **100** being pre-calibrated, or calibrated prior to installation, eliminates the need for onsite high calibration of NO sensors and enables fast and simple replacement of a failed or expired gas sensor module, allowing for off-site re-calibration and repair if applicable.

[0030] The gas sensor module **100** can be utilized, or in-use, and maintain calibration stability for at least one month. In at least one example, the in-use calibration stability period for the gas sensor module **100** can be extended from the conventional one month to approximately three months. In at least one example, the gas sensor module **100** can have a shelf-life calibration stability period (for example, stability when not installed in a gas delivery device **50**) of at least 1 month, alternately at least 3 months, alternately at least 6 months, or alternately at least 1 year. In some examples, the shelf-life of the gas sensor module **100** may be extended by including a battery **132** or other voltage source to provide an electrical potential across the sensors during storage to maintain the calibration. In at least one example, the gas sensor module **100** can include an expiration date. A user can be provided with gas sensor module replacement reminders/alarms via, for example, a graphic user interface and/or an app and/or program associated with the therapeutic gas delivery device.

[0031] In at least one example, as illustrated in FIG. **4**, the gas sensor module **100** can include and/or be electrically connected to an apparatus **400** which includes a voltage source **402** that may be used in conjunction with an ultra-low power consumption setting to ensure the sensors **118** retain calibration stability for a predetermined period, for example, up to 6 months. The plurality of sensors **118** in the gas sensor module **100** can be pre-calibrated, and with the apparatus **400**, an electrical potential can be provided across the sensors **118** to maintain the calibration of the sensors **118**. For example, the voltage source **402** may provide an electrical potential across the plurality of sensors **118** of the gas sensor module **100** at predetermined times to maintain calibration stability of the sensors **118** when the gas sensor module **100** is in a non-installed configuration. As such, the end-user may order multiple gas sensor modules **100**, keeping them in storage until they are required to replace in-use gas sensor modules **100** when recalibration and/or replacement is due. In at least one example, the voltage source **402** can be a battery or a power transformer. In at least one example, the voltage source **402** can be internal to the gas sensor module **100**, as seen in FIG. **2**C. In other examples, the voltage source **402** can be external to the gas sensor module **100**. The voltage source **402** can cease to provide electrical potential across the sensors **118** when the gas sensor module **100** is installed within the therapeutic gas delivery device **50**. In at least one example, the apparatus **400** and the voltage source **402** can be removable from the gas sensor module prior to installation in the therapeutic gas delivery device **50**. In another example, the voltage source **402** can remain connected to the gas sensor module **100** after installation but no longer provide an electrical potential across the sensors **118**, **122** of the gas sensor module **100**. In at least one example, as illustrated in FIG. **2**C, the battery **132** can directly connect with the sensing circuit **124** such that a separate apparatus **400** is not needed to connect the battery **132** to the gas sensor module **100**.

[0032] The implementation of pre-calibration and/or off-site calibration provides for calibration accuracy. For example, the conventional, single-point high calibration protocol assumes a single linear function across the range of administered NO concentrations. While sufficient to address current requirements for a +/−20% calibration accuracy, this could be improved upon significantly by employing a multi-point calibration protocol, something that is not compatible with a user-run calibration but which can be carried out automatically in a factory calibration scenario. With such an approach, calibration functions for multiple sub-ranges of NO concentration may be generated and stored for implementation (for example, in the form of a simple lookup table in device memory). The gas sensor module **100** can then determine the appropriate calibration function to use when measuring gas delivery based on, for example, the set dose and the range in which it sits. This is particularly important in pediatric or other low concentration applications for NO administration, where many calibration gases are supplied at a set concentration of 45 ppm, often more than twice the administered NO concentration. This would also address an issue experienced with certain users, who are uncomfortable with the display of a concentration that may be up to 20% less/greater than the set dose.

[0033] Furthermore, an off-site (for example factory) calibration and/or pre-calibration can utilize a calibration manifold **356** (shown in FIGS. **3**A and **3**B) that can control at least one of temperature, relative humidity, and pressure, facilitating the generation of calibration functions that not only provide a more accurate measurement of gas, such as NO, in specific sub-ranges but also enable compensation for different temperatures, pressures, and relative humidity values.

[0034] Additionally, an off-site calibration and/or pre-calibration can facilitate precise measurement of the gas, such as NO, concentration used in the calibration gas mixture. Rather than use calibrated gas cylinders that have been prepared in batches for distribution to end-users, calibration gas can be precisely quantified in terms of gas concentration.

[0035] FIGS. **3**A and **3**B illustrate a detailed exploded view of a gas sensor assembly **10**. As discussed above, the gas sensor assembly **10** includes the gas sensor module **100** which is removably received in the assembly inner housing **200**. The gas sensor module **100** can be removably coupled with the assembly inner housing **200** by one or more fasteners such as, for example, screws, clips, rotatable abutments, or any other suitable fastener such that the gas sensor module **100** can be removed from the assembly inner housing **200** without special tools or expertise. The assembly inner housing **200** can be received in and/or coupled with the assembly main housing **302**, which is within or in fluid communication with the therapeutic gas delivery device. In an example, the assembly inner housing **200** and the assembly main housing **302** remain fixed within the therapeutic gas delivery device, while the gas sensor module **100** is removably replaced as needed.

[0036] A sample gas is taken from the therapeutic gas delivery device and passed to the gas sensor module **100** through the gas sensor assembly **10** such that the gas sensor module **100** can detect and report at least one property of the sample gas. The sample gas can enter the assembly main housing through port **304**. In an example, a two stage filter luer interface **306** can be connected to the port **304**, external to the assembly main housing **302**. The port **304** can be fluidly connected to a pump **308** inside the assembly main housing **302**. The pump **308** is operable to pump the sample gas through the gas sensor module **100**. The pump **308** can retrieve the sample gas from the gas delivery device, for example, through the port **304** and a pump feeder tube **310**. The pump feeder tube **310** can be coupled with the pump **308** using a fastener **314**, such as a clip. The pump **308** includes a fan **316** which is operable to be rotated to promote flow of the sample gas. In at least one example, the sample gas can then be received in a restrictor feed tube **318**, passed through a restrictor **320** which is received in a restrictor housing **322**, and passed through a restrictor return tube **324**.

The restrictor **320** can be operable to restrict gas flow by creating a pressure differential. In at least some examples, the restrictor **320** can be incorporated into the calibration manifold **356**. In other examples, as seen in FIG. **3**B, the gas analyzer unit **300** may not include the restrictor feed tube, restrictor, restrictor housing, or restrictor return tube. In this example, the calibration manifold **356** can incorporate the function of the restrictor **230** by including a restrictor aperture to restrict sample gas flow to create the pressure differential, as seen in FIG. **3**B.

[0037] The restrictor **320** and/or calibration manifold **356** can be utilized to control the speed and/or quantity of the sample gas received by the gas sensor module **100**. The sample gas can then pass through the pump **308** and out the pump delivery tube **312**.

[0038] The gas sensor assembly **10** can include a sample tube **352** fluidly connected to the gas delivery device **50** and the gas sensor module **100** operable to receive the sample gas. For example, the sample tube **352** can be fluidly connected to the pump delivery tube **312**. In at least one example, at least a portion of the sample tube **352** can be a Nafion tube. As illustrated in FIGS. **3**A and **3**B, the gas sensor assembly **10** can additionally include a humidity component **354** and a calibration manifold **356**. The humidity component **352**, the Nafion tube portion of the sample tube **352**, the calibration manifold **356**, any other suitable components for example to control the temperature and/or pressure, or any combination thereof can control at least one of temperature, relative humidity, and pressure, facilitating the generation of calibration functions that not only provide a more accurate measurement of gas, such as NO, in specific sub-ranges but also enable compensation for different temperatures, pressures, and/or relative humidity values. For example, the humidity component **352**, the Nafion tube portion of the sample tube **352**, and/or the calibration manifold **356** can lower the humidity of the gas sample to increase the calibration stability of the gas sensor module **100**. A gas analyzer subframe **357** can be included to house at least a portion of the humidity component **352**, the Nafion tube portion of the sample tube **352**, and/or the calibration manifold **356**. One or more fasteners **358** can retain at least one of the humidity component **352**, the Nafion tube portion of the sample tube **352**, and/or the calibration manifold **356** within the gas analyzer subframe **357**. The fasteners **358** can be, for example, screws, adhesives, and/or nuts and bolts.

[0039] The gas sensor assembly **10** additionally can include a high differential link tube **360** and a low differential link tube **362**. In at least one example, the gas sensor assembly **10** can include an ambient air pressure link tube **364** which is fluidly connected with external atmosphere or ambient air. To provide ambient air, the gas sensor assembly **10** can include an ambient air inlet tube **368** which is fluidly connected with exterior of the gas sensor assembly **10** to provide ambient air. A filter **372** is coupled with an end of the ambient air inlet tube **368** opposite the end connected with the exterior of the gas sensor assembly **10**. The filter **372** can filter the ambient air to prevent particles or other substances which may affect the gas sensor module **100** from determining accurate measurements of the sample gas. A connector tube **366** can be included to fluidly connect the Nafion tube portion of the sample tube **352** with the calibration manifold **356**. Additionally, in at least one example, a filter tube **370** can be fluidly connected with the filter **372** to provide a passage of the ambient air to the Nafion tube portion of the sample tube **352**.

[0040] The sample gas is received through the port **206** of the assembly inner housing **200**. The port **206** is fluidly connected with the sample inlet **119** of the gas sensor module **100**, and the sample gas is received within the sample chamber **101** of the gas sensor module **100**.

[0041] Also provided herein is a method for providing a gas sensor module for use in a therapeutic gas delivery device. In some examples, the method may include calibrating the plurality of sensors in the gas sensor module, and providing electrical potential across the plurality of sensors to maintain the calibration of the plurality of sensors. The calibration of the plurality of sensors can be maintained for at least 1 month, at least 3 months, at least 6 months, or at least 1 year. The electrical potential may be provided by an apparatus with a voltage source, such as a battery. In some examples, the method may further include removing the apparatus/voltage source prior to or simultaneously with the installation of the gas sensor module in the therapeutic gas delivery device. The gas sensor module can be installed within the assembly inner housing and assembly outer housing in the therapeutic gas delivery device. In some examples, the installation of the gas sensor module results in less than 5 minutes of down time in the measurement of at least one property of a sample gas from the therapeutic gas delivery device. In other examples, the installation of the gas sensor module results in no down time in the delivery of therapeutic gas to a patient.

[0042] The disclosures shown and described above are only examples. Even though numerous characteristics and advantages of the present technology have been set forth in the foregoing description, together with details of the structure and function of the present disclosure, the disclosure is illustrative only, and changes may be made in the detail, especially in matters of shape, size and arrangement of the parts within the principles of the present disclosure to the full extent indicated by the broad general meaning of the terms used in the attached claims. It will therefore be appreciated that the examples described above may be modified within the scope of the appended claims.

[0043] Numerous examples are provided herein to enhance the understanding of the present disclosure. A specific set of statements are provided as follows.

[0044] Statement 1: A removable gas sensor module for a therapeutic gas delivery device, the gas sensor module comprising: a sample chamber operable to receive a sample gas from the therapeutic gas delivery device; and a gas detection unit comprising a plurality of sensors operable to measure at least one property of the sample gas, wherein the plurality of sensors include two or more of a gas detection sensor, a humidity sensor, a temperature sensor, or a combination thereof, wherein the gas sensor module is self-contained within the therapeutic gas delivery device and swappable with another gas sensor module.

[0045] Statement 2: The gas sensor module of Statement 1, wherein replacement of the gas sensor module results in less than 5 minutes of down time of the measurement of at least one property of the sample gas.

[0046] Statement 3: The gas sensor module of Statement 1, wherein replacement of the gas sensor module results in no down time in delivery of therapeutic gas from the therapeutic gas delivery device.

[0047] Statement 4: The gas sensor module of Statement 1, wherein the gas detection sensor is one or more of an NO sensor, an NO_2 sensor, an O_2 sensor, or combinations thereof.

[0048] Statement 5: The gas sensor module of Statement 1, wherein the gas detection unit comprises at least two gas detection sensors.

[0049] Statement 6: The gas sensor module of Statement 4, wherein the gas detection unit comprises an NO sensor and an NO_2 sensor.

[0050] Statement 7: The gas sensor module of Statement 1, wherein the gas detection unit comprises two or more different sensors.

[0051] Statement 8: The gas sensor module of Statement 6, wherein the gas detection unit comprises one or more gas detection sensors and a humidity sensor.

[0052] Statement 9: The gas sensor module of Statement 1, wherein the at least one property of the sample gas is one or more of a concentration of NO, a concentration of NO_2, a concentration of O_2, humidity, temperature, or a combination thereof.

[0053] Statement 10: The gas sensor module of Statement 1 further comprising a sensing circuit operable to detect and report the at least one property of the sample gas to a gas analyzer controller in the therapeutic gas delivery device.

[0054] Statement 11: The gas sensor module of Statement 1, wherein the therapeutic gas delivery device is continuously operable when the gas sensor module is replaced.

[0055] Statement 12: The gas sensor module of Statement 1, wherein the sample chamber comprises an inner housing and an outer housing.

[0056] Statement 13: The gas sensor module of Statement 1, wherein the gas detection unit is operable to electronically store or send to the therapeutic gas delivery device serial numbers, calibration data, and/or usage information of the gas sensor module.

[0057] Statement 14: The gas sensor module of Statement 1, wherein the gas sensor module is pre-calibrated and shelf stable for at least 1 month.

[0058] Statement 15: The gas sensor module of Statement 13, wherein the gas sensor module is shelf stable for at least 3 months.

[0059] Statement 16: A gas sensor assembly comprising: the gas sensor module of any one of Statements 1-15; an assembly inner housing operable to removably receive the gas sensor module; and a gas analyzer unit comprising: a sample tube fluidly connected to the gas delivery device and the gas sensor module operable to receive the sample gas; and a pump connected to the gas sensor module through the sample tube, wherein the pump is operable to pump the sample gas through the gas sensor module.

[0060] Statement 17: The gas sensor assembly of Statement 16, wherein the gas analyzer unit further comprises a gas analyzer controller.

[0061] Statement 18: The gas sensor assembly of Statement 16, wherein the gas analyzer unit further comprises an assembly main housing operable to receive the assembly inner housing, wherein the assembly main housing is within the therapeutic gas delivery device.

[0062] Statement 19: The gas sensor assembly of Statement 16, wherein at least a portion of the sample tube is a Nafion tube.

[0063] Statement 20: An apparatus comprising: a voltage source; and the gas sensor module of any one of Statements 1-15, wherein the voltage source provides an electrical potential across the plurality of sensors in the gas detection unit to maintain calibration of the plurality of sensors when the gas sensor module is in a non-installed configuration.

[0064] Statement 21: The apparatus of Statement 20, wherein the voltage source is a battery or a power transformer.

[0065] Statement 22: The apparatus of Statement 20, wherein the voltage source ceases to provide electrical potential across the plurality of sensors when the gas sensor module is installed within the therapeutic gas delivery device.

[0066] Statement 23: The apparatus of Statement 20, wherein the current source is internal to the gas sensor module.

[0067] Statement 24: A method for providing a gas sensor module comprising: calibrating the plurality of sensors in the gas sensor module of any one of Statements 1-15; and providing electrical potential across the plurality of sensors to maintain the calibration of the plurality of sensors.

What is claimed is:

1. A method for providing at least one gas sensor module for a therapeutic gas delivery device, the method comprising:

calibrating a plurality of sensors in the at least one gas sensor module; and

providing an electrical potential across the plurality of sensors to maintain calibration of the plurality of sensors,

wherein the at least one gas sensor module maintains calibration stability of the plurality of sensors when the at least one gas sensor module is not installed in the therapeutic delivery device for at least 1 month from a time of calibration.

2. The method of claim **1**, wherein the at least one gas sensor module comprises a first gas sensor module and a second gas sensor module.

3. The method of claim **2**, the method further comprising installing the first gas sensor module in the therapeutic gas delivery device.

4. The method of claim **3**, the method further comprising disconnecting the electrical potential from the plurality of sensors in the first gas sensor module prior to or simultaneously with installation of the first gas sensor module in the therapeutic gas delivery device.

5. The method of claim **3**, the method further comprising:

receiving a sample gas in a sample gas chamber of the first gas sensor module; and

measuring at least one property of the sample gas by the plurality of sensors.

6. The method of claim **5**, the method further comprising removing the first gas sensor module from the therapeutic gas delivery device when the first gas sensor module fails and/or a service period of the first gas sensor module expires.

7. The method of claim **6**, the method further comprising installing the second gas sensor module in the therapeutic gas delivery device.

8. The method of claim **7**, wherein removing the first gas sensor module and installing the second gas sensor module results in a down time of less than 5 minutes in measurement of the at least one property of the sample gas.

9. The method of claim **7**, wherein removing the first gas sensor module and installing the second gas sensor module results in no down time in delivery of therapeutic gas from the therapeutic gas delivery device.

10. The method of claim **5**, wherein the at least one property of the sample gas includes one or more of a concentration of NO, a concentration of NO2, a concentration of O_2, humidity, temperature, or a combination thereof.

11. The method of claim **5**, wherein receiving the sample gas includes pumping the sample gas though a sample tube fluidly connected to the therapeutic gas delivery device and the at least one gas sensor module, wherein at least a portion of the sample tube comprises a Nafion tube.

12. The method of claim **1**, wherein the plurality of sensors include two or more of a gas detection sensor, a humidity sensor, a temperature sensor, or a combination thereof.

13. The method of claim **12**, wherein the gas detection sensor is one or more of an NO sensor, an NO2 sensor, an O2 sensor, or combinations thereof.

14. The method of claim **12**, wherein the plurality of sensors include at least two gas detection sensors.

15. The method of claim **1**, the method further comprising storing, in the at least one gas sensor module, serial numbers, calibration data, and/or usage information of the at least one gas sensor module.

16. The method of claim **15**, the method further comprising transmitting, via the at least one gas sensor module, the serial numbers, calibration data, and/or usage information of the at least one gas sensor module to the therapeutic gas delivery device.

17. The method of claim **1**, wherein the at least one gas sensor module maintains calibration stability of the plurality of sensors when the at least one gas sensor module is in the non-installed configuration for at least 3 months from the time of calibration.

18. The method of claim **1**, wherein the electrical potential is provided by a voltage source.

19. The method of claim **18**, wherein the voltage source is a battery or a power transformer.

20. The method of claim **18**, wherein the voltage source is internal to the at least one gas sensor module.

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